Energy Storage System

Roadmap for India: 2019-2032

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Roadmap for India: 2019-2032

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Dated: 6th August, 2019

I am pleased to note that India Smart Grid Forum (ISGF) has developed an Energy Storage System Roadmap for India for the period 2019-2032.

Governments of India's target of 40 GW of roof top solar by 2022 is progressing well on track having already achieved 4300 MW by March 2019. The increase in penetration of roof top solar in the distribution grid will have significant impact on the stability of the distribution grid. Besides, Government of India's programme of electrification of transportation will witness millions of electric vehicles getting connected on the low voltage distribution grid. In order to integrate the rooftop solar and electric vehicles, the distribution grid need to be flexible and smart. Energy storage systems will play a key role in providing this flexibility by both acting as a load when there is surplus generation as well as a generation source when there is supply shortage thereby stabilizing the grid and smoothening the output of the solar rooftop which is intermittent. This aspect of integration of rooftop solar resources on the low voltage and medium voltage grid was not studied in detail so far. The ISGF study has analyzed this scenario through extensive modelling studies and prepared the energy storage requirements for grid support under different scenarios of rooftop solar penetration.

The Union Cabinet has also recently approved the National Mission on Transformative Mobility and Battery Storage. The Mission with its Inter-Ministerial Steering Committee chaired by Chief Executive Officer (CEO), NITI Aayog will promote clean, connected, shared, sustainable and holistic mobility initiatives. The requirement of energy storage for mobility applications will be much bigger than that for grid support applications. ISGF in association with India Energy Storage Alliance (IESA) have estimated the requirements of energy storage for different stationary applications and mobility applications for the years 2022, 2027 and 2032. This is a good starting point and this roadmap will be reviewed and updated periodically based on the progress of new policies and programs. This Energy Storage System Roadmap for India will help both policy makers and utilities in decision making related to investment and implementation of energy storage systems to support integration of renewable energy sources leading to a more reliable and low carbon grid.

I congratulate ISGF for this good work and wish them success in their future endeavors.

(R P Gupta)

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9th September, 2019

Message

I am pleased to note that India Smart Grid Forum (ISGF) for undertaking the detailed studies on energy storage systems requirements for rooftop PV integration on the distribution grid and preparing the Energy Storage System Roadmap for India (2019-2032) which will provide insights to the policymakers and utilities on investment related decisions for energy storage systems for integration of renewable energy to the distribution grid.

India is committed to reducing GHG emission intensity up to 33-35% by 2030 from the 2005 level and set the target of 40% non-fossil based electricity generation in the energy mix. This will require scaling up of share of renewable energy (RE) considerably beyond the present target of 175 GW by 2022. With the increase in penetration of renewable energy sources and electric vehicles (EV) in the coming years, it will be a challenge for grid operators to ensure grid reliability and supply of 24X7 quality power and thereby paving the way for deployment energy storage systems for grid support.

This roadmap details out the role of energy storage systems in maintaining grid reliability with the increase in RE and EV penetration on the grid and will also facilitate the utilities to understand the economic opportunities of energy storage system at various levels of RE and EV penetrations.

I compliment ISGF for this important work which is a good starting point for further studies which will shape the future policies and programs related to renewable energy development and electric vehicles rollout in the country.

09.9.2019
(Mritunjay Kumar Narayan)

RIGHT TO INFORMATION

Preface

Reji Kumar Pillai
President, India Smart Grid Forum
Chairman, Global Smart Grid Federation

At COP 21 in Paris in 2015, India made a commitment of meeting 33-35% of its energy from non-fossil fuels by 2030. This bold commitment requires a host of new policy initiatives to scale up the share of clean energy drastically. The 175 GW of renewable energy target by 2022 needs to be enhanced to 500 GW or more through new policies and programs in the following 8 years running to 2030. The integration of distributed generation resources on the low voltage grid require the support of active demand response and energy storage systems to maintain grid stability. In a fast-changing technological environment, it is important to have a clear vision of priorities and needed actions to realize the full benefits of energy storage to help in accelerating the deployment of renewable energy technologies. In February 2018, an Expert Committee under the chairpersonship of Secretary, Ministry of New and Renewable Energy, with representatives from relevant Ministries, industry associations, research institutions and experts were constituted by the Ministry of New & Renewable Energy to plan the launch of a National Energy Storage Mission for India. This initiative was subsequently moved to NITI Aayog and Government of India launched the "***Transformative Mobility and Energy Storage Mission***" in March 2019.

In order to support the energy storage mission of the Government of India, ISGF initiated preparation of an Energy Storage Roadmap for India 2019 – 2032 in association with India Energy Storage Alliance (IESA). The initial objective of the roadmap was to study in detail the grid integration issues related to 40 GW of solar rooftop that will be connected to medium and low voltage grid (MV and LV grid). We have undertaken detailed modelling studies of MV and LV grids in six states in India using CYMDIST software. The evaluation of the effectiveness of energy storage technologies in addressing the grid stability issues with high levels of VRE penetration detailed in the report will help the policy makers, regulators and utilities in planning for rooftop PV rollouts. The key outcomes of this study are: **1. Energy Storage Roadmap for India 2019-2032; 2. Energy Storage India Tool (ESIT) and; 3. Guidelines for determining the Variable Renewable Energy (VRE) hosting capacity on LV and MV grids.** The ESIT tool developed as part of the project for techno-commercial evaluation of ESS projects will help the stakeholders choose the optimum levels of ESS for different applications. The guidelines for assessing the hosting capacity of VRE on the distribution grid will help utilities to plan their grid upgrade requirements to match with the expected penetration of VRE.

We started the project to estimate the energy storage systems (ESS) requirements for 40 GW rooftop PV integration, but the scope was enlarged to include total ESS requirements in the country till 2032. This was done keeping in view of the fact that the ESS requirements for electric mobility is much larger than that for grid applications. Although we closely examined the viability of different ESS technologies, we have finally chosen to estimate the ESS requirements in terms of Lithium Ion Batteries owing to its versatile applications and fast declining cost. This is a first of its kind work and the estimates given in this report may be debatable due to policy uncertainties. However, we hope this energy storage roadmap will instil confidence in the industry and investors for building manufacturing capacities in the country on fast track.

India Smart Grid Forum (ISGF) would like to take this opportunity to thank MacArthur Foundation for supporting this study and we wish to dedicate our strong commitment to work towards making a greener and cleaner future. I would also like to thank all the stakeholders for their valuable contribution in preparation of this roadmap for India, particularly, Shri R.P. Gupta, Additional Secretary, NITI Aayog and his team, Dr. P.C. Maithani, Scientist-G, MNRE and Mr. Vivek Goel, Chief Engineer - Distribution Planning & Technology, CEA, who have provided valuable inputs for this study.

Authors & Acknowledgement

India Smart Grid Forum (ISGF) would like to express our sincere gratitude to MacArthur Foundation who has extended a grant to ISGF for undertaking first of its kind project in the country to prepare an ***Energy Storage Roadmap for India 2019 – 2032.*** MacArthur Foundation works to primarily support mitigation interventions that seek sustainable solutions to challenges India faces from climate change.

We would like to thank Mr R P Gupta, Additional Secretary, NITI Aayog and his team for providing all the necessary guidance and support to undertake the study for the preparation of this report.

We wish to thank Mr Mrityunjay Kumar Narayan, Joint Secretary, and Mr Vishal Kapoor, Director, Ministry of Power, for their support for this important project.

We would like to thank Dr P C Maithani, Scientist-G, Ministry of New and Renewable Energy (MNRE) and his team for extending their support and guidance throughout this study.

We would like to thank Mr Vivek Goel, Chief Engineer – Distribution Planning and Technology, Central Electricity Authority (CEA) and his team for providing all the necessary guidance related to the electrical infrastructure of the country.

We would like to thank all the six distribution companies, Adani Energy Mumbai Ltd (AEML), Andhra Pradesh Southern Power Distribution Company Ltd (APSPDCL), Bangalore Electricity Supply Company Ltd (BESCOM), CESC Ltd (Kolkata), Tata Power Delhi Distribution Ltd (TPDDL) and Uttar Haryana Bijli Vitran Nigam (UHBVN), who helped us in conducting the load flow studies of their distribution network.

We also wish to extend our sincere gratitude to all the stakeholders whom we consulted during the course of this study for their cooperation and relevant inputs which were very valuable for this study.

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Abbreviations

AEML	:	Adani Energy Mumbai Limited
AGC	:	Automatic Generation Control
AGF	:	Advanced Grid Functions
APSPDCL	:	Andhra Pradesh Southern Power Distribution Company Limited
AT&C	:	Aggregate Technical & Commercial
BESCOM	:	Bangalore Electricity Supply Company Limited
BESS	:	Battery Energy Storage System
BMS	:	Battery Management System
BU	:	Billion Unit
CAES	:	Compressed Air Energy Storage
CBA	:	Cost-Benefit Analysis
CEA	:	Central Electricity Authority
CERC	:	Central Electricity Regulatory Commission
CESC	:	Calcutta Electricity Supply Company
C&I	:	Commercial & Industrial
DISCOM	:	Distribution Company
DoD	:	Depth of Discharge
DG	:	Diesel Generator
DR	:	Demand Response
DSM	:	Demand Side Management
DT	:	Distribution Transformer
EHV	:	Extra High-Voltage
ESCO	:	Energy Service Company
ESIT	:	Energy Storage India Tool
ESS	:	Energy Storage System

EV	:	Electric Vehicle
E2W	:	Electric 2-Wheelers
E3W	:	Electric 3-Wheelers
FRAS	:	Fast Response Ancillary Service
GCF	:	Green Climate Fund
GDP	:	Gross Domestic Product
GW	:	Gigawatt
HVAC	:	Heating Ventilation and Air Conditioning
HT	:	High Tension
ICE	:	Internal Combustion Engine
IESA	:	India Energy Storage Alliance
IEGC	:	Indian Electricity Grid Code
IRR	:	Internal Rate of Return
ISGF	:	India Smart Grid Forum
INDC	:	Intended Nationally Determined Contribution
JNNSM	:	Jawaharlal Nehru National Solar Mission
kVA	:	Kilovolt Ampere
kW	:	Kilowatt
kWh	:	Kilowatt–Hour
kWp	:	Kilowatt peak
LA	:	Lead Acid
LCOS	:	Levelized Cost of Energy Storage
LFC	:	Load Frequency Control
LFP	:	Lithium Iron Phosphate
LiB	:	Lithium-ion Battery
LT	:	Low Tension
LV	:	Low Voltage
MNRE	:	Ministry of New and Renewable Energy
MoP	:	Ministry of Power
MSP	:	Meter Service Provider

MV	:	Medium Voltage
MW	:	Megawatt
MWh	:	Megawatt-Hour
NBFI	:	Non Banking Financial Institution
NEP	:	National Electricity Plan
NESM	:	National Energy Storage Mission
NLC	:	Neyveli Lignite Corporation
NMC	:	Nickel Manganese Cobalt
NPV	:	Net Present Value
NREL	:	National Renewable Energy Laboratory
NTPC	:	National Thermal Power Corporation Limited
PCC	:	Point of Common Coupling
PCS	:	Power Conversion System
PF	:	Power Factor
PHS	:	Pumped Hydro Storage
PGCIL	:	Power Grid Corporation of India Limited
POSOCO	:	Power System Operation Corporation
PQ	:	Power Quality
RE	:	Renewable Energy
RMI	:	Rocky Mountain Institute
RTPV	:	Rooftop Photo Voltaic
SAPF	:	Shunt Active Power Filter
SCS	:	Supervisory Control System
SECI	:	Solar Energy Corporation of India
SHP	:	Small Hydro Plant
SMI	:	Smart Micro Inverters
SoC	:	State of Charge
SoH	:	State of Health
T&D	:	Transmission and Distribution
ToD	:	Time of Day

TPDDL	:	Tata Power Delhi Distribution Limited
THD	:	Total Harmonic Distortion
UHBVN	:	Uttar Haryana Bijli Vitran Nigam Limited
UT	:	Union Territory
VRE	:	Variable Renewable Energy
VRLA	:	Valve Regulated Lead Acid
V2G	:	Vehicle to Grid
VGI	:	Vehicle Grid Integration
VSI	:	Voltage Source Inverter

Executive Summary

Energy Storage System Roadmap for India 2019-32

Energy Storage System (ESS) is fast emerging as an essential part of the evolving clean energy systems of the 21st century. Energy storage represents a huge economic opportunity for India. Ambitious goals, concerted strategies, and a collaborative approach could help India meet its emission reduction targets while avoiding import dependency for battery packs and cells. This could help establish India as a hub for cutting-edge research and innovation, boost its manufacturing capabilities, create new jobs, and foster economic growth. India's strengths in IT and manufacturing, its entrepreneurial and dynamic private sector, and its visionary public and private sector leadership will be key factors in realizing these ambitions. Creation of a conducive battery manufacturing ecosystem on fast track could cement India's opportunity for radical economic and industrial transformation in a critical and fast-growing global market.

India is committed to reducing emission intensity up to 33-35% from the 2005 level by 2030 and set the target of 40% non-fossil fuel based electricity generation in the energy mix. This requires radical measures to scale up the share of renewable energy (RE) besides the ongoing program of 175 GW RE by 2022. The new targets for RE by 2030 could be in the order of 350 to 500 GW. Integration of such massive amounts of RE which are intermittent and distributed in the power system pose serious challenges to grid operations. Studies and analysis show that extra flexibility investments in the Indian grid are needed on fast track for managing the RE resources efficiently. Energy storage is going to play critical role in grid integration and management of RE as the share of RE in the grid increases. India Smart Grid Forum (ISGF) pioneered the effort to prepare an Energy Storage System Roadmap for India for the period 2019 to 2032 (till 15th Five Year Plan period) with the primary objective of estimating the ESS requirements for grid support for integration of RE into the grid – both at extra high voltage transmission grid where large solar and wind farms are connected; as well as at medium voltage and low voltage distribution grid where rooftop solar panels and other small size RE resources are connected. In this important task, ISGF partnered with India Energy Storage Alliance (IESA) and the project was supported through a grant by MacArthur Foundation, USA. This exercise of preparation of the ESS Roadmap included modelling studies of the electric grid with different levels of penetration of RE. The key project outputs are:

i. Energy Storage Roadmap for India for 2019-2022, 2022-2027 and 2027-2032
ii. Energy Storage India Tool (ESIT), a tool for conducting cost benefit analysis of different ESS technologies for different applications
iii. Guidelines for assessing the hosting capacity of rooftop solar PV (RTPV) on low voltage distribution lines

We have examined different ESS technologies such as batteries, super capacitors, compressed air energy storage system (CAES), fly wheels, pumped hydro storage (PHS) plants, etc with regard to technology maturity and price trajectory. However, the fast pace of developments taking place in the battery technologies and the consequent price competitiveness have put batteries as the first choice for most applications. Few PHS plants in India (cumulative capacity: 5.7GW) have been identified long time back, but these projects have not made any progress in the past two decades owing to variety of issues. Hence, the PHS plants are not considered in this report. New form of gravity storage involving large blocks of concrete/stones is still in its infancy and not sure of achieving commercial viability before 2032; and hence, not considered in these estimates. Super capacitors, fly wheels and compressed air energy storage are far more expensive than the latest range of lithium-ion batteries (LiB) and those technologies have their own limitations with regard to size, location, energy density and maximum hours of operation etc. making them less attractive compared to LiBs.

Table below presents the ESS requirement for medium voltage (MV)/low voltage (LV) grid support based on estimated penetration of solar PV (both ground mounted and rooftop) likely to be connected to the MV and LV grid.

Energy Storage Estimations for MV/LV Grid (MWh)

Estimates	2019	2022	2027	2032
Generation (GW)				
Thermal	209	NA	NA	NA
Hydro	43	NA	NA	NA
Nuclear	6	NA	NA	NA
Solar	26	107	244	349
Ground Mounted Solar	24	68	148	206
RTPV	1.5	40	98	144
Connected to EHV	14	34	66	94
Connected to MV	11	35	84	112
Connected to LV	2	40	98	144
Wind	35	NA	NA	NA
Small Hydro	4.5	NA	NA	NA
Biomass & Biopower	10	NA	NA	NA
Peak Load (GW)	192	333	479	658
Energy (BUs)				
Annual Energy Requirements	1192	1905	2710	3710
Storage Recommended (MWh)				
Battery for LV Grid	241	5908	14617	21484
Battery for MV Grid	1054	3482	8393	11191
Total Storage (MWh)	**1295**	**9390**	**23010**	**32675**
Approximate (GWh)	**1 GWh**	**10 GWh**	**24 GWh**	**33 GWh**

Note: Peak Load and Annual Energy Requirements are taken from CEA Estimates (18th Electric Power Survey). In congruence with the RE target of 175 GW by 2022, the calculations were done on the basis of 100 GW Solar, out of which 40 GW is RTPV, 20 GW is medium size installations and 40 GW is from large solar parks. Similarly, for 2027 and 2032, the ratio of RTPV were taken in accordance with the 2022 targets constituting of 40% RTPV of the total solar installed capacity. All the values for 2027 and 2032 have been forecasted using the best available data in public domain.

During the course of this project, electric vehicles (EVs) have assumed high priority in the country. In the recent years, several large cities in India have emerged as the most polluted cities in the world and a significant share of the air pollution is coming from the automobiles. In order to address this serious problem in a holistic manner, Government of India (GoI) has launched a national mission in March 2019, the *"Transformative Mobility and Energy Storage Mission"*. Constantly declining cost of LiBs coupled with their performance improvements and rapid innovations in the EV domain is expected to make EVs competitive in the near term in all categories: 2 Wheelers, 3 Wheelers, Cars, Buses and Goods Carriers. GoI is committed to develop the complete ecosystem around EVs including manufacturing of batteries and all other components domestically. The expected requirements of batteries for EVs is much higher than that for grid support and hence a national roadmap for ESS without incorporating the demand for the largest sector would look incomplete. From that perspective, we enlarged the scope of the report by including ESS demand from different sectors based on best estimates and data available in the public domain. Regarding ESS requirements for extra high voltage (EHV) transmission grid for integration of large solar and wind farms, no detailed studies have been undertaken to estimate the demand beyond 2022. The study made by Power Grid Corporation of India (POWERGRID) in 2013 for the Green Corridor Report suggested 500 MWh of ESS for integration of 31 GW of RE. The RE targets have multiplied more than 5 times to 160 GW (solar and wind) by 2022 and will further increase drastically by 2032. The estimates in this report for EHV Grid support is best estimates by IESA. The consolidated estimates of ESS from different sectors for the period 2019-2022, 2022 to 2027 and 2027 to 2032 are presented in the table below:

Consolidated Energy Storage Roadmap

	Consolidated Energy Storage Roadmap					
	Applications		Energy Storage (GWh)			
			2019-2022	2022-2027	2027-2032	Total by 2032
Stationary Storage	Grid Support	MV/LV	10	24	33	67
		EHV	7	38	97	142
	Telecom Towers		25	51	78	154
	Data Centres, UPS and Inverters		80	160	234	474
	Miscellaneous Applications (Railways, Rural Electrification, HVAC application)		16	45	90	151
	DG Usage Minimization		-	4	11	14
	Total Stationary (GWh)		138	322	543	1,002
Electric Vehicles	E2W		4	51	441	496
	E3W		26	43	67	136
	E4W		8	102	615	725
	Electric Bus		2	11	44	57
	Total Electric Vehicles (GWh)		40	207	1,167	1,414
Total Energy Storage Demand (GWh)			**178**	**529**	**1710**	**2416**

While the total requirements of ESS for grid support is 17 GWh by 2022, that for e-Mobility is 40 GWh and total from all sectors is 178.5 GWh by 2022. Depending upon the overall economic growth and development of the infrastructure sectors, this could be certainly above 100 GWh. Most of these are likely to be imported. The cumulative demand of ESS by 2032 estimated is in excess of 2700 GWh which is a strong case for setting up of giga-scale battery manufacturing plants in India on fast track.

This report's intended audiences are investors, developers, utility planners, policy makers in the power industry and others who want to know the significant role that energy storage is likely to play in the future's smart grid.

Chapter 1 provides the background of energy storage purpose, scope and approach of study.

Chapter 2 introduces the various types of energy storage technologies such as mechanical, electrochemical, thermal and electrical etc. In addition, some case studies – the ongoing large-scale energy storage projects in India are covered.

Chapter 3 presents the study of integration of 40 GW of RTPV which will be connected to the distribution grid (MV/LV) and its stabilization and optimization requirements. The characteristics of renewable energy that require energy storage as the penetration of renewable energy rises are described. Other than the obvious concerns related to mismatch of renewable energy production compared to load, there are issues related to lower grid inertia and lower spinning reserves during times of high renewable energy production. Energy storage is a solution for addressing these concerns.

Chapter 4 is discussing about the observations and results of the load flow studies done on MV/LV distribution networks in six states in India. The issues and impact of RTPV faced by utilities pan-India varies according to their geographical locations and MV/LV network topologies. In order to analyze the details of the MV/LV network, six distribution utilities were selected to conduct a detailed load flow analysis of distribution feeders. A CYMDIST Library has been created for estimating the RTPV hosting capacity of low voltage feeders. This library of files are listed in Appendix 4 which opens only with CYMDIST modelling software. Majority of the distribution utilities in India use CYMDIST for their power system modelling and hence can take advantage of this library.

Chapter 5 presents the Energy Storage India Tool (ESIT) developed as a part of this project. The basic function of this tool is to take network load data and optimize the energy storage capacity. This tool is capable of conducting cost benefit analysis for different ESS technologies for different grid applications. The value streams captured by ESIT include both monetizable benefits and non-monetizable benefits.

Chapter 6 deals with energy storage projects cost-benefit analysis. The tool outlined in chapter 5 has the ability to comprehend the techno-commercial advantages of using a storage at a specific place through various cost advantages, it can make use of the network at a specific stage. The instrument does not analyze voltage drop, voltage fluctuations and many such parameters of load flow.

Chapter 7 presents the estimated ESS requirements in India for the periods 2019-22, 2022-27 and 2027-32 for different applications. The roadmap has been prepared using separate projections for different ESS applications: RTPV Integration on MV/LV Grid, EHV Grid, e-Mobility, Telecom Towers, Data Centres, UPS and Inverters, DG Replacement and other > 1 MW applications.

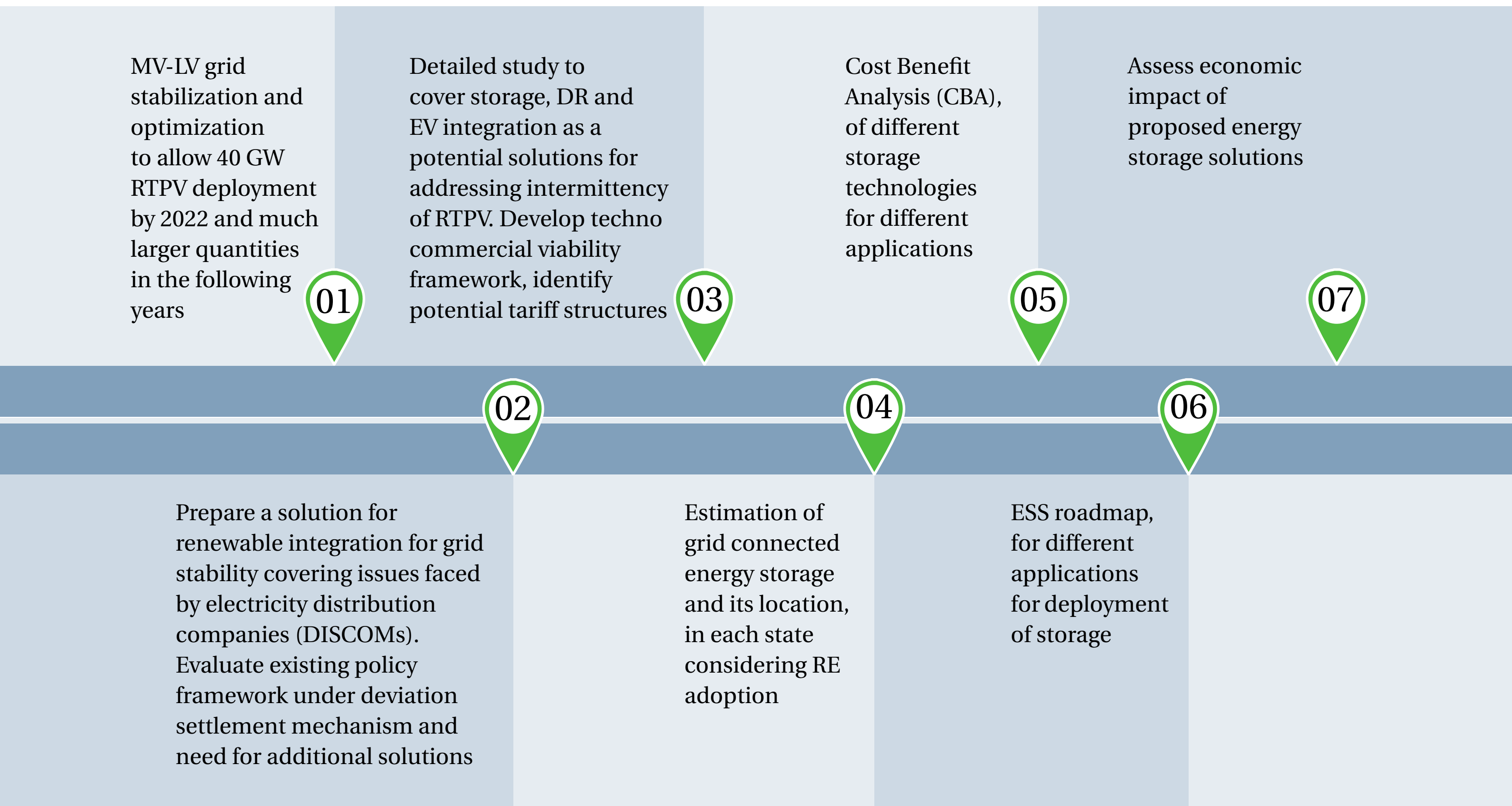
Chapter 8 covers the policy support required for energy storage projects. Best practices for policy including setting tariff for each of the services provided by energy storage, incorporating energy storage in an energy master plan, incentivizing development of energy storage and distributed renewable energy, and support for pilot projects.

1 Introduction and Background

1.1 Purpose of the Study

At COP 21 in Paris in 2015, India made a commitment of meeting 40% of its electricity generation from non-fossil fuels by 2030. This bold commitment requires a host of new technologies. The 175 GW of renewable energy target by 2022 needs to be augmented with much larger capacity as well as new policies and programs towards low carbon development in the power and transport sectors. The integration of distributed generation resources on the low voltage grid require the support of active demand response and energy storage systems to maintain grid stability. In a fast-changing technological environment, it is important to have a clear vision of priorities and needed actions to realize the full benefits of energy storage to help in accelerating the deployment of renewable energy technologies. The scope of this study for ESS Roadmap is presented below:

As an outcome of this detailed study we have prepared an Energy Storage System (ESS) Roadmap for India for the period 2019-2032 that will help policy makers and utilities in decision making related to investments in energy storage for integration of renewable energy leading to a reliable and low carbon grid in India. India is poised to increase its wind and solar power generation to 160 GW by 2022 and plan to expand this further so that the non-fossil-based energy consumption



will account for 40% by 2030. The increased capacity addition of Variable Renewable Energy (VRE) resources in the recent years has already emphasized the need for grid flexibility to accommodate its inherent intermittency. RTPV will contribute to a significant share of the VRE plan with a target of 40 GW by 2022. RTPV capacities have already been doubling year on year driven by robust policies coupled with declining cost of PV panels and increasing utility tariffs. The increased penetration of distributed energy sources, particularly solar PV and small wind turbines is affecting grid stability on the medium and low voltage distribution network. The uncertainty of generation from VRE resources because of its intermittency affect the energy planning of utilities. The anticipated penetration of Electric Vehicles (EV) with a national vision of "100% electrification of transportation by 2030" will further affect the grid stability. ESS is one of the key solutions to address the grid stability as well as to smoothen the output from RTPV.

The grid stability is a growing concern for DISCOMs in recent times and the DISCOMs are seeking technical and policy measures to sustain the uptake of VRE resources. ESS coupled with Demand Response (DR) and Vehicle Grid Integration (VGI) will add flexibility to the grid. Pilot projects with ESS are being studied by Power Grid Corporation of India Ltd (POWERGRID). However, there is a clear lack of guiding principles in helping DISCOMs in deciding the right technology and solutions to adopt ESS as they continue to evolve. The increasing share of solar power generation that is non-synchronous is reducing the inertia of the grid which is vital for the grid stability. There is an increasing tendency to adopt batteries as ESS owing to its declining cost but batteries are failing to support the grid with inertia. Other ESS such as Compressed Air Energy Storage (CAES) and flywheels could add inertia to the grid.

This study assessed different ESS technologies and prepared this roadmap. This report will help utilities choose the right ESS technology for solving VRE integration issues both at the transmission and distribution levels considering various scenarios of penetration of VRE in the grid. Cost of several ESS technologies have been constantly on the decline in the past few years, but it is only Lithium-ion batteries have reached the inflexion point of becoming commercially viable for grid applications. A large market like India embarking on adoption of ESS in a big way with a clear roadmap would send the right signals to the industry to invest in local capacity which will help reduce the cost of ESS.

Energy storage requirement needs to be assessed by evaluating the various scenarios of VRE penetration as outlined in various studies in India including NREL's "Greening the Grid[1]" report which concluded that integration of 160 GW of solar/wind capacity is possible. NREL study evaluated the system feasibility at transmission grid level and considered various scenarios for VRE penetration. A study undertaken by Indo-German Energy Forum and GIZ evaluated the need for dedicated transmission corridors to evacuate VRE. A comprehensive study on evaluating the impact of large scale VRE penetration along with EVs has not been undertaken so far in India. This study undertook comprehensive analysis of the distribution grid level issues and formulated this roadmap to address them by enhancing grid flexibility through ESS.

This study involved following steps:

- Assessment of ESS solutions for Medium Voltage (MV) and Low Voltage (LV) grid stabilization and optimization to facilitate 40 GW RTPV deployment by 2022 and much larger quantities in the following years and prepare an effective solutions portfolio for VRE integration for grid stability
- Study of different ESS technologies and its effectiveness when deployed in tandem with other applications such as demand response (DR) and vehicle grid integration

[1] https://www.nrel.gov/docs/fy17osti/68530.pdf

(VGI) for enhancing the flexibility of the grid to accommodate VRE resources

- Detailed techno-commercial evaluation of different ESS technologies and its viability in the Indian context and prepared a guiding document that Indian utilities and decision makers can leverage for choosing ESS solutions
- Estimation of grid connected ESS and its locations for different ESS technologies in each state considering VRE penetration trends
- Prepared guidelines for determining the VRE hosting capacity on LV and MV feeders
- Prepared the Energy Storage Systems Roadmap for India and an Energy Storage India Tool which governments, regulators and utilities can adopt and use

Key activities undertaken are:

- Review of existing studies as well as ground research to assess preparedness of Indian grid for adoption of 40 GW RTPV and other VRE resources
- Identification of potential technical issues and grid interconnection challenges that needs to be addressed for enabling VRE integration in distribution grid
- Mapping of ESS technologies and other solutions to meet the functional requirements of the grid including active and reactive power compensations
- Studied the impact of EVs on the grid which can serve both as load as well as energy source through VGI applications
- Built network models of the distribution grid in 6 states using CYMDIST modelling tool and conducted load-flow studies to assess the hosting capacity for different scenarios of VRE penetration with ESS support and other flexibility solutions
- Developed an Energy Storage India Tool (ESIT), a techno-commercial evaluation framework to assess the viability of various ESS technologies to address intermittency of VRE resources
- Based on the expected VRE deployment targets in various states and utilities, developed capacity requirements for ESS under different scenarios in VRE rich states and other regions in India
- Developed a detailed Energy Storage Roadmap for India for deployment of different ESS technologies with timelines under various scenarios of VRE and EV penetrations
- Identified suitable locations for deployment of ESS projects owned by utility/service provider/community
- Evaluation of existing and emerging ESS technologies and its deployment under current tariff framework and evaluate potential tariff structures that can provide incentives for utilities, service providers and customers to deploy ESS
- Identified barriers that are preventing deployment of ESS and additional value streams that need to be developed
- Tested various combinations of ESS and other flexibility solutions and prepared guidelines for determining the VRE hosting capacity of distribution grids

This approach for preparation of the roadmap encompassed the evaluation of technical, commercial and regulatory challenges in India for adoption of large scale VRE resources. The activities followed a bottom - up approach that started with identification of grid integration challenges at distribution level. A scenario analysis has been performed to evaluate the anticipated penetration of distributed energy generation in the grid based on the current installation capacities and projected targets. Government policies and study forecasts from relevant agencies like MNRE, CEA, POSOCO (National Power System Operator), POWERGRID and state utilities have been taken into consideration for this study. The analysis have led to identification of the various grid interconnection challenges and identification of utilities/locations where the problems are likely to be severe.

The technical side of evaluation covered review of various energy storage technologies available. The analysis will help identify the right ESS technology for different durations of storage applications in VRE firming, peak time shifting, frequency regulation etc. The ESIT is developed on the proprietary platform CoMETS (Competitive Market Evaluation Tool for Storage) developed by India Energy Storage Alliance (IESA) and their associates. The utilities and other stakeholders will be given access to the ESIT which can be used to appraise the operational feasibility and economic viability of ESS projects. Following features are included in ESIT:

- Techno-commercial evaluation of ESS projects
- Consideration of multiple use cases
- Evaluation of monetizable and non-monetizable benefits
- Testing of different policy incentives

ESIT can evaluate multiple storage technologies for the given application/use case. The tool will not only provide financials of the energy storage but will also provide key statistics in terms of charge-discharge cycles and energy throughput which can be utilized to assess the degradation of storage capacity.

The potential outcomes of this ESS Roadmap are aimed to benefit central and state governments, and all the electricity transmission and distribution companies. This ESS Roadmap will provide utilities on assessment of their preparedness for expanding VRE resources and EV penetration and possible integration challenges. The Roadmap will also benefit all producers of VRE as the integration and power evacuation challenges of VRE will be effectively addressed through the ESS solutions. At a higher level, the Roadmap will provide a long-term ESS procurement strategy for utilities, regulators and policy makers.

1.2 Indian Imperative

1.2.1 India's National Commitment to Reduce Green House Gas Emission

India is facing challenges to sustain its speedy economic growth and on the same front, dealing with global threat of climate change. Keeping in mind its development agenda and commitment to low carbon growth, India has communicated its Intended Nationally Determined Contribution (INDC) in response to COP (Conference of Parties) decisions 1/CP.19 and 1/CP.20 for the period 2021 to 2030, which will directly or indirectly lead to reduced GHG emissions[2]. The key points are:

- During COP 2009 at Copenhagen, Denmark, voluntary commitment is made to reduce emission by 20 to 25% by 2020 from 2005 levels
- Launched Jawaharlal Nehru National Solar Mission (JNNSM) with a target of 20 GW of grid connected solar power by 2020 which has been enhanced in 2015 to 100 GW by 2022
- At COP21 at Paris, India INDC commitments are:
  - To adopt a climate friendly and a cleaner path than the one followed hitherto by others at corresponding level of economic development
  - To reduce the emissions intensity 33 to 35% by 2030 from 2005 level
  - To achieve about 40% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 with the help of transfer of technology and low-cost finance from international institutions including Green Climate Fund (GCF)
  - To create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030

[2] https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/recent-facts-about-photovoltaics-in-germany.pdf

In order to achieve the above targets, India has launched new initiatives in the following priority areas:

01. Introducing new, more efficient and cleaner technologies in thermal power generation

02. Promoting renewable energy generation and increasing the share of alternative fuels in overall fuel mix

03. Full implementation of Green India Mission and other programmes of afforestation

04. Planning and implementation of actions to enhance climate resilience and reduce vulnerability to climate change

1.2.2 Initiatives by Various Government Agencies

In February 2018, an expert committee under the chairmanship of Secretary, Ministry of New and Renewable Energy (MNRE), with representatives from relevant ministries, industry associations, research institutions and subject matter experts was constituted by the MNRE to prepare draft proposal for setting up National Energy Storage Mission (NESM) for India. This expert committee has prepared the draft NESM with objective to strive for leadership in energy storage domain by creating an enabling policy and regulatory framework that encourages manufacturing, deployment, innovation and further cost reduction. NITI Aayog and Rocky Mountain Institute's (RMI) joint report on India's energy storage mission has proposed three stage solution approach i.e. creating an environment for battery manufacturing, growth and scaling up supply chain strategies and scaling of battery cell manufacturing. Energy Storage is one of the most crucial and critical components of India's energy infrastructure strategy and also for supporting India's sustained thrust to renewables.[3]

Key areas for Energy Storage applications

- Integrating renewable energy with transmission grids and distribution grids
- Setting up rural micro grids with diversified loads or stand-alone systems
- Developing storage component for electric mobility plans

1.2.3 Details of 175 GW Renewable Energy Target by 2022

175 GW RE Program

- Solar : 100 GW- (60 GW from ground-mount and 40 GW from rooftop)
- Wind : 60 GW
- Small Hydro : 5 GW
- Bioenergy : 10 GW

The Government of India has ambitious plans to scale up renewable energy in a cost-effective ways to integrate ever increasing quantum of renewables with the power system. India's estimated potential for electricity generation from renewables is 900 GW. The present target is 175 GW by 2022.

[3] http://pib.nic.in/newsite/PrintRelease.aspx?relid=181698

Out of 100 GW solar target, 40 GW is estimated from RTPV while remaining 60 GW is from ground-mounted, grid-connected medium and large solar projects.

Table 1:
RE Capacity region wise and total Target for 2022 (MW)

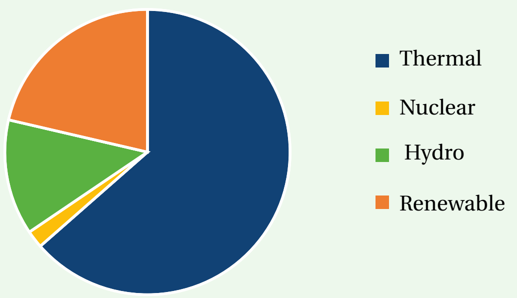
State	Solar	Wind	Small Hydro Plants (SHP)	Biomass and Biopower	Total RE Target 2022 (MW)	Installed Capacity (MW) (April 2019)
Northern Region	31119	8600	2450	4149	46318	14842
Western Region	28410	22600	125	2875	54010	23305
Southern Region	26531	28200	1675	2612	59018	39080
Eastern Region	12237	0	135	244	12616	1444
North Eastern Region	1206	0	615	0	1821	1444
All India Total	**99,534**	**60,000**	**5,000**	**10,000**	**1,74,534**	**80,115**

Source: MNRE

If the target of 175 GW by 2022 is achieved, it would contribute to achieving 19.44% of the total RE potential of 900 GW and about 20.3% of electricity in the total demand. This would mean generation of around 327 BU[4] of electricity (162 BU from solar, 112 BU from wind, 38 BU from biomass, 15 BU from SHP).

With the accomplishment of this ambitious target, India will become one of the largest green energy producers in the world, even surpassing several developed countries. The share of renewable energy in overall installed capacity in the country is given Figure 1.

Figure 1:
Installed Capacity



Source: MNRE

1.2.4 Breakdown of 40 GW Rooftop Solar PV (RTPV)

Solar is one of the fast growing and talked about energy generation technologies globally. Increasing awareness of climate change, energy security needs, incentives from government, decline in list of solar panels and emergence of new and innovative business models are some of the prime drivers for the large-scale development and deployment of solar energy systems.

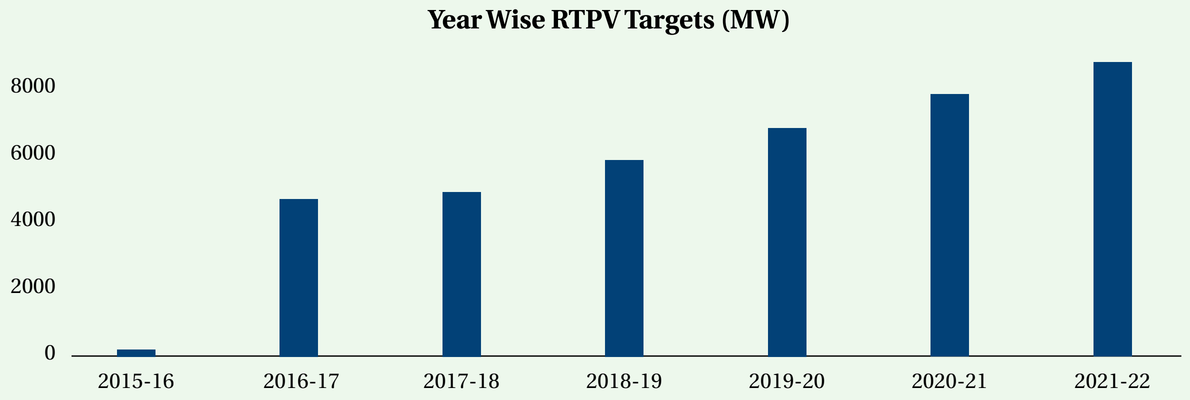
Rooftop Solar (RTPV) Program by Government of India

Government of India has taken ambitious targets of 100,000 MW of solar power by 2022 out of which 40,000 MW is to be achieved through Rooftop Solar (RTPV) power plants as per the clean climate commitments. The year wise rooftop solar targeted capacity (MW) addition during 2016-2022 is shown in Figure 2.[5]

[4] Billion Units – 1 Unit being 1 KWh, 1 BU is Terra Watt – hour (TWh)

[5] https://solarrooftop.gov.in/notification/Notification-24012017.pdf

Figure 2:
Year wise Rooftop Solar Targeted Capacity



Source: MNRE

1.2.5 Regulatory Landscape by States/ Governments in Promoting Rooftop Solar PV (RTPV)

In comparison to other countries, India's renewable energy targets in total are ambitious, but not overly so. However, what is different from the other countries is the projected speed of development. India is looking at a huge capacity increase within a very short time frame without much experience in the sector. That does not mean that the targets are unrealistic, as installation cost has dropped, there is considerable investor interest. It simply indicates that development (including revisions of regulations and incentives) and the studies that go with it has to be kick-started very quickly to reach the official targets. Net metering policies are in effect in all states and Union Territories (UTs) in India.

Table 2:
Regulations for RTPV connection in India

State or Union Territory	RTPV Limit for Individual Customers	Installed Capacity Limit as % of DT capacity
Andaman and Nicobar Islands (UT)	<500 kWp	50% of DT capacity
Andhra Pradesh	Not Specified	60% of DT capacity
Arunachal Pradesh	<1000 kWp	15% of DT capacity
Assam	40% of contracted load, 2016, 80% of contracted load of Individual, 2017 draft	Specified by commission from time to time, 2015, 20% of DT capacity
Bihar	<Sanctioned load	15% of DT capacity
Chandigarh (UT)	<500 kWp: 80% of the sanctioned load	50% of DT capacity
Chhattisgarh	Not Specified	
Dadra and Nagar Haveli (UT)	<500 kWp	50% of DT capacity
Daman and Diu (UT)	<500 kWp	50% of DT capacity

State or Union Territory	RTPV Limit for Individual Customers	Installed Capacity Limit as % of DT capacity
Delhi	No limit specified (depends on feasibility)	Not less than 20% of DT capacity
Goa	<500 kWp	50% of DT capacity
Gujarat	<50% of the sanctioned load	65% of DT capacity
Haryana	<Connected load	30% of DT capacity in case of interconnection is at LT and 15% of the peak capacity of the PT in case of interconnection is at HT
Himachal Pradesh	<80% of the sanctioned contract demand for consumers under two-part tariff <30% of the sanctioned connected load for consumers under single part tariff	30% of DT capacity
Jammu and Kashmir	<50% of the sanctioned load of the consumer	20% of DT capacity
Jharkhand	<100% contracted load	15% of DT capacity
Karnataka	<100% contracted load	80% of DT capacity
Kerala	<100% contracted load	For generation at LT: 15% of DT capacity. For generation at HT: Cumulative capacity connected to the distribution feeder under a particular power transformer is less than 80% of the average load as in the previous one year
Lakshadweep (UT)	<500 kWp	30% of DT capacity
Madhya Pradesh	<1MWp at HT	30% of DT capacity
Maharashtra	<100% contracted load	40% of DT capacity, allowed to exceed upon detailed load study
Manipur	<100% contracted load	40% of DT capacity
Meghalaya	<100% contracted load	15% of DT capacity
Mizoram	<100% contracted load	40% of DT capacity
Nagaland	<80% of the sanctioned load	15% of DT capacity
Odisha	Not Specified	75% of DT capacity
Puducherry (UT)	<500 kWp	50% of DT capacity
Punjab	80% of the sanctioned load	30% of DT capacity
Rajasthan	80% of the sanctioned load	30% of DT capacity
Sikkim	<100% contracted load	For generation at LT: 15% of DT capacity. For generation at HT: Cumulative capacity connected to the distribution feeder under a particular power transformer is less than 80% of the average load as in the previous one year
Tamil Nadu	<100% contracted load	30% of DT capacity
Telangana	For Residential and Government consumers: up to a maximum of 100% of the consumer's sanctioned load; For Industrial, Commercial and Other Consumers: up to a maximum of 80% of the sanctioned load/contracted demand of the consumer	For LT consumers, 50% of DT capacity. For HT consumers, 50% of the maximum load permitted on the feeder, allowed to exceed upon detailed load study

State or Union Territory	RTPV Limit for Individual Customers	Installed Capacity Limit as % of DT capacity
Tripura	<100% contracted load	15% of DT capacity, allowed to exceed upon detailed load study
Uttar Pradesh	<100% contracted load	75% of DT capacity
Uttarakhand	<500	15% of DT capacity, issue raised to increase this value
West Bengal	>5 kW, injection shall not be more than 90% of the consumption from the licensee's supply in a year	Not Specified

1.3 Scope of Study

1.3.1 Study of Different ESS Technologies and its Effectiveness in Indian Context: Detailed Techno-Commercial Evaluation and Guiding Document for Choosing ESS Solutions

This study has undertaken detailed analysis of ESS to integrate 40 GW of RTPV. Achieving RTPV targets with inflexible low voltage and medium voltage grid will have its own challenges. However, with a little planning and defining right feeders which can take higher penetration of RTPV, a lot of challenges can be tackled. Germany on its way to 45.9 GW solar PV by end of 2018, had 98% of the capacity connected to distribution grid.[6] As the grid was seeing effects of high solar PV penetration in distribution grid in Germany, many interventions had to be made like derating of generation below 10 kW to 70% of the rated capacity, firmware upgrade of over 10 GW of inverters to respond to new grid codes, which had budget implications of over € 300 million on the country and lastly introduction of smart inverters. It is understood that one out of two houses which have installed RTPV in Germany in Q1 of 2019, have also installed energy storage. A similar story can be witnessed in India on its way to 40 GW RTPV installations and beyond.

For different utilities, feeder and DT capacity are fixed. Excess solar generation may feed back to the DT and causes failure of Feeder. Thus, it is recommended to know the optimal size of energy storage before any installation. In some cases, rooftop solar may not be feasible from economic standpoint, but installation of storage can make the RTPV installation feasible. Keeping these ideas in mind, Energy Storage India Tool (ESIT) has been developed particularly for India. The basic function of this tool is to take network load data and optimize the requirement for flexible assets like smart inverters and BESS. This tool is well versed with distribution feeder and customer level analysis. For a given input related to site and parameter of a particular project, this tool has the capability to give value benefits discussed in Chapter 5.

Using ESIT tool, the requirement for ESS was determined for rooftop PV integration, which can capture many of the network issues like power quality, peak load management, distribution asset deferral apart from capturing behind-the-meter benefits like electricity savings through ToD tariff and diesel usage optimization for back-up power.

After splitting the RTPV targets across states, customer feeders, the study has segregated RTPV installations into 12 categories, and for each category energy storage requirement has been evaluated based on low and high feeder penetration of RTPV. As found out through the analysis in this study, the storage requirement for base case scenario will be around 9.4 GWh. In majority of these categories of RTPV, across period of 2020-2025, adding energy storage

[6] https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/recent-facts-about-photovoltaics-in-germany.pdf

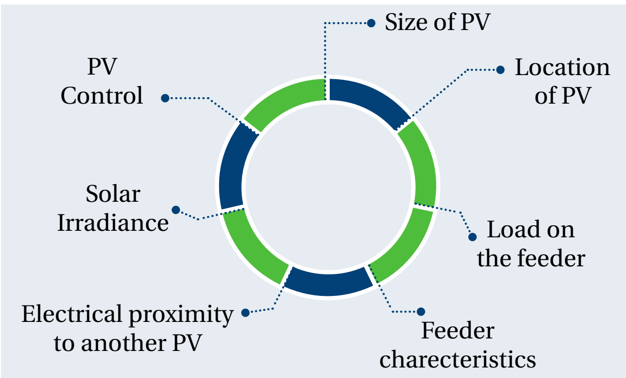
is making sense commercially, as it is able to capture multiple value benefits namely:

- Distribution grid upgrade deferral
- Power factor correction
- Electricity savings
- Diesel optimization/Penalty savings (as there is a likelihood of distribution companies getting penalized for reliability issues)

However, only LiB technologies[7] like Lithium Nickel Manganese Cobalt Oxide (NMC) and Lithium-ion Iron Phosphate (LFP) are making commercial sense as they are available at competitive prices in the Indian market along with promising warranties and performance parameters.

1.3.2 Hosting Capacity of Variable Renewable Energy (VRE) on MV/LV Feeders

RTPV hosting capacity is the total PV power that can be accommodated on a given feeder without any adverse impacts. Distributed solar PV generation has begun to impact distribution systems. The impact is unique to individual distribution feeders and is based on certain or all issues ranging from voltage, loading, power quality, protection, and control. The impact of distributed PV will have on a specific distribution feeder can only be determined with knowledge of the characteristics of feeder. These characteristics include but are not limited to load, voltage, regulation, and impedance. The hosting capacity of a feeder depends on certain key factors such as:



The key requirements to determine the hosting capacity are the distribution characteristics such as voltage response, short-circuit response, locational information, accurate feeder models and the PV characteristics such as location and size.

1.3.3 Technical Issues and Challenges

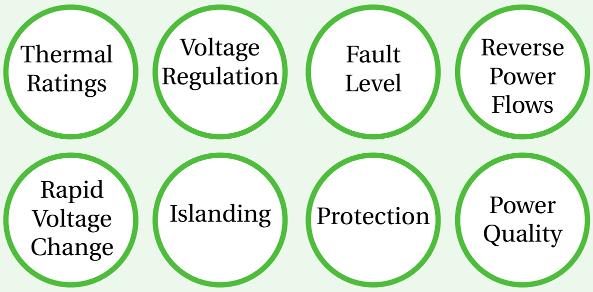
Over the years, significant steps have been made towards promoting the use of renewable energy sources and the integration of such resources with the electricity grids. Nevertheless, interconnection of VRE to the network, especially at high penetration levels, raises important technical issues. In order to mitigate implications from the high penetration of VRE, utilities have established evaluation methodologies based on technical criteria including the thermal ratings of network components, short circuit contribution and resulting fault level, voltage regulation, power quality (flicker, harmonics) etc. These criteria ensure the integrity, security of operation and safety of the networks but still constitute limits for the VRE hosting capacity of the networks.

Technical factors limiting DER interconnection to the distribution networks are:

- Thermal rating of network equipment, such as transformers and feeders, are always an important consideration
- Voltage regulation, mainly voltage rise, is one of the most important problems faced at high VRE penetration
- Increased fault levels, due to the contribution of VRE, is also an important limitation, particularly for MV networks
- Reverse power flows that may affect adversely the operation of voltage regulators and tap changers, impact on network losses and reliability, power quality related issues, islanding considerations and impact on the operation of network protection are additional technical constraints limiting the hosting capacity of feeders and distribution networks

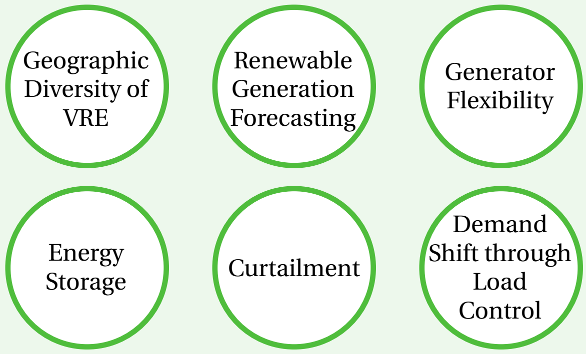
[7] The choice of using LiB was done to showcase the best life cycle cost, effective use as well as better mix of power-energy needs given today's use. The other technologies such as advanced lead acid batteries may indeed suit niche applications.

Figure 3:
Technical Issues Limiting VRE Hosting Capacity of Feeders



1.3.4 Solutions Portfolio for VRE Integration

There are a variety of challenges to integrate high levels of VRE into electric grids. The solutions are always system and location dependent and may or may not be applicable to different situations. The main attribute of VRE that must be addressed is the variability of the resource and how to account for this variability over several time scales. Since VRE is not dispatchable, there are a number of technical opportunities to upgrade grids that are more flexible and can accommodate higher levels of VRE. The solutions to enable a suitable portfolio for VRE integration are:



2 ESS Technologies

2.1 Introduction

Energy storage deployments on electricity grids are being deployed at a rapid scale. As per Department of Energy (DOE), USA, till mid-2018, almost 177 GW of energy storage systems are installed at grid level and over 95% of it is pumped hydro storage plants. Over 14 GW of new pumped storage projects are announced across the world in 2018. However, due to their long gestation period most of these projects will be realized by 2030. In 2018, over 4 GWh[8] of BESS are either under-construction, contracted or announced. Hence, annually more BESS are getting installed and contracted than any other storage technologies. Additionally, out of over 4 GWh BESS in pipeline, over 80% are LiB-based projects. Most of these LiB projects are grid connected and rest of them are for behind the meter applications. Battery capacity for behind the meter applications like bill management and demand response is less than 10% of upcoming LiB based BESS. These numbers do not include battery installed for backup power applications like UPS, inverter backup and telecom tower backup power applications. Apart from BESS, there are other mechanical storage technologies like flywheels, gravitational ESS and modular Compressed Air Energy Storage (CAES) which accounts for about 200 MW of contracted, under construction or announced projects globally.

Grid scale energy storage installations in India are also mostly in the form of pumped hydro storage plants, at capacity of 4.8 GW. Deployment of large-scale battery energy storage projects in India started in 2017 with POWERGRID installing their first pilot projects for frequency regulation. The projects have been designed for multiple grid service applications but in the initial operation period they have been used for frequency regulation services. The existing and upcoming large-scale energy storage projects are summarized in the Table 3, most of which are likely to be commissioned by 2019 and 2020.

Most of the proposed energy storage projects in India 2018-19 are expected to come up in the Andaman & Nicobar Islands to reduce the dependency on diesel use. Solar Energy Corporation of India (SECI) is also evaluating energy storage projects along with the bids of large scale solar and wind projects in the future beginning with a proposed 160 MW hybrid project in Andhra Pradesh.

As the installed capacity of RE increases, the role of the conventional generation will be reduced to provide base load. Renewable energy being intermittent adds its own challenge to the grid. Energy storage is being increasingly seen as the flexible resource that can address this concern. It has a number of applications in ancillary services, generation smoothening, load following, peak power shaving, energy time shifting and emergency back-up etc.

As highlighted by the Central Electricity Regulatory Commission (CERC) Staff Paper on Energy Storage[9], transmission companies can deploy energy storage systems at grid level substations and use the assets to participate in energy markets for grid support like the ancillary services. Transmission companies

[8] DOE database and Customized Energy Solutions (CES) analysis
[9] Staff Paper on Introduction of Electricity Storage Systems, CERC, 2017

Table 3:

Energy Storage Projects in India (2017 - 2019)

Project	Capacity	Location	Status of the Project
Power Grid Corporation Limited	3 x 500 kW, 250 kWh BESS	Puducherry	Completed
NLC	2 x 10MW Solar PV + 8MWh/16MW BESS	Port Blair, Andaman & Nicobar Islands	Planned for completion in 2020
NTPC	2MWh BESS	Port Blair, Andaman & Nicobar Islands	Planned for completion in 2019
NTPC	17MW Solar PV + 6.8MWh/6.8MW BESS	South Andaman, Andaman & Nicobar Islands	Planned for completion in 2019
NTPC	8MW Solar PV 3.2MWh/3.2MW BESS	South Andaman, Andaman & Nicobar Islands	Planned for completion in 2019
Tata Power Delhi Distribution Limited (TPDDL)	10MWh BESS	Sub-station, Delhi	Completed
Solar Energy Corporation of India (SECI)	10 MW/20 MWh BESS for 160 MW Wind + Solar Hybrid	Andhra Pradesh	Planned for completion in 2019
SECI	2 MW Solar PV Project + 1 MWh BESS	Kaza, Himachal Pradesh	Planned for completion in 2019
SECI	2 x 1.5 MW Solar PV +2 x 2.5 MWh BESS	Leh District, J&K	Planned for completion in 2019
Andhra Pradesh State Electric Utility	5 MW Solar PV Project + 4MWh BESS	Makkuva, Andhra Pradesh	Planned for completion in 2019

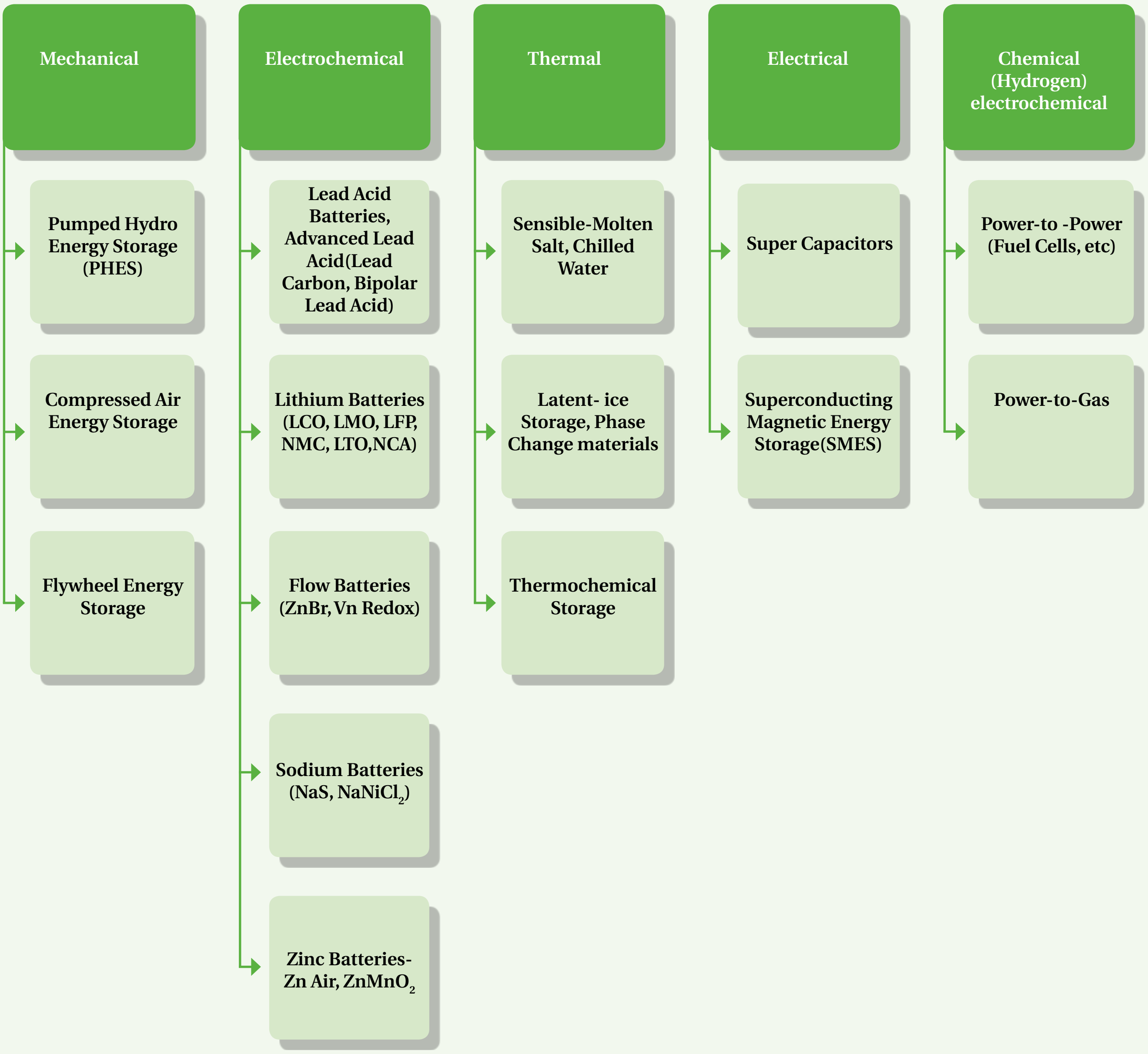
can be the owners of energy storage systems without being involved in trading of the stored energy. The National Electricity Plan (NEP)[10] highlights the role of energy storage in maintaining grid security with increasing penetration of renewable energy in addition to addressing the intermittency of RE to a large extent. For behind the meter applications, Indian battery energy storage market has been traditionally driven by lead acid batteries for back-up power applications. Batteries for power back-up applications is a major market among stationary applications. The recent air pollution issues have only amplified the need to switch off diesel generators. With energy storage solutions offering a comparable cost per unit, a sizeable capacity will be deployed in this space. Large scale batteries can be installed along with the solar and wind farms to provide a stable output to the grid. Market mechanisms are expected to incentivize the performance of these flexible assets but it will be a slow growing market, in the business as usual scenario.

2.2 Description of Energy Storage Technologies

Energy storage could apply to different technologies ranging from pumped hydro storage, flywheels, super capacitors, compressed air, thermal energy storage and batteries. Advanced energy storage technologies are capable of dispatching electricity within seconds and can provide power back-up ranging from minutes to many hours.

[10] National Electricity Plan (Vol 2, Transmission, draft), CEA, 2017

Figure 4:
Classification of Energy Storage Technologies



- ***Mechanical Storage*** includes Pumped Hydro Storage (PHS), Compressed Air Energy Storage (CAES) and Flywheels:
  - ***Pumped Hydro Storage (PHS)*** stores electrical energy as the potential energy of water. Generally, this involves pumping water into a large reservoir at a high elevation—usually located on the top of a mountain or hill. When energy is required, the water in the reservoir is guided through a hydroelectric turbine, which converts the energy of flowing water to electricity. PHS is often used to store energy for long durations for use in a future period.

    Global PHS capacity is over 180 GW. Potential available in India for PHS, assessed by Central Electricity Authority (CEA) is more than 96.5 GW.[11] However, at present, total installed capacity of

[11] https://www.hydropower.org/publications/the-world%E2%80%99s-water-battery-pumped-hydropower-storage-and-the-clean-energy-transition

pumped hydro is about 4.8 GW that consists of nine plants. Additionally, two projects of 1080 MW capacity are now under construction (Tehri - 1000 MW and Koyna - 80 MW). Also, four projects with cumulative capacity of 2600 MW (Kundah– 500 MW, Malshej Ghat- 700 MW, Humbali- 400 MW, and Turga- 1000 MW) are under planning stage.[12] However, at a given point of time, many of these assets are either under maintenance or are on water 'release only' mode as they are linked to irrigation department and pumping is a secondary function. Hence the full capacity of PHS is seldom realized in India.

- ***Compressed Air Energy Storage (CAES)*** converts electrical energy into compressed air, which is stored either in an underground cave or above ground in high-pressure containers. When excess or low-cost electricity is available from the grid, it is used to run an electric compressor, which compresses air and stores it. When electrical energy is required, the compressed air is directed towards a modified gas turbine, which converts the stored energy to electricity. A recent advancement that is maturing through research and development by several startups is storage of the heat produced during the compression. This type of CAES does not use natural gas to reheat the air upon decompression and is therefore emissions-free, as well as more efficient overall. Similar to pumped hydro, CAES systems are used for storing energy over longer periods. Secondly, similar to pumped hydro storage, a natural CAES plant would require a cavern. Hence, CAES systems are limited in nature with restricted availability of natural caverns.

- ***Flywheel Energy Storage (FES)*** store electrical energy as the rotational energy in a heavy mass. Flywheel energy storage systems typically consist of a large rotating cylinder supported on a stator. Stored electric energy increases with the square of the speed of the rotating mass, so materials that can withstand high velocities and centrifugal forces are essential. Flywheel technology is a low maintenance and low environmental impact type of energy storage. In general, flywheels are very suitable for high power applications due to their capacity to absorb and release energy in a very short duration of time. Globally, total installed capacity of grid scale FES systems is 975 MW, mainly for frequency regulation applications. Other popular applications are in transportation and rotary UPS[13] key application in India. Typical Flywheels run 15 – 30 min but recent developments in power electronics have increased the duration of flywheel up to 4 hours.

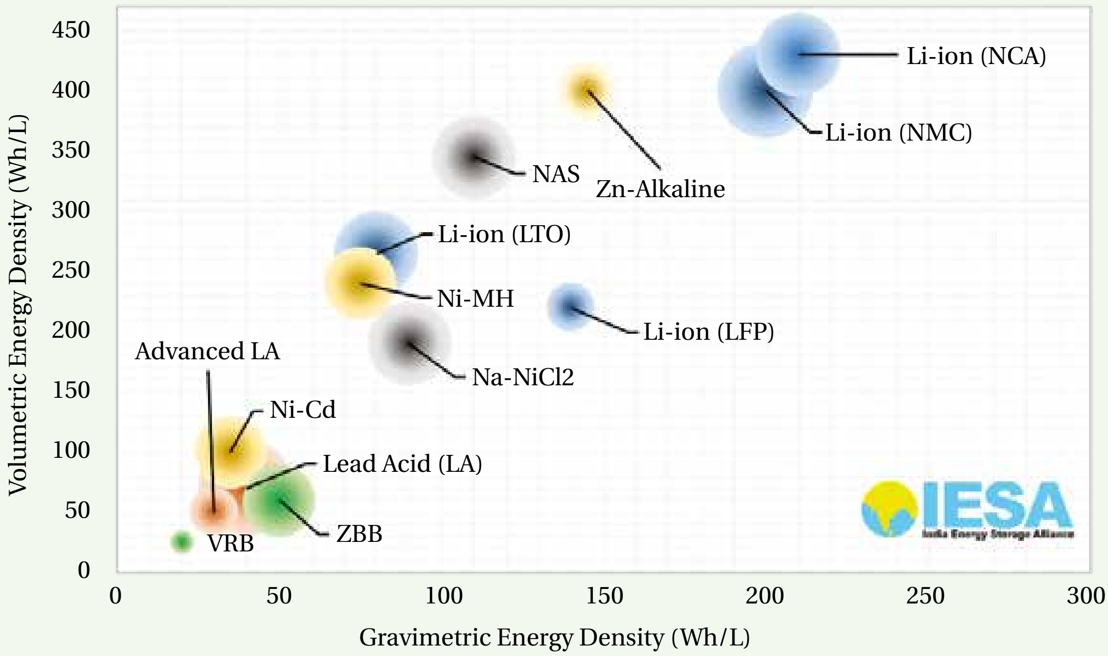
- ***Electrochemical Storage*** includes various battery technologies that use different chemical compounds to store electricity. Each of the numerous battery technologies have slightly different characteristics and are used to store and then release electricity for different durations ranging from a few minutes to several hours. There are two main categories of batteries: (1) Traditional solid rechargeable batteries where the chemical energy is stored in solid metal electrodes, and, (2) Flow batteries where chemical energy is stored in varying types of flowing liquid electrolytes kept in tanks separate from the actual electrochemical cells.
  - ***Rechargeable Batteries***
    - ***Lead Acid*** batteries have been in commercial use in different applications for over a century. Lead acid is the most widely used battery technology worldwide. High

[12] National Electricity Plan (Vol 2, Transmission, draft), CEA, 2017
[13] A flywheel driven rotary UPS is used for applications requiring ride-through of short duration power system outages, voltage dips.

performance variations of lead acid batteries are classified as *advanced lead acid* and are known to have a longer life

- ***Advanced Lead Acid*** batteries are of two types, namely Lead Carbon type and Bipolar Lead Acid type. Lead Carbon type uses carbon additives to improve the energy density, cycle life and better charging-discharging properties than the lead acid type. Its key applications includes frequency regulation in solar farms and has an installed capacity of 27.398 MW globally.
- ***Bipolar Lead Acid Battery*** has bipolar plates and eliminates the high current density seen around the terminals in the conventional design. In the bipolar design, each point on an electrode is in contact with the current collector. This type has higher specific energy and energy density, ~ 40% lesser footprint (compared to monopolar type) and recyclable materials.
- ***Lithium Ion Batteries (LiB)*** are lightweight and have high energy density. They are particularly suited for portable applications (electric vehicles and electronic devices). There are many possible variations depending on the internal chemistry: Lithium Cobalt Oxide (LCO), Lithium Titanate Oxide (LTO), Lithium Manganese Oxide (LMO), Lithium Iron Phosphate (LFP), Lithium Nickel Manganese Cobalt Oxide (NMC), and Lithium Nickel Cobalt Aluminum Oxide (NCA). In recent years, it witnessed rapid progress in the research and development leading to a steep price reduction as the manufacturing and installations have scaled up. A key inflexion point that tilted the benefits towards LiB is the increasing energy densities compared to lead acid batteries. As on 2017, the cumulative global manufacturing capacity of LiB has crossed 100GWh a year and is expected to surpass lead acid battery market soon. Sustained interest in the electric vehicle space has created an increased demand for lithium batteries and the global capacity is expected to be 4 times the current state by end of this decade.
- ***High Temperature Sodium:*** This type of battery is made from inexpensive, non-toxic materials. The battery operates at a high temperature (above 300^{o}C) and has been shown to have a long cycle life. Two types are Sodium Sulphur (NaS) and Sodium Nickel Chloride ($NaNiCl_2$) are under these categories.
- ***Sodium Sulphur (NaS) is*** manufactured with molten sodium and liquid Sulphur enclosed in a cell container usually cylindrical in shape and enclosed in a steel casing. One Japanese company is the only manufacturer for this battery. By 2018, 195 MW of NaS batteries were installed globally. Key application includes spinning reserve, frequency regulation, energy time shift and transmission congestion relief. In India, NaS battery was trial tested by NTPC, for its feasibility in Indian grid conditions in a solar system.
- ***Sodium Nickel Chloride ($Na\text{-}NiCl_2$)*** operates at a lower temperature with molten sodium as cathode, $NaAlCl_4$ as electrolyte and nickel chloride as anode. Major applications include black start, renewable energy time shift, and frequency regulation.
- ***Zinc-based Batteries*** combine zinc with various chemicals and are earlier in their development stage than some of the other battery technologies. Historically, zinc batteries were not rechargeable but developers are overcoming challenges to produce fully rechargeable zinc-based

Figure 5:
Volumetric (Wh/L) and Gravimetric (Wh/kg) energy density for commercially available battery technologies



* For flow batteries VRB and ZBB (zinc bromine), only electrolyte weight and volume is considered

chemistries. This technology is known for being lightweight, low-cost, and non-toxic.

- ***Zinc Air Battery*** also known as Zinc Air fuel cells functions by oxidizing Zinc with oxygen, and the reaction rate is controlled by controlling air flow. It comes in both rechargeable and non-rechargeable forms. Applications include vehicle propulsion and grid storage. This battery is in test trial stage, with a few projects announced in the US.
- ***Zinc Manganese Battery:*** One manufacturer has recently developed a rechargeable $ZnMnO_2$ battery with 2-8 hours discharge duration. These batteries are safe and non-toxic without lead, heavy metals or flammable electrolytes which is expected to be cheaper replacement for LiBs.

Energy densities of different batteries are shown in Figure 5. Higher energy density batteries are more suitable for transportation applications due to their compactness and lower weight.

- ***Flow Batteries***
  - Flow batteries differ from conventional batteries as the that energy is stored in the electrolyte (the fluid) instead of the electrodes. The electrolyte solutions are stored in tanks and pumped through a common chamber separated by a membrane that allows for transfer of electrons—flow of electricity—between the electrolytes.

- There are many different types of flow batteries, of which at least three varieties are currently commercially available: *vanadium redox flow batteries, zinc-iron flow batteries*, and *zinc-bromine batteries*. Variations such as zinc-iron flow batteries and hydrogen-bromine flow batteries are also under development.
- This technology has reached commercialization globally with 326 MW of grid connected flow batteries across 108 projects till 2018.
- In India, the technology adoption is limited to test-trials. A 30kW Vanadium Redox battery was installed in 2015 for a microgrid. Also, at IISc Bangalore, a new type of flow battery called the soluble lead acid flow battery is under technology development.

- ***Thermal Energy Storage*** includes ice-based storage systems, hot and chilled water storage, molten salt storage and rock storage technologies. In these systems excess thermal energy is collected for later use.
  - ***Sensible Heat Storage:*** Available energy is stored in the form of an increase or decrease in temperature of a material, which can be used to meet a heating or cooling demand. Few existing variations of this technology are: *Molten salt storage* (generally coupled with Concentrated Solar Power (CSP) plants), *hot water storage* and *chilled water storage* (designed to serve households or a community).
  - In ***Latent Heat Storage,*** energy is stored in a material that undergoes a phase change (transition between solid and liquid) as it stores and releases energy. Examples include ice storage tanks for domestic or industrial cooling applications
  - In ***Thermochemical Storage,*** reversible chemical reactions are used to store thermal energy in the form of chemical energy. The available variations are currently in initial developmental stage.
- ***Electrical Storage*** *Super capacitors and Superconducting Magnetic Energy Storage (SMES)* systems store electricity in electric and electromagnetic fields with minimal loss of energy. A few small SMES systems have become commercially available, mainly used for power quality control in manufacturing plants such as microchip fabrication facilities. These technologies are ideal for storing and release high levels of energy over short bursts.
- ***Chemical Storage*** typically utilizes electrolysis of water to produce hydrogen as a storage medium that can subsequently be converted to energy in various modes, including electricity (via fuel cells or engines), as well as heat and transportation fuel (power–to-gas).
  - ***Electrolyzes (Power to Gas):*** Excess electrical energy can be utilized by these systems for electrolysis of water to produce hydrogen (H_2) and oxygen (O_2). The stored hydrogen may be used directly as fuel for heating applications or in fuel cells. Electrolyzes are unidirectional devices only allowing storage of energy.
  - ***Fuel Cells:*** Chemical energy stored in fuels (ethanol, hydrogen or natural gas) can be converted to electrical energy. Several variations exist such as SOFC (solid oxide fuel cells), PEM (proton exchange membrane), and PAFC (phosphoric acid fuel cells). These systems can be used for stationary storage or transportation applications.

2.3 Key Players and Technologies

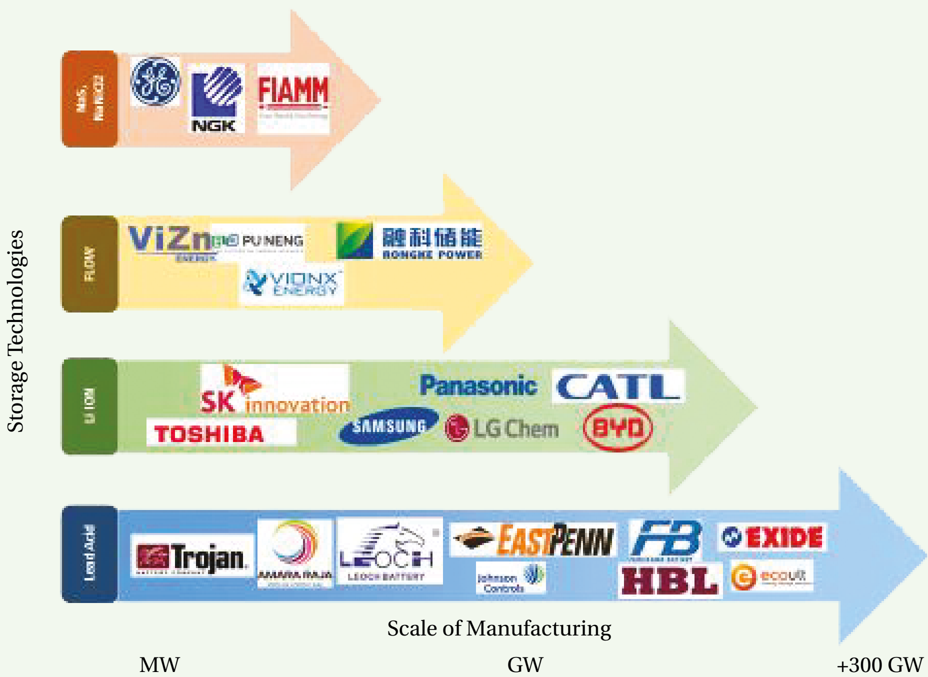
The energy storage landscape is well split among organizations with various technologies and these technology companies are broadly based out of Japan, China, Korea, US and Germany. Some of the key companies across the spectrum are listed in Figure 6.

Figure 6:
Global and Indian Energy Storage Landscape

Source: CES

However, these technologies are at different stage of commercialization and also at different stage of manufacturing. LiB chemistries are at point of overtaking lead acid production.

Figure 7:
Global and Indian Energy Storage Landscape



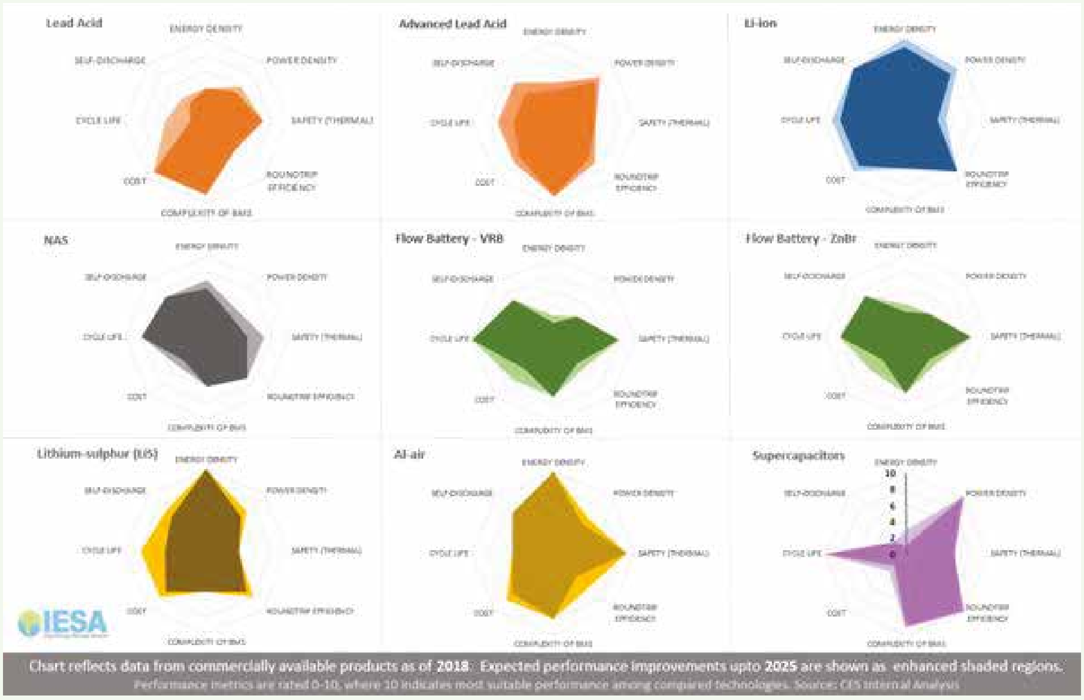
Energy Storage – Technologies Performance and Characteristics

Each type of available energy storage system (ESS) has specific attributes. These factors must be evaluated in order to choose the suitable technology for a specific purpose. Table 4 provides a comparison of different technical parameters, such as operating costs and technology maturity, as well as practical considerations, line space requirements, development and construction periods for select ESS.

Figure 8:

Comparison of leading Energy Storage Technologies based on key performance parameters

Expected Technological Performance Improvements during 2018-2025



Source: CES and IESA Research

The C-rate of the system is an important parameter that varies significantly between different energy storage types particularly electrochemical batteries. C-rate is an inverse measure of the rate (length of time) over which a system can provide its maximum rated power. The range of discharge duration is therefore directly linked to the C-rate. It is normally expressed in terms that look like 1C, 2C or C/2. For instance, a system with a C-rate of 2C can supply all its stored energy in ½ hour while a system with a C-rate of C/2 can do the same in 2 hours. Therefore, a system with a higher C rate can discharge at a higher maximum power than a similarly-sized system with comparable energy capacity but a lower C rate. In other words, systems with a higher C-rate have a higher power to energy ratio. High power applications typically require systems with a high C-rate and a short discharge duration. These applications are particularly suitable for LiB and advanced lead acid batteries. Sodium based batteries and flow batteries, as well as CAES and PHS, are more suitable for high energy and longer duration applications. C-rate is typically not used for CAES and PHS as the duration of energy storage is not limited by the technology as in case of electrochemical batteries, but is typically based on physical availability of storage capacity.

Table 4:

Performance Characteristics of Energy Storage Technologies

Energy Storage System Attributes	Lead Acid	Li –Ion	NaS	Flow Batteries	Flywheel	CAES	PHS
Round Trip Energy Efficiency (DC-DC)	70-85%	85-95%	70-80%	60-75%	60-80%	50-65%	70-80%
Range of Discharge Duration	2-6 Hours	0.25–4+ Hours	6-8 Hours	4-12 Hours	0.25-4 Hours	4-10 Hours	6-20 Hours
C Rate	C/6 to C/2	C/6 to 4C	C/8 to C/6	C/12 to C/4	C/4 to 4C	N.A.	N.A.
Cost range per energy available in each full discharge ($/kWh)[14]	100-300	250-800	400-600	400-1000	1000-4000	>150[15]	50-150[16]
Development & Construction Period	6 months - 1 year	6 months - 1 year	6 months - 1.5 year	6 months - 1.5 year	1-2 years	3-10 years	5-15 years
Operating Cost	High	Low	Moderate	Moderate	Low	High	Low
Estimated Space Required	Large	Small	Moderate	Moderate	Small	Moderate	Large
Cycle life: # of discharges of stored energy	500-2000	2000 -10,000+	3000-5000	5000 - 8000+	100,000	10,000+	10,000+
Maturity of Technology	Mature	Commercial	Commercial	Early to moderate	Early to moderate	Moderate	Mature

As shown in the Table 4, the system prices vary greatly, especially in terms of initial capital costs. Overall, the cost of energy storage is rapidly declining with scaling up of manufacturing and learnings from the early deployments. The cost of energy storage technologies has significantly decreased in recent years, driven by the growth of the battery manufacturing for consumer electronics, stationary applications and electric vehicles. As battery costs contribute approximately 60-75% of an energy storage project (depending on the duration or energy capacity required), capital cost reductions can

[14] Cost numbers are for the system level costs at DC level (i.e. not considering PCS and balance of system costs)

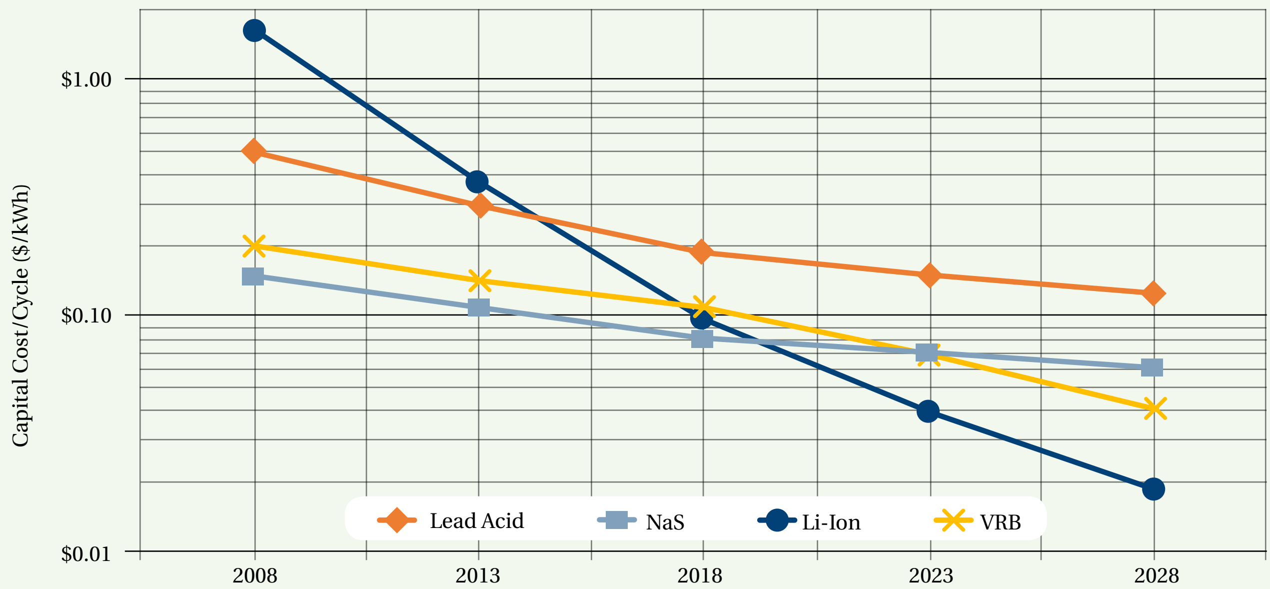
[15] For CAES, the operating costs are significantly higher as it also involves cost of natural gas for source of heat during discharge cycle in addition to electricity cost for compression during charging cycle.

[16] The average capital costs for pumped hydro on per kWh of storage capacity are significantly lower, but requires huge upfront cost given the size of the projects. These costs also can be higher in case of delays in environmental clearances.

drive energy storage project development.[17] Levelized cost method is often used to compare costs across different energy sources or technologies. Other critical factors in selection of energy storage technologies include space requirement and maturity of technology. With improvements in materials as well as system design, energy density of most storage technologies is increasing and particularly LiBs are finding applications where space and weight is a critical consideration. In terms of maturity, Lead Acid batteries have been around for over 100 years and are very mature in terms of technology performance and manufacturing. LiBs have also reached commercial maturity with multiple companies setting up GWh scale manufacturing plants.

Figure 9 depicts the steadily decreasing capital costs per cycle ($/kWh-cycle) of certain storage technologies. The depicted levelized cost shown takes into account the total predicted cycle life, or the operational lifetime of the technology, and thus normalizes the capital cost over the entire lifetime of the project.

Figure 9:
Forecast of Estimated Levelized Capital Costs by Storage Technology and Type

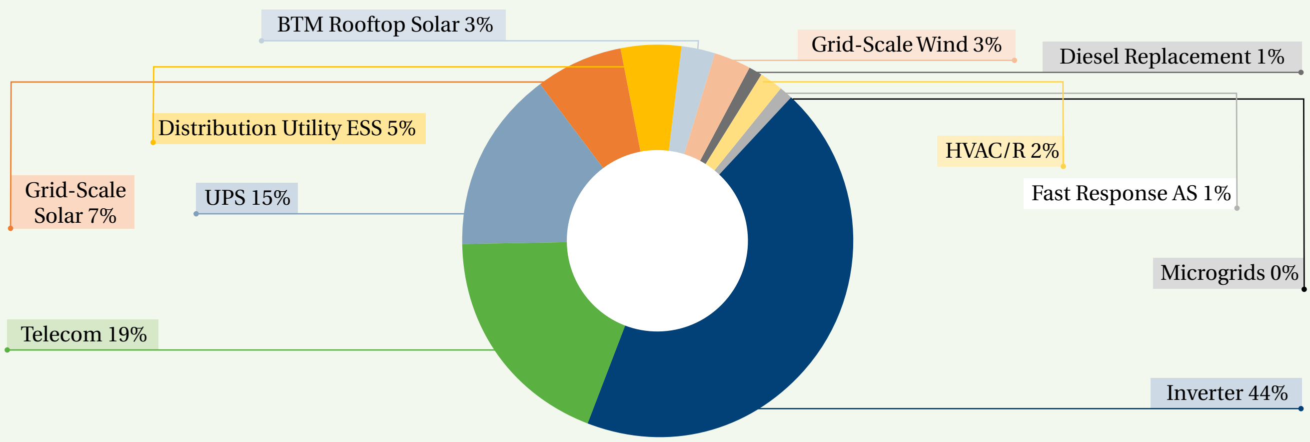


2.4 Need for Energy Storage in India

India has committed to increase its share of non-fossil fuel-based generation sources to 40% by 2030 which necessitates a demand for flexibility in power systems. The 'Power for All' target of 24x7 electricity for all by 2019 created an increase in power requirement and a need to balance the supply and demand of electricity. Energy storage will play a crucial role in increasing the system's overall flexibility by serving multiple grid applications. The recent developments in the Electric Vehicle (EV) sector and its ambitious targets will only increase the demand for energy storage systems.

[17] Energy Storage Update, Lithium-ion costs to fall by up to 50% within five years, July 30, 2016; http://analysis.energystorageupdate.com/lithium-ion-costs-fall-50-within-five-years

Figure 10:
2019-2025 Energy Storage Requirement, India



Source: CES analysis

Energy storage market in India witnessed a demand of 23 GWh in 2018 with 56% of the battery demand coming from power backup inverter segment. During 2019-2025, the cumulative potential for energy storage in behind the meter and grid side applications is estimated to be close to 190 GWh by India Energy Storage Alliance. Interestingly, only 17% of energy storage is likely to be deployed at grid scale. Majority of the deployment during this period at grid scale will be driven by RE integration, Fast Response Ancillary Service (FRAS) market and T&D deferral. On the other hand, electric vehicle industry, consumed over 5 GWh of batteries in 2018 in India. This number is likely to be over 36 GWh by 2025. During 2019-2025, the EV industry is forecasted to consume over 110 GWh of batteries. Some of these can be used through V2G (Vehicle to Grid) technology to meet flexibility needs of the distribution grid.

Large requirement for storage and batteries across the applications will help in reduction of costs in the market. Lastly, new installations of ESS for distribution grid and rooftop PV integration can be reduced if the network planning can be done around utilizing of V2G and some of existing back-up battery base.

2.5 Energy Storage System (ESS) Applications

Energy storage is a uniquely flexible type of asset in terms of the diverse range of benefits it can provide, locations where it may be sited, and the large number of potential technologies which may be suited to provide value to the grid. Fundamentally, energy storage shifts energy from one-time period to another time period. However, the value of energy stored by a resource varies highly based upon the controllability, dispatch and use of that energy.

The electricity system has historically operated on a “just-in-time” basis – with decisions about electricity production based on real-time demand and the availability of transmission system to deliver it. Because of this, generation and load must always be perfectly balanced to ensure high power quality and reliability to end customers. At very high penetrations of variable wind and solar generation, energy storage can be effective for storing excess energy at certain times and moving it to other times, enhancing reliability and providing both economic and environmental benefits.

Storage's unique physical characteristics enable it to perform multiple functions on the grid, at the customer level and in transportation sector. The ability to store energy when there is no demand and deploy energy when load is needed can be applied to all aspects of the energy systems. In addition, storage systems can function like a power plant, dispatching electricity. When renewable resources such as solar, wind or hydropower produce excess energy, ESS can store it for later use, reducing energy waste.

2.5.1 EV Adoption

The automobile market in India is at the cusp of paradigm shift from Internal Combustion Engine (ICE) vehicles to zero emission vehicles. India's dependency on crude oil imports, rising pollution levels in several cities, commitment to reduce the carbon emissions, and the global shift towards electric vehicles are the key drivers for this paradigm shift towards zero emission vehicles.

The current share of battery-operated electric passenger vehicles is approximately 0.1% whereas in case of electric 2 wheelers, it is approximately 0.2% and there are only few hundred electric buses. The EV Industry in India is mainly dominated by electric 2 wheelers and 3 wheelers; and now witnessing growth of electric buses.

Vehicle to Grid

As electric vehicles have started gaining momentum at a higher pace globally, the utilities, system operators, and the policymakers have started addressing the issues related with the vehicle charging management to the smooth integration of load coming from electric vehicles on the grid.

Regular power cuts and high peak demand tariffs could become a thing of past with the use of vehicle to grid (V2G) concept. The V2G concept acts (and looks) very similar to a standard charging point. The difference is that the energy flows both to and from the vehicle, turning it to a portable battery bank.[18] There are three basic system components involved that actually defines the environment for recharging a vehicle or discharging energy from the vehicle to the electrical grid. i) The location where the vehicle connects with the electrical grid, ii) The electric vehicle supply equipment (EVSE) to which a vehicle connects, and iii) The electric vehicle (or more specifically the battery management system) that manages the battery's charge-discharge cycle.[19]

With respect to practical demonstration of the concept, pilot projects have been carried out so far in Denmark, Netherlands, Spain and USA. V2G has been already commercialized in Denmark and the Netherlands.

V2G concept could provide important services to grid operators such as balancing renewables peaks, balancing frequencies, providing spinning reserves, providing excess energy and bulk storage etc. But on the other hand, there are lots of constraints associated with it such as battery degradation, the need for intensive communication between vehicles and the grid, infrastructure changes, effects on distribution grid equipment etc.

The results obtained from the pilot projects carried out globally are indicating that the V2G concept can play a key role in grid balancing. For the implementation of V2G concept, a thorough study of network at the local level along with its impact on the local distribution network and the techno-economic feasibility from the vehicle's owner perspective should be done for framing appropriate policies.

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[18] www.cenex.co.uk/vehicle-to-grid/

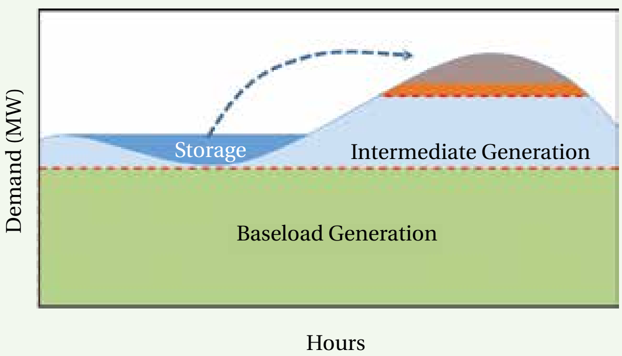
[19] Vehicle-to-Grid (V2G) Power Flow Regulations and Building Codes, INL, September 2012

2.5.2 Peak Shaving

The 19th Electric Power Survey (EPS)[20] estimates that India's electric energy requirement would be 1566 BU in 2021-22 with a peak load demand of 226GW. The reduction in demand forecast between the 18th and 19th EPS is attributed to the Demand Side Management (DSM), Energy Conservation and Efficiency improvement programmes, reduction in AT&C losses, and low GDP growth than the forecast in 2011 when the 18th EPS was published. The energy demand and peak load demand is likely to grow by 6.18% and 6.88% respectively as per the 19th EPS. The estimates from the 19th Electricity Power Survey and National Electricity Plan projects India's installed capacity to grow from 335GW to 479GW at a rate of 9% while the peak demand is growing only at 6%. The contribution of renewable energy in the mix is set to double during the same period both in terms of added capacity and as a percentage of peak demand.

In addition to the fundamental benefit of storage being able to charge during low-cost times, storage has other qualities that make it competitive compared other peak generators. Storage tends to be much more responsive than generation-based peaking resources because, for most types of storage:

Figure 11:
Storage as a Peaker Resource



[20] Nineteenth Electric Power Survey of India, Jan 2017, CEA

a) Start-up is very quick (low response time)
b) Output can be varied rapidly
c) Can be operated at part load easily and efficiently

2.5.3 Ancillary Services

The existing regulatory framework in India permits floating of grid frequency within the band of 49.90 – 50.05 Hz. The frequency is observed to have remained within the specified band for about 70-75% of the time since the last revision to frequency band in 2014. The frequency profile and fluctuations from 2004 onwards is shown in below Figure 12.

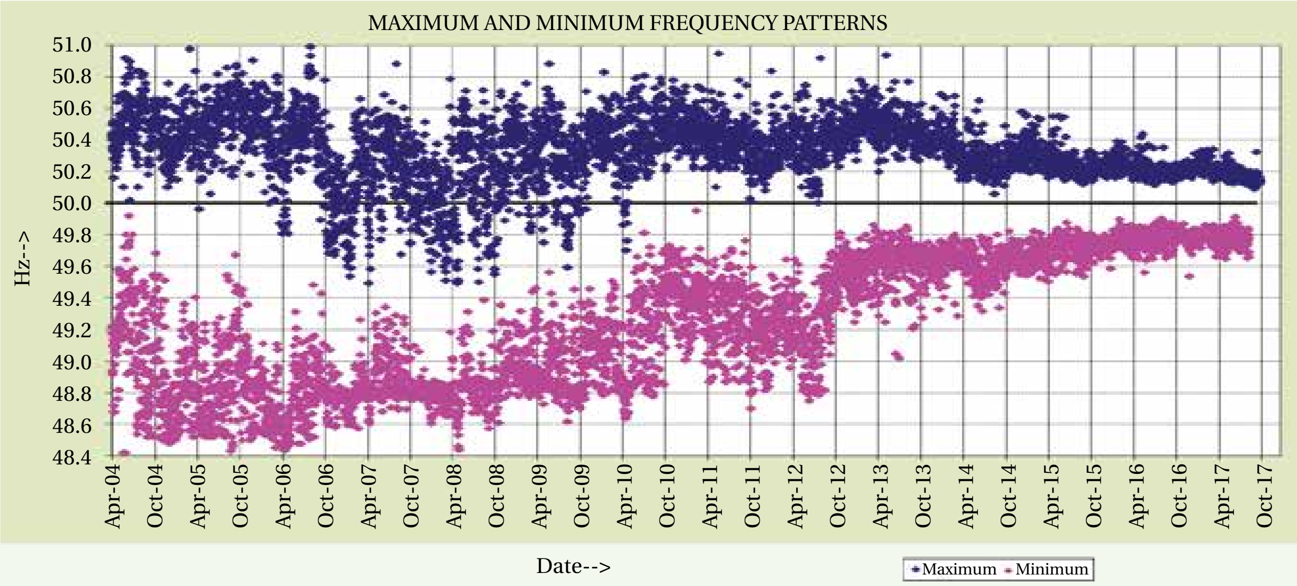
The Frequency Response Characteristics (FRC) for All India Grid has improved from 6000 MW/Hz to 9000MW/Hz over the last two years which is still lower than comparable grid sizes in which has FRC of the order of 20000MW/Hz. With stricter framework including ancillary services through FRAS and governance, the frequency has come under control to a large extent. But still, it remains over and above the upper limit of 50.05 Hz for around 25% times.

The Indian Electricity Grid Code (IEGC) 2010 defines ancillary services in power system as "services necessary to support the power system (or grid) operation in maintaining power quality, reliability and security of the grid, e.g. active power support for load following, reactive power support, black start etc." Ancillary services are integral to the electricity industry and can be seen as complimentary to the primary function of the grid – that is to transfer and deliver electricity reliably and in appropriate quality to the consumers. Such services are also mandatory for security and reliability of the overall grid system in its physical operation.

Primary frequency control refers to automatic control of generating stations and consumption of controllable loads (such as inductive loads) which are able to adjust quickly to any imbalance in the system. Such controls are inherent in the

Figure 12:

Frequency Profile and Fluctuations of the Grid in India (CERC-Technical Committee Report)



system and are designed to stabilize it in case of sudden outages. In generators synchronous with the grid, the control is achieved by speed governors whereas in loads, it is performed through self-regulating aspects of frequency sensitive loads such as induction motors or through relays that connect or disconnect the load from the system to maintain the frequency thresholds. Secondary frequency control refers to a centralized automatic control that adjusts the active power production of the generating units by changing the reference point of generation or by starting or stopping the power station to restore the frequency deviation and interchanges with other systems following an imbalance. Only the generating units that are located in the area of imbalance participates in this control. This type of control mechanism is termed as load frequency control (LFC) or automatic generation control (AGC). Tertiary frequency control are manual changes in dispatch of generating units and is used to restore the primary and secondary frequency control reserves, to manage congestions in transmission network, and to bring the frequency and the interchanges back to their set values.

2.5.4 Transmission and Distribution Grid Upgrade Deferral

The distribution networks are sized for the peak demand of the consumers. As the consumer demand grows, distribution infrastructure have to be upgraded just to meet the peak demand occurring for few hours in a year. Building new distribution infrastructure will be expensive and might not be feasible in certain urban locations. Increase in the installation of distributed solar rooftops will increase the impact on distribution infrastructure and as seen in recent developments, consumers are barred from adding solar rooftop projects as their local distribution transformer is capped for a certain loading. ESS systems can be deployed under such circumstances to avoid or defer new distribution infrastructure. ESS can also reduce high line-loss that occur during peak demand[21] and also avoid deviation penalties. India can also think of innovative ways of using already existing back-up inverter batteries to help with peak demand issues in the last mile networks.

[21] The role of energy storage with renewable energy generation, NREL, 2010

The projected RE development is likely to be concentrated in 8 Indian states accounting for more than 77% of capacity addition by 2022.[22] The Southern Region (SR) is expected to double its installed capacity of wind and solar power plants to 60 GW by 2022. Similarly, the peak solar power evacuation is projected to increase from about 12,000 MW[23] in 2018 to about 31,000 MW in 2022. The transmission network will have to increase by the same measure to accommodate the capacity addition. However, only for about 5% of the time in a year, the system is expected to evacuate power between 26,000 MW to 31,000 MW and the additional 5,000 MW of transmission infrastructure will be idle for the remaining 95% of the time. According to the cost estimates from the first phase of Green Energy Corridors, the cost for building a 1MW transmission system is about INR 12 million.[24] The option of building large scale energy storage systems to offset the investment in transmission network expansion can be a better approach in future.

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[22] India Green Energy Corridors, GIZ, 2015
[23] This is only for southern region
[24] India Green Energy Corridors, GIZ, 2015

3 Assessment of MV/LV Stabilization and Optimization for 40 GW RTPV: Technical Issues and Challenges

3.1 Issues at MV Level and LT Level (3-Phase and 1-Phase)

In most of the states across India, Medium Voltage (MV) is 33 kV and 11 kV for electrical power distribution and Low Voltage (LV) is set at 430 V/415 V. The rooftop solar PV penetration is at both MV and LV level. At MV level, generally HT consumer has rooftop PV connected at 11 kV or 33 kV, depending upon their load profile. Similarly, on LV distribution network, generally small scale industrial, commercial, domestic and rural consumers have RTPV connected, where reverse power flow occurs. As per planned target of 40 GW RTPV, there will be an increase of PV penetration level into the distribution systems. The more and more PV injection in the system beyond a limit will create situations where PV power generation can exceed the load demand, and hence can produce power flow from customers to the grid. This is in opposite to the direction of power flow in a traditional distribution grid. Following are the main problems which can occur at MV and LV levels due to high level of injection of PV to the grid.

The impacts of the integration of solar PV in clustered form may propagate to the upstream networks. Hence, the changes produced by the solar PV units in the LV networks may impact the operation of the voltage control devices in the MV networks. For example, tap operation of voltage regulators may be influenced by the change in voltage profile caused by solar PV units.

Due to the potential impacts of PV integration, distribution utilities are imposing network PV penetration limits which refer to the maximum amount of PV generation that can be connected to a distribution feeder without violating power quality and system security limits. The permissible limit is yet to be analysed. In India, most of the states are imposing a limit up to 25% of Distribution Transformer (DT) capacity. Therefore, a comprehensive analysis of PV impacts is required and, based on the results from the analysis, new mitigation approaches need to be developed to increase the PV penetration level in the distribution networks.

Distribution systems, especially at the low voltage level in modern distribution grids are becoming more active due to integration of distributed generation. Therefore, it has become necessary to revisit the distribution network analysis approaches to investigate the solar PV impacts more accurately. Commercial tools for distribution network analysis need to be deployed for necessary analysis for PV impact assessment.

01 Voltage rise

If the generation from PV resources are high enough to offset the loads on the feeder, the surplus power will create voltage rise. With cluster-based installation of PV, the voltage rise impact may propagate to upstream MV network.

02 Effect of clouds

Due to the dependency on the irradiation level, PV output ramps up and down at high rates. Weak systems are vulnerable to voltage fluctuations created by such high ramp-rate PV output. At certain locations, voltage at inverter end may exceed beyond a certain limit, which may cause undesirable tripping of inverters at PV end.

03 High neutral current

An unbalanced allocation of PV units at different phases of a distribution feeder can create a high neutral current, particularly in the mid-day, when reverse power flow is at the peak level. In presence of neutral grounding resistance, this high neutral current may produce considerable neutral potential.

04 Lower power factor

Due to PV running near at Unity Power Factor (UPF), it is observed that some LT circuits produces active power. This power factor produces power quality issues. So, along with PV generation, reactive power compensation or power factor improvement is needed.

05 Variation of feeder power loss

Decrease in losses in feeder as less amount of power is imported from the substation. However, with a high penetration of PV cluster, if the reverse power flow is higher than the power flow without PV, an increase in feeder power loss maybe observed. Power loss may vary due to the variation of PV output throughout the day.

06 Voltage unbalance

As the allocation of inverters of a feeder are varied by the category of customers, the distribution of PV generation may not be equal at all the phases. This may deteriorate the existing voltage unbalance factor of the network. The unbalance factor may vary from time to time due to the variations of solar irradiance and PV output.[25]

07 Change in tap operations

Voltage regulators may tap up or down their positions to keep voltage at the load centre within a bandwidth of voltage limits. Voltage rise caused by PV clusters may require the regulators to operate during midday to keep the voltage profile below the upper limit.

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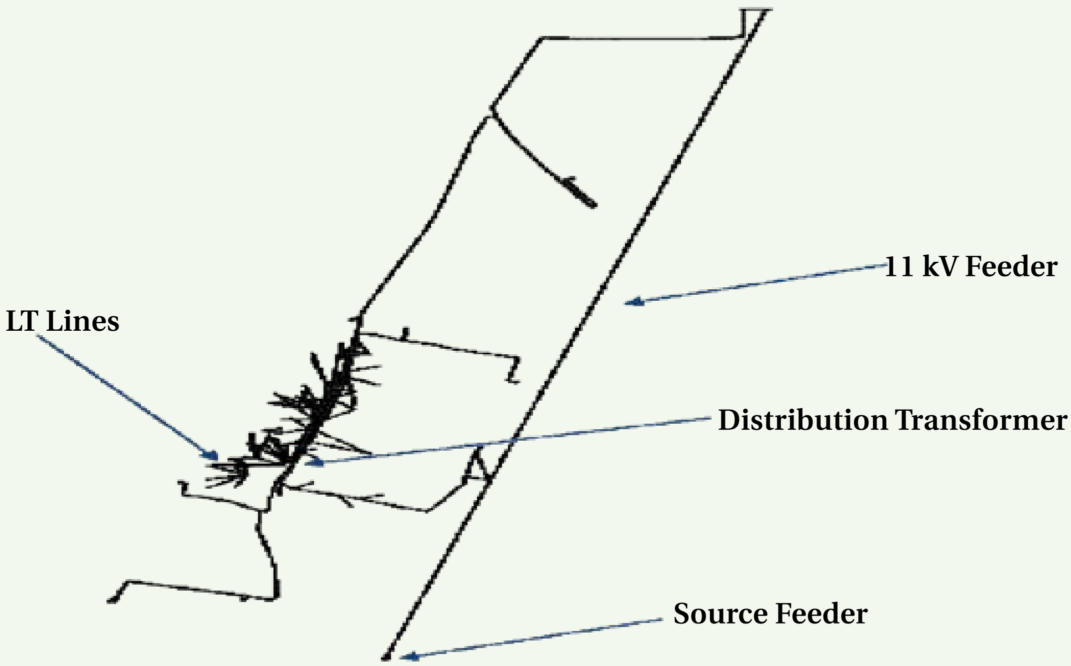
[25] The DISCOMs giving RTPV connections must plan single phase connections in such a manner that the RTPV is equally distributed on all three phases.

3.2 VRE on MV and LV Coupled by Same Transformer

Load flow simulation study has been conducted on different types of feeders across selected utilities in India using CYMDIST software. During load flow studies following major issues are found when RTPV is increased across LT side of a DT with different values of connected loads.

Figure 13:
Single line diagram of TPDDL feeder



The summary of Power Quality (PQ) issues found during load flow studies are mentioned in Table 5. These results are found during load flow of Tata Power Delhi Distribution Limited (TPDDL) 11 kV feeder. The major parameters of feeder are:

- Distribution Transformer (DT): 630 kVA
- Voltage Level: 11 kV/433 V
- Length of Feeder: 5.38 km[26]
- Number of consumers connected at present: 181
- Number of RTPV: 3 customers with total capacity 70 kWp

With different DT loading conditions following scenarios are run in CYMDIST software:

- The time slots selected for study i.e. 11:00 AM to 07:00 PM on 03 May 2017 data
- In each scenario, the DT connected load is increased (i.e. 50%, 75%, 100% and 120%)
- Then the RTPV connections are increased in steps in every load flow study from existing 11% of DT capacity to 100% (i.e. 11%, 20%, 40%, 60%, 80%, 90% and 100%)

[26] The HT feeder length is 5.38 km, while 6.3 km is the distributed length of the LT network.

Time Slots →

Solar RTPV Capacity ↓

Already connected: 11% of DT Capacity

Solar RTPV Capacity	Scenario 1 Time 8-11 AM	Scenario 2 Time 11-1 PM	Scenario 3 Time 1-4 PM	Scenario 4 Time 4-7 PM
11% of DT Capacity	70 kWP	70 kWP	70 kWP	70 kWP
20% of DT Capacity	120 kWP	120 kWP	120 kWP	120 kWP
40% of DT Capacity	240 kWP	240 kWP	240 kWP	240 kWP
60% of DT Capacity	360 kWP	360 kWP	360 kWP	360 kWP
80% of DT Capacity	480 kWP	480 kWP	480 kWP	480 kWP
90% of DT Capacity	540 kWP	540 kWP	540 kWP	540 kWP
100% of DT Capacity	600 kWP	600 kWP	600 kWP	600 kWP

Summary of PQ issues found during load flow studies are presented in Table 5:

Table 5:
Summary of PQ results found during load flow studies

DT loading scenario	Over voltage (V > = 1.06 PU)	Under voltage (V <= 0.94 PU)	Observations
11% DT loading	540 kWp (90% RTPV)	None	When DT is lightly loaded, RTPV insertion beyond 80% can cause overvoltage at RTPV end. This may cause undesirable tripping of inverters at RTPV.
20% DT loading	540 kWp	None	
50% DT loading	None	70 kWp and 120 kWp (20% RTPV)	Undervoltage is removed by 50% of RTPV connections. So, system becomes healthy.
75% DT loading	None	70 kWp, 120 kWp and 240 kWp (40% RTPV)	On some sections of LT, lower power factor observed. On some sections, overvoltage is observed, which may cause tripping of inverter.
100% DT loading	None	70 kWp, 120 kWp, 240 kWp, 360 kWp, 480 kWp, 540 kWp, 600 kWp and 620 kWp (special case)	100%, 120% DT loading cases are not practically viable. Moreover, with 100% and 120% RTPV connections, undervoltage is still present.
120% DT loading	None	70 kWp, 120 kWp, 240 kWp, 360 kWp, 480 kWp, 540 kWp, 600 kWp and 755 kWp (special case)	

Analysis of PQ issues:

- With increase in RTPV when DT is lightly loaded, Undervoltage is found in some of sections of DT, LT side is removed. So, RTPV improves the health of system
- When DT is more than 75% loaded i.e. heavily loaded and RTPV is increased more than 50% of DT capacity overvoltage is found in some of LT sections near to inverter end. This may increase the voltage at inverter end. This overvoltage is observed randomly across different sections of LT depending upon the solar irradiance level, inverter and load present on sections of conductor

3.3 RTPV on MV and LV on Different Transformers

The main issue is grid stability on MV and LV distribution network with the increase in RTPV at LT and HT consumer side. The RTPV generation will provide active power and reactive compensation will be required from grid side which will produce power quality issues to other distribution transformers and lines at MV and LV side. Moreover, harmonics can affect to some extend whenever there is high PV penetration. High voltage is also observed in some sections during load flow study at MV and LV side due to increase in RTPV on different transformers on the LT side. In order to mitigate all these issues, power factor improvement and reactive power compensations are required for which smart inverter and energy storage devices can be used.

3.4 Power Quality (PQ) and Harmonics

The PV panel is an array of PV modules either in series or parallel. The output will depend mainly on the solar intensity and cloud cover. PQ problems will depend on irradiation and the overall performance of the PV systems including the module, inverters and filters controlling mechanisms, etc. Good PQ translates into a sinusoidal voltage and current output from a PV system that avoids harmonics, inter-harmonics and eventually voltage distortion. Important point is the quality of the electricity, namely the voltage and current profiles, generated by the inverter, the element in a PV system responsible for converting energy.

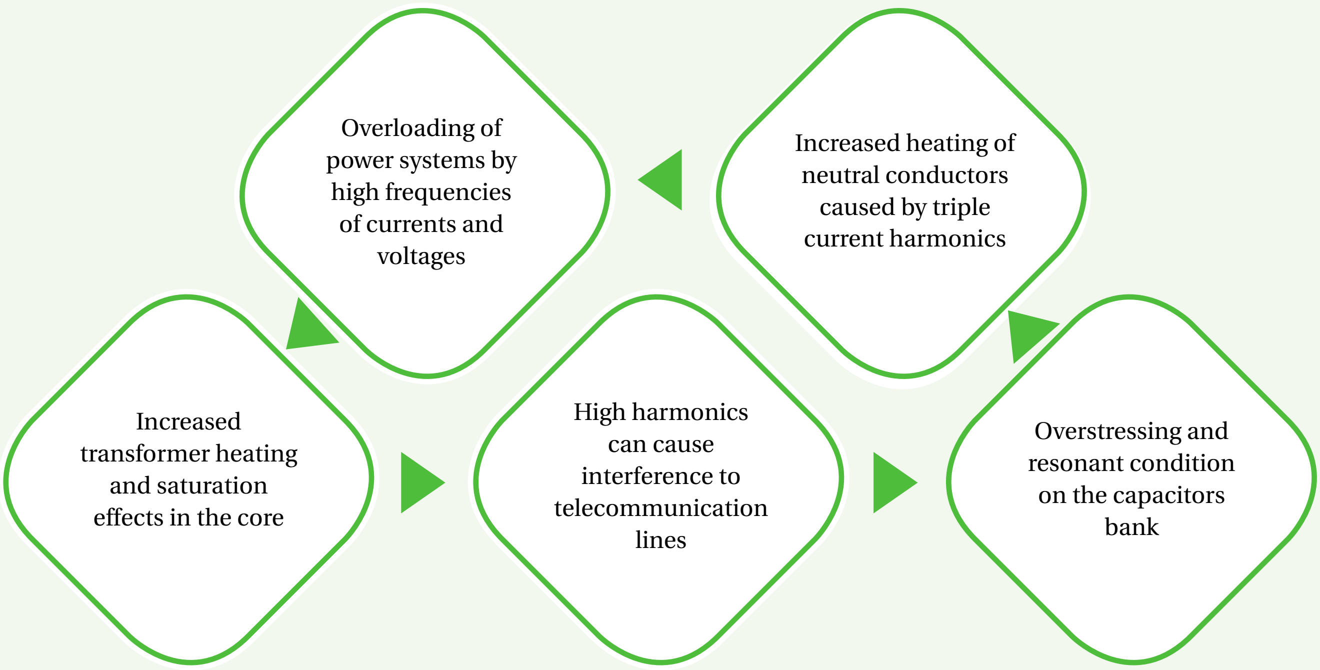
Voltage swells may occur when heavy loads are removed from the connection or disturbances affect the voltage causing the disconnection of inverters from the grid and therefore resulting in losses of energy and degradation of efficiency. If a large number of PV systems are connected to a branch of a LV distribution system, voltage increases at the connection point and power might flow backwards, and thus voltage levels could increase during periods of small load and high solar irradiance.

As photovoltaic systems incorporate power converters, which are harmonic generating devices, they will have an influence on the power quality of the supply network. The most cited PQ problems that may arise due to grid connected PV generation are voltage dips and fluctuations, harmonic distortions, transient phenomena and reverse power flow. These effects result in potential damaging of sensitive electronic equipment and capacitor banks, overheating of transformers, neutral conductors and additional losses in the power system. Degraded power quality entails additional costs for both the electricity distributor and its customers. The presence of harmonics in the electrical system may lead to changes in line impedances, imbalances in line voltages and alterations in AC voltage values. Moreover, a LV public grid must have a degree of quality in electric power that may prevent the abnormal operation of the PV generator. Consequently, the abnormal operation of a PV generator can lead to a shutdown.

The harmonic generation of a PV system depends on the inverter technology, solar irradiance, temperature, loads, and the supply system characteristics. The harmonic distortion generated in PV plants can occur as a result of intrinsic and extrinsic effects. Intrinsic harmonic distortions are related to inverter deficiencies, e.g. components and control loop nonlinearities, measurement inaccuracies, and limited pulse-width modulation (PWM) resolution. Connection to a weak and distorted electrical grid can be considered an extrinsic effect on the output waveform of a PV plant. A distorted voltage acts like a disturbance in the inverter control system, causing distortion of the current waveform generated by the inverter.

Several factors affect the power quality characteristics of the PV inverter output current. Both the current total harmonic distortion (THD) and the output reactive power are related to the output active power levels, which in turn are strongly dependent on solar irradiance levels. Most of the inverters consume or feed reactive power into the network depending on their output active power and their technology. During operation at low solar irradiance levels (e.g. sunrise, sunset, cloudy days), current THD values can increase rapidly, since the THD factor is inversely proportional to the output active power of the PV inverters. Nevertheless, THD is notably reduced as the output active power of the PV Inverters increases and reaches its nominal value. The intrinsic characteristics of the control circuit and nonlinear components of PV inverters may explain the current distortion behaviour in the low power generation stages. Varying power density of renewable energy resources (i.e. irradiance level and temperature in PV conversion) potentially cause voltage and frequency variation or sag/swell patterns in the grid. Also, application of power converters as interfaces between energy sources and the grid and their interaction with other system components may cause high harmonics distortion. The most important impacts of harmonics are:

Figure 14:
Impact of harmonics on the power system

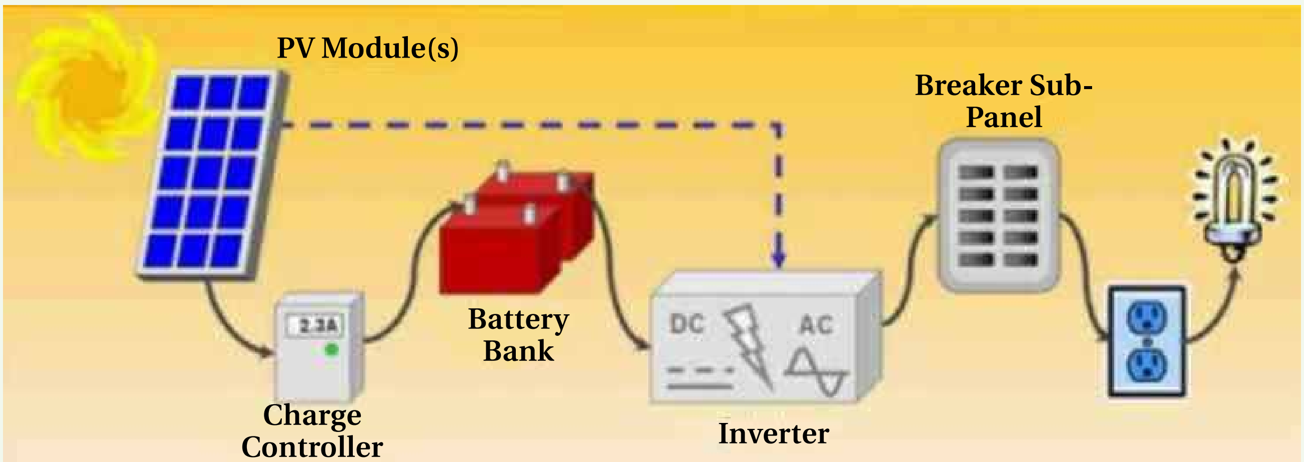


There are two ways to mitigate the PQ problems, either from the customer side or from the utility side. One approach is loading conditioning and another solution is to adopt power conditioning system to avoid possible disturbance. Presently, smart inverters are utilized which can improve the power quality. Another arrangement is to utilize Shunt Active Power Filter (SAPF) by which harmonics can be proficiently wiped out. The SAPF is a Voltage Source Inverter (VSI), related to the load. SAPF can keep the current adjusted and sinusoidal after compensation for various burden conditions.

3.5 Comparison of Regular and Smart Inverters (Autonomous and SCADA Controlled)

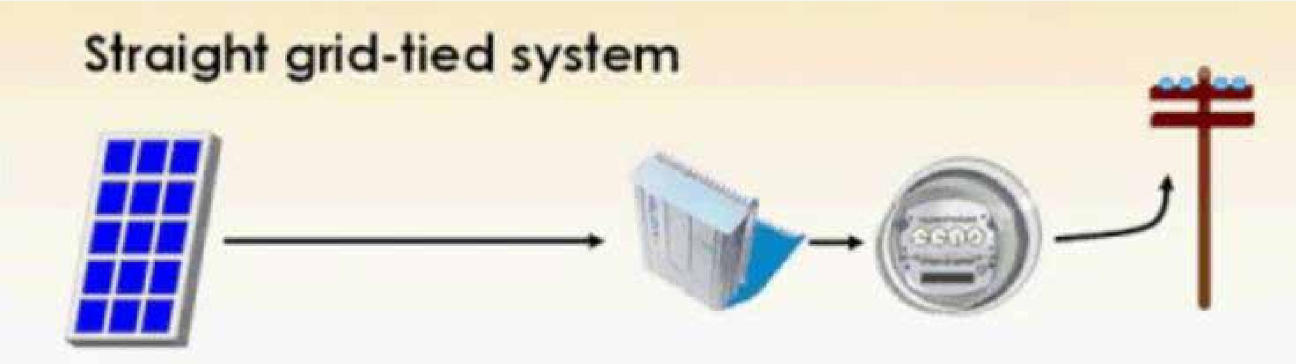
The term "smart inverter" has become a buzzword in the industry, but what does it really mean? For an inverter to be considered smart, it must have a digital architecture, bidirectional communications capability and robust software infrastructure. The system begins with reliable, rugged and efficient silicon-centric hardware, which can be controlled by a scalable software platform incorporating a sophisticated performance monitoring capability. A smart inverter must be adaptive and able to send and receive messages quickly, as well as share granular data with the owner, utility and other stakeholders. Such systems allow installers and service technicians to diagnose operational and maintenance issues, including predicting possible inverter or module problems and remotely upgrade certain parameters in moments. These intelligent power electronics devices must also include Applications Programming Interface (API) functionality that provides fleet owners and other partners a way to tie in their own software to create powerful enterprise level tools.[27]

Figure 15:
Off Grid Inverter



[27] An API is a set of programming instructions for accessing web software or a web-based tool. When a company releases its API, users are able to have their own software interact with the company's.

Figure 16:
Grid Connected Inverter



Advantages of using Smart Micro Inverters (SMI):

The increasing technical complexity and enhanced capabilities of inverters show that many manufacturers are well on their way to meeting the smart inverter challenge, but not all inverter topologies and software control packages are created equal.

Micro inverter technology, in particular, provides some advantages to residential, commercial and (eventually) utility-scale solar PV installations. This includes high redundancy through a distributed AC architecture that improves system cost and reduces operations and maintenance complexity.

An integrated micro inverter package can help lower the Levelized Cost of Energy (LCOE), facilitating higher energy production over the life time of the system, unit reliability and system uptime, all the while lowering systems cost by reducing installation labour and materials. Micro inverters are also capable of providing a suite of Advanced Grid Functions (AGF) required by some regulatory standards for grid stability, such as ramp rate control, power curtailment, fault ride-through and voltage support through VARs.

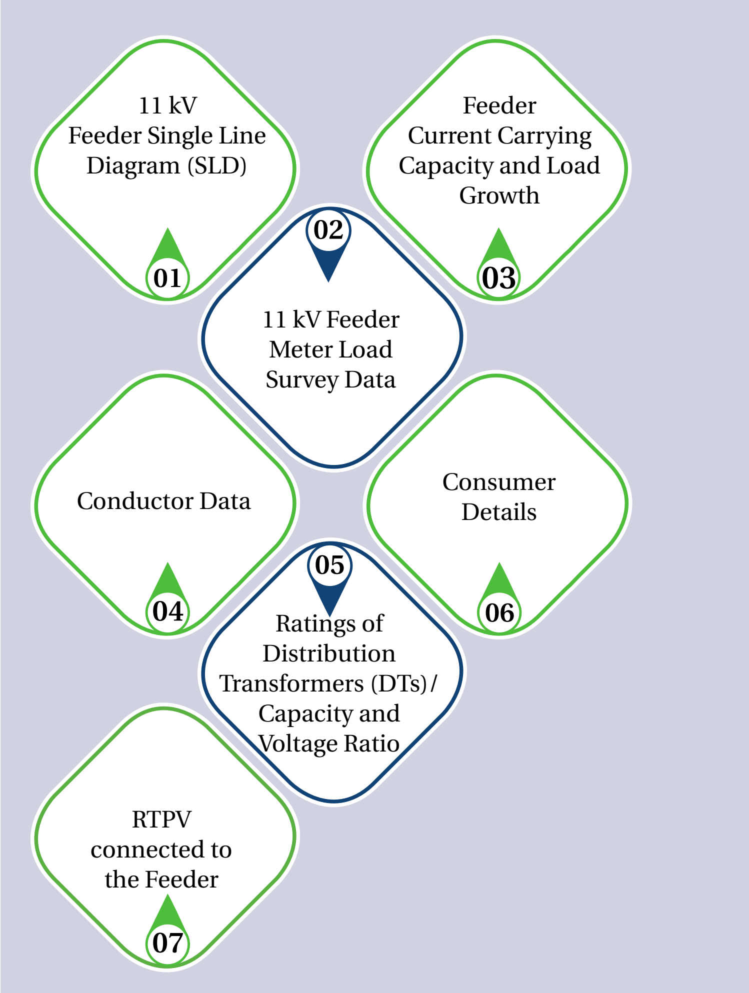
The most advanced micro inverters are adaptive and essentially constitute the core of what could be called a fully networked, software defined inverter. The benefits of such a software-controlled system include the ability to provide grid support services in an evolutionary manner over the more than 20-year lifetime of the inverter platform through software updates that can be done without any hardware replacement or truck-rolled, hands-on labour.

Utilities may encounter more noteworthy voltage fluctuations and expected to make a more extensive voltage window to make up for the changeability on account of the developing number of sun based establishments in its administration region. So as to retrofit these issues, the job of smart inverter becomes an integral factor. In addition, presently, some of the smart inverters are concentrating on new reactive and on-demand communications methodologies that will help deal with the greater distributed generation load. While the computerized engineering, bidirectional correspondences and programming foundation innovations that support smart inverters are unquestionably significant, the organizations that give such propelled frameworks should likewise be advanced in the manner they team up on new utility necessities and guidelines.

4 Load Flow Studies on MV/LV Lines with RTPV

4.1 Methodology

In order to identify potential technical issues and grid interconnection challenges that needs to be addressed for enabling VRE integration in distribution grid active and reactive power compensations, the load flow analysis was to be done on MV and LV distribution networks. The distribution network issues and impact of RTPV faced by the utilities across the country varies according to their geographical locations and MV/LV network topologies. In order to analyze the details of the MV/LV network, six distribution utilities were selected to conduct a detailed load flow analysis of distribution feeders. A criterion had been set each based on which the detailed study was conducted. Utilities were requested to select any two feeders each from two circles i.e. 4 feeders; these feeders should have solar PV injection at present or planned in the near future. For each feeder, following data has been collected:



4.2 Selection of Samples per DISCOMs

Following is the list of state DISCOMs that provided feeder data for the load flow studies:

Table 6:
List of DISCOMs that participated in the study

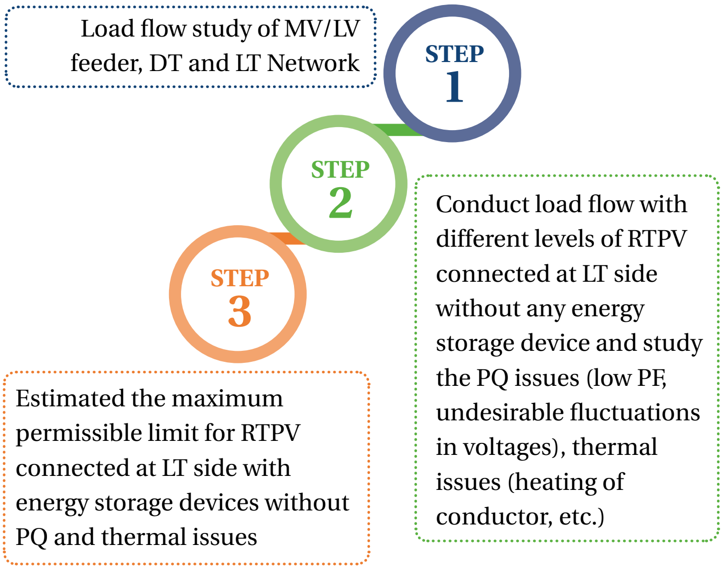
Region	Selected state	Feeder category	DISCOM Name
North	Delhi	Urban lightly loaded	Tata Power Delhi Distribution Ltd. (TPDDL)
	Haryana	Agricultural	Uttar Haryana Bijli Vitran Nigam Ltd. (UHBVN)
South	Karnataka	11 kV	Bangalore Electricity Supply Company Ltd. (BESCOM)
	Andhra Pradesh	Semi urban heavily loaded	Andhra Pradesh Southern Power Distribution Company Ltd. (APSPDCL)
West	Maharashtra	Urban lightly loaded	Adani Energy Mumbai Ltd. (AEML)
East	West Bengal	Urban heavily loaded	CESC, Kolkata

4.3 Analysis of Varying VRE Levels on Sample Feeders (Without Energy Storage)

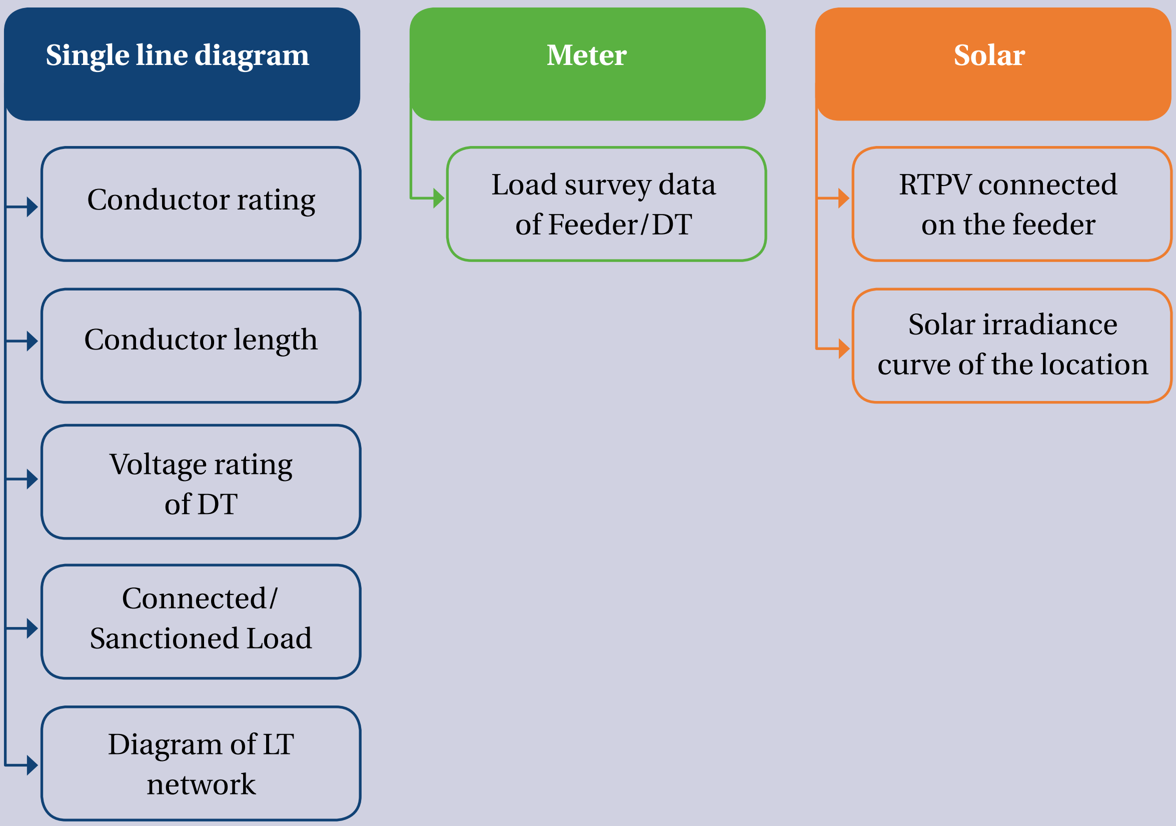
The load flow study was conducted on the feeders of the six DISCOMs in order to estimate the impact of increase in solar penetration at LT side, DT and feeder without energy storage devices. During load flow study, solar penetration is increased in steps at LT side for consumers (residential, industrial, commercial and agriculture). The solar penetration is increased in percentage steps based on DT rated capacity as most of DISCOMs allow user to connect solar generation based on DT capacity.

4.3.1 Methodology of Work

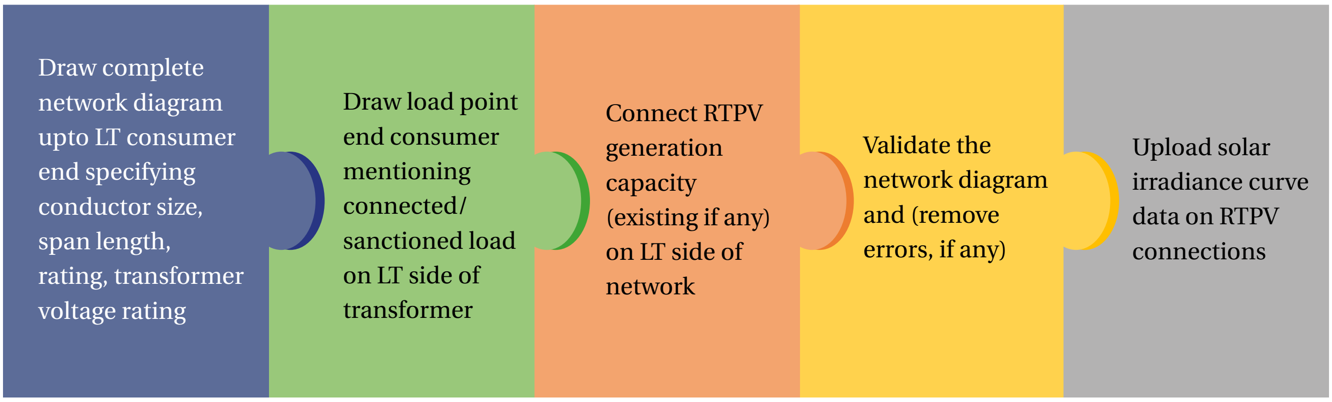
Purpose of study: Maximum solar connection is allowed at LT side in order to achieve 40 GW targets of RTPV by 2022.



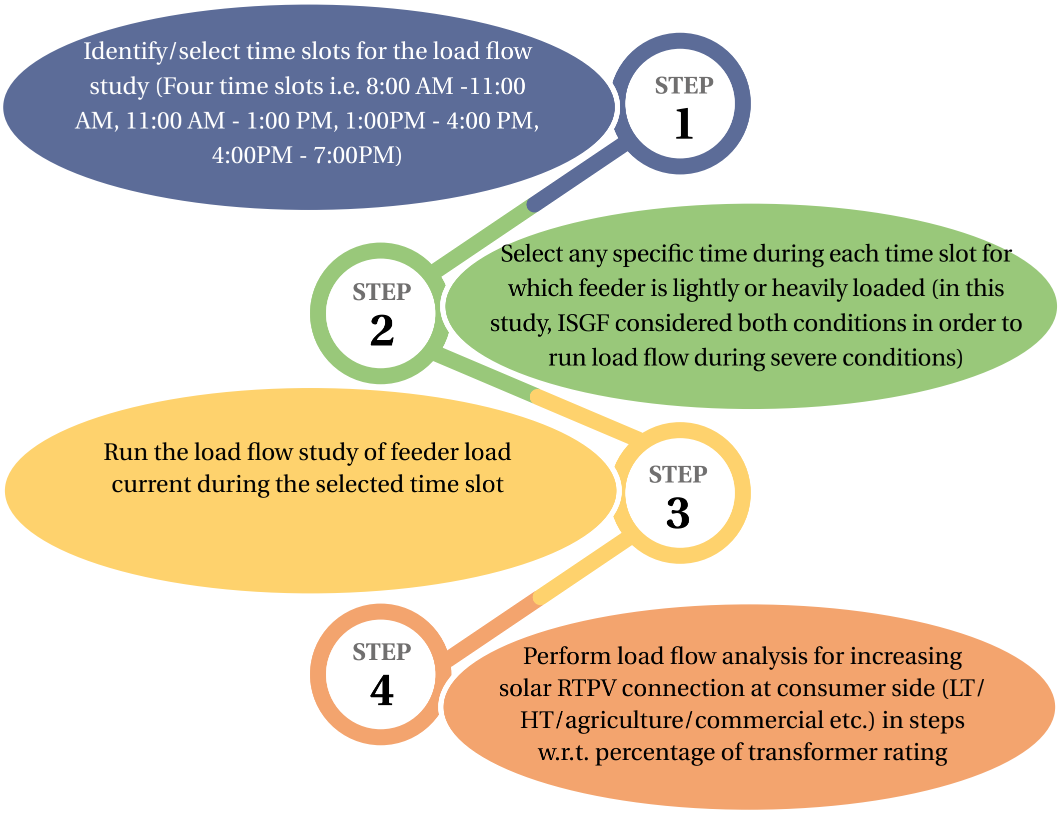
Before starting load flow, following data was collected:



Preparation of network in CYMDIST for load flow study[28]:



Run load flow study:



Let us assume DT capacity of 630 kVA, then scenarios run during load flow are:

Report generation and analysis of load flow study:

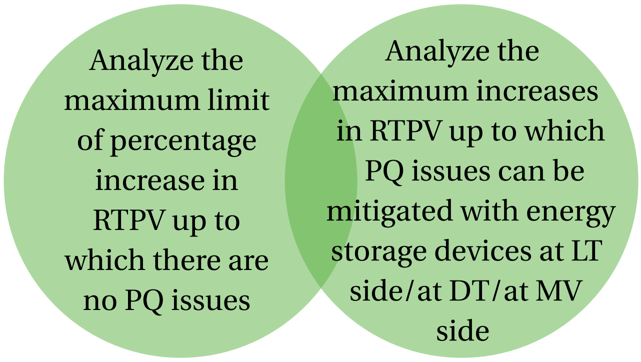
- Generate load flow report after running load flow study for each scenario:
  - Feeder loading report
  - DT loading report
  - Section loading report
  - PV generation report
- Draw graph of feeder percentage loading (kVA) V/S increase in RTPV capacities – it will provide effect on feeder side w.r.t. increase in RTPV
- Draw a graph for DT percentage loading (kVA) w.r.t. increase in RTPV during each scenario
- Analyze PQ issues and thermal issues in section loading report for each section of feeder side and LT side during each scenario:
  - This report will display Undervoltage/

[28] TPDDL had provided CYMDIST ready files to ISGF.

overloading voltage sections in different colours

- This report will display overcurrent in section (if any)
- Analyze power factor violation in report
- Analyze voltage variation, kVA loading
- Analyze reverse power flow across DT from LT side to MV side due to increase in RTPV connections
- Analyze the effect on the network

Results of the study:



In every scenario during load flow studies, RTPV connections are increased based on percentage of DT capacity e.g. for 630 kVA DT, percentage increase in RTPV.

Time Slots →

Solar RTPV Capacity ↓

Already connected: 11% of DT Capacity

Solar RTPV Capacity	Scenario 1 Time 8-11 AM	Scenario 2 Time 11-1 PM	Scenario 3 Time 1-4 PM	Scenario 4 Time 4-7 PM
11% of DT Capacity	70 kWP	70 kWP	70 kWP	70 kWP
20% of DT Capacity	120 kWP	120 kWP	120 kWP	120 kWP
40% of DT Capacity	240 kWP	240 kWP	240 kWP	240 kWP
60% of DT Capacity	360 kWP	360 kWP	360 kWP	360 kWP
80% of DT Capacity	480 kWP	480 kWP	480 kWP	480 kWP
90% of DT Capacity	540 kWP	540 kWP	540 kWP	540 kWP
100% of DT Capacity	600 kWP	600 kWP	600 kWP	600 kWP

Time Slots

Already connected

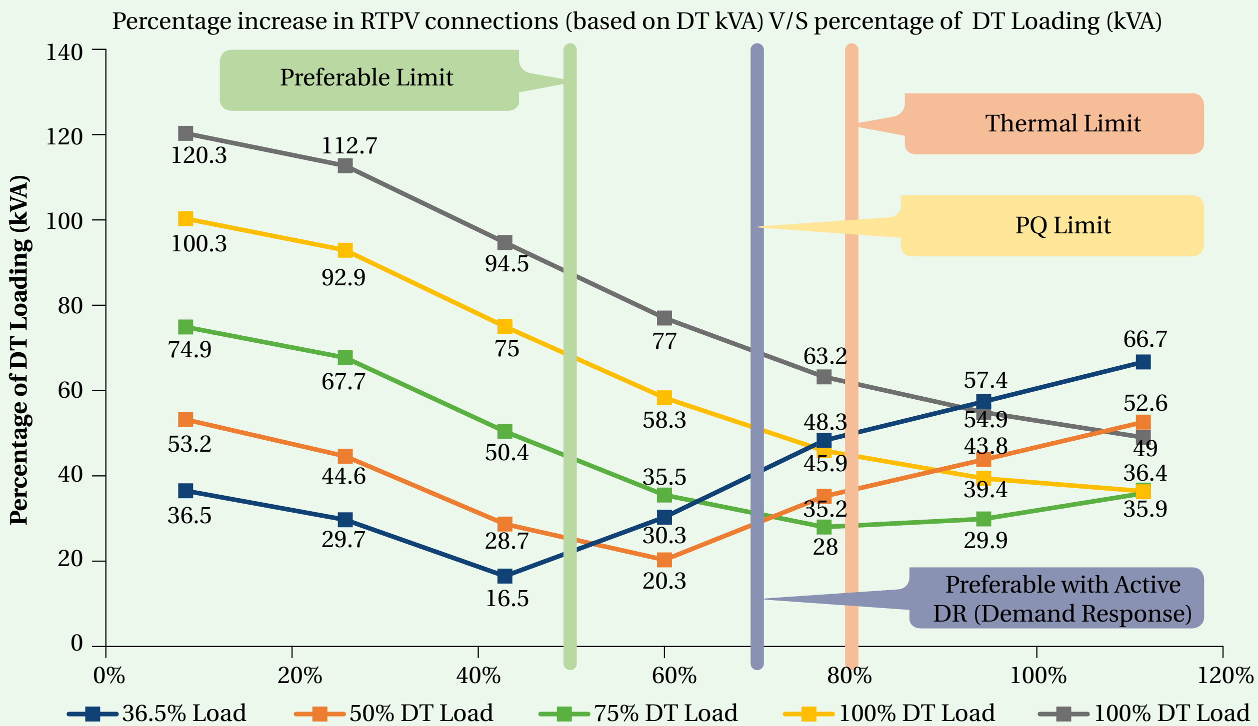
Solar RTPV Capacity	Scenario 1 Time 8-11 AM	Scenario 2 Time 11-1 PM	Scenario 3 Time 1-4 PM	Scenario 4 Time 4-7 PM
Without Solar	–	–	–	–
AS-IS	0 kWP	0 kWP	0 kWP	0 kWP
20% of DT Capacity	20 kWP	20 kWP	20 kWP	20 kWP
40% of DT Capacity	40 kWP	40 kWP	40 kWP	40 kWP
60% of DT Capacity	60 kWP	60 kWP	60 kWP	60 kWP
80% of DT Capacity	80 kWP	80 kWP	80 kWP	80 kWP
100 % of DT Capacity	100 kWP	100 kWP	100 kWP	100 kWP

4.3.2 Load Flow Studies

The result and summary of load flow studies are discussed below:

4.3.2.1 Load Flow Study Analysis – Urban Lightly Loaded Feeder (TPDDL) in Delhi

Figure 17:
TPDDL Feeder - Load Flow Analysis[29,30]

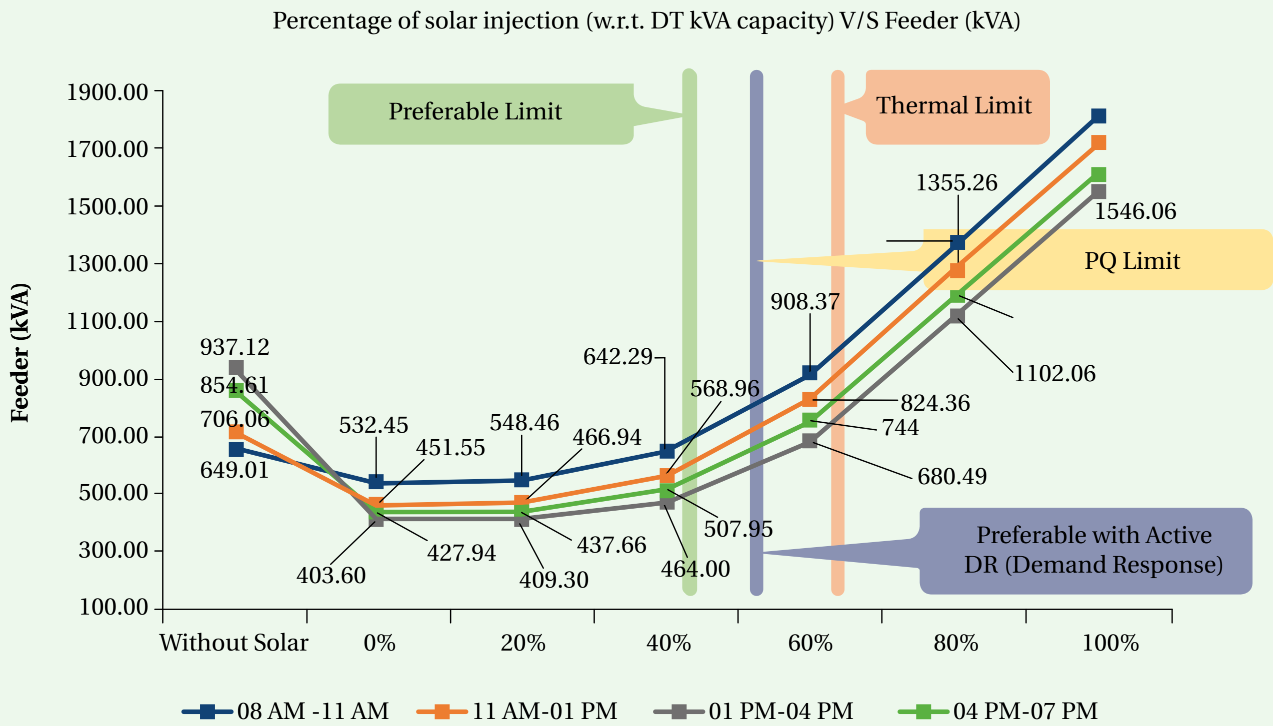


[29] The choice of using LiB was done to showcase the best life cycle cost, effective use as well as better mix of power-energy needs given today's use. The other technologies such as advanced lead acid batteries may indeed suit niche applications.

[30] For industrial and commercial feeders with weekly off days, there could be reverse power flows to 11 kV systems on off-days. Such cases have not been studied in detail; which will be undertaken in the next phase of the study. Feeders with mixed loads that have 50% load during daytime are ideal for 50-70% RTPV.

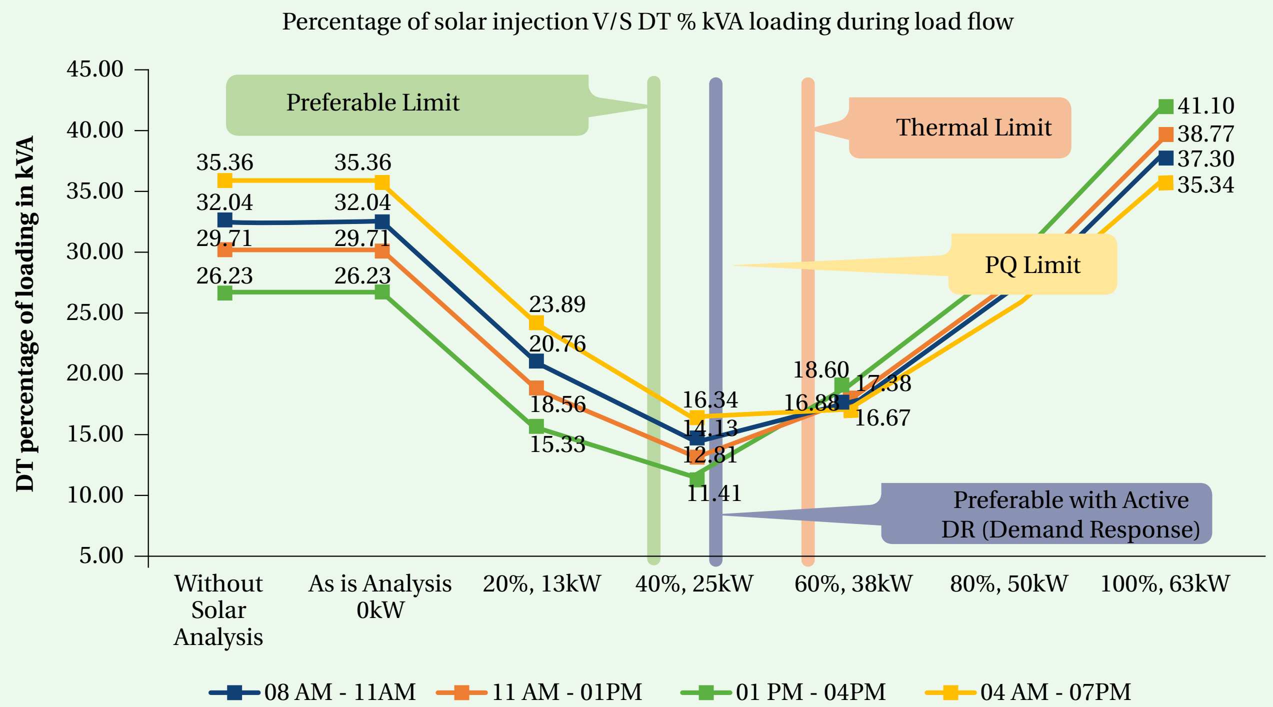
4.3.2.2 Analysis of Agricultural Feeder (UHBVN)

Figure 18:
UHBVN Feeder Load Flow Analysis



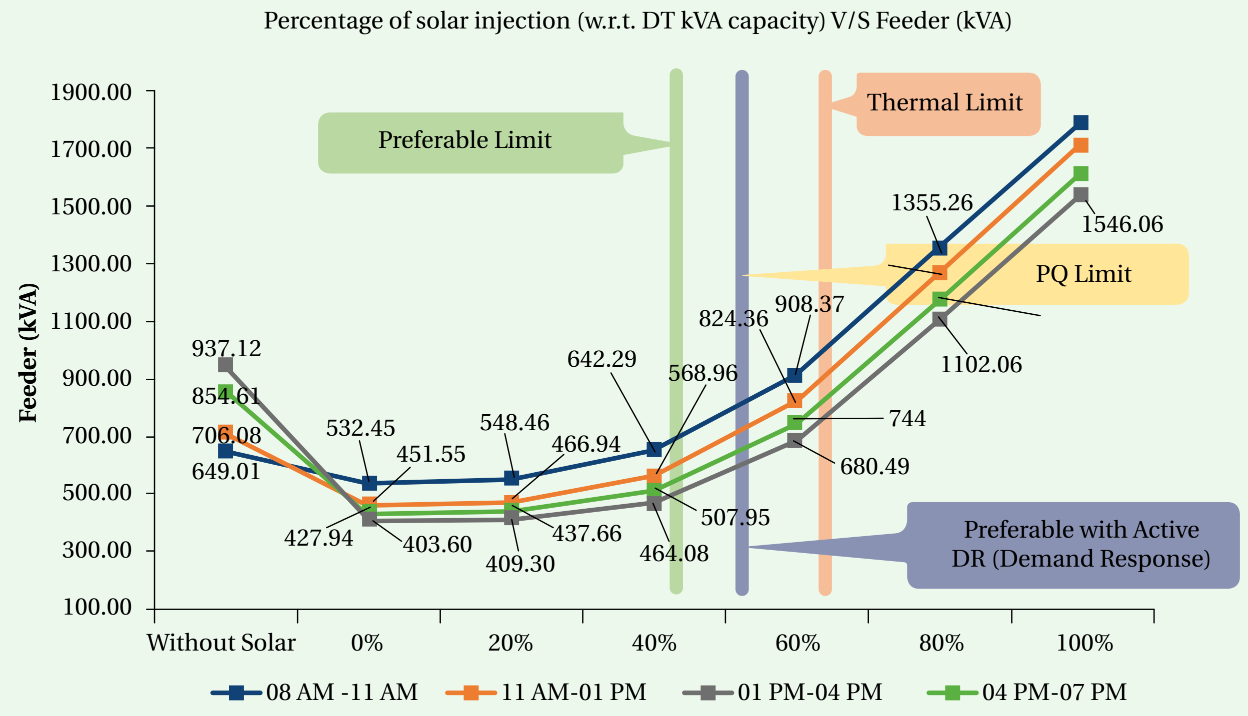
4.3.2.3 Analysis of 11 kV Feeder (BESCOM)

Figure 19:
BESCOM Feeder Load Flow Analysis



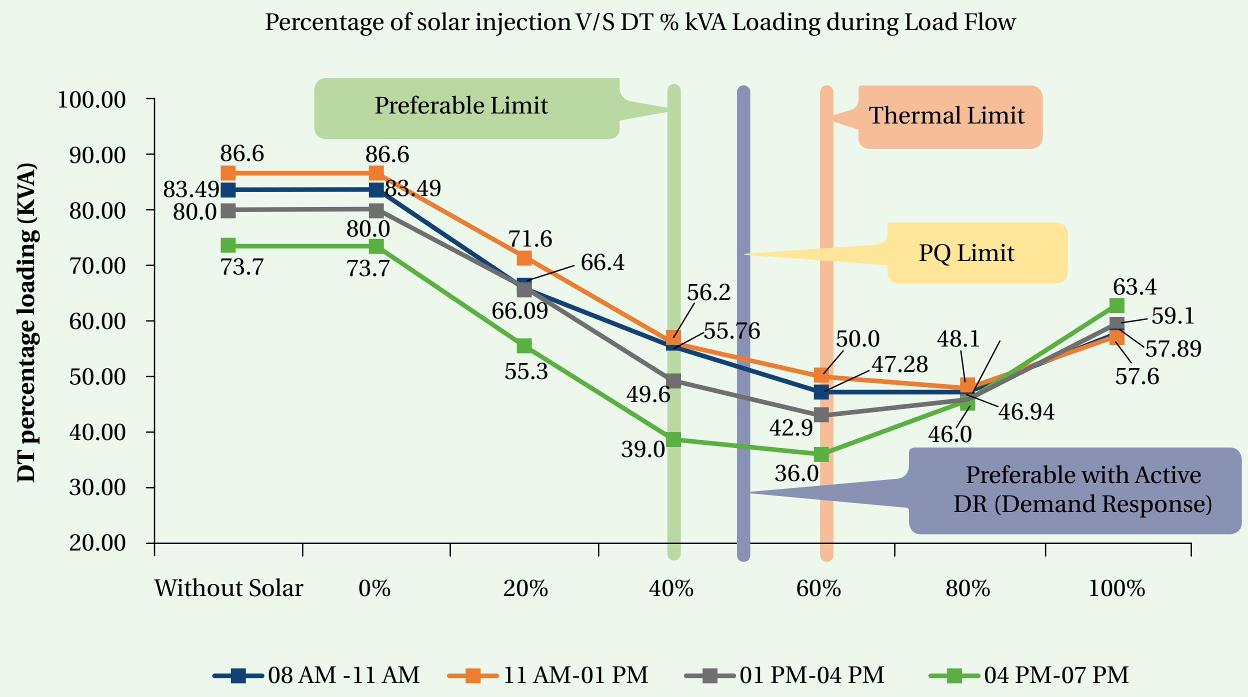
4.3.2.4 Analysis of Semi Urban Heavily Loaded Feeder (APSPDCL), Tirupati

Figure 20:
APSPDCL Feeder Load Flow Analysis



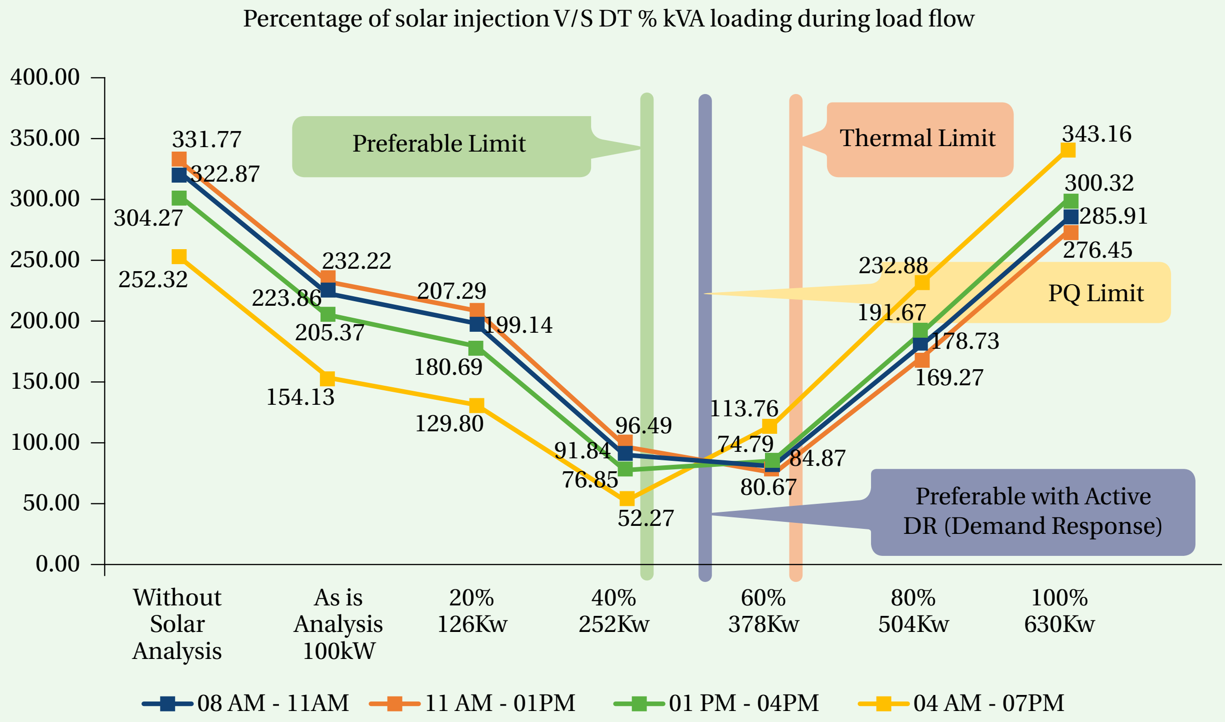
4.3.2.5 Analysis of Urban Heavily Loaded Feeder (CESC), Kolkata

Figure 21:
CESC Feeder Load Flow Analysis



4.3.2.6 Analysis of Urban Lightly Loaded Feeder (AEML), Mumbai

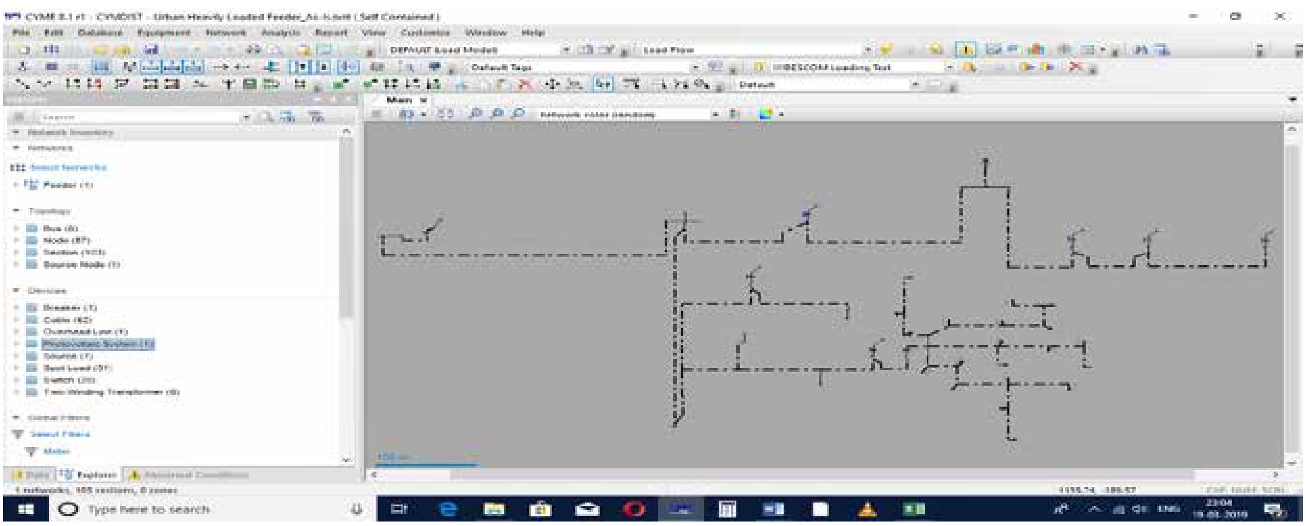
Figure 22:
AEML Feeder Load Flow Analysis



The details of load flow study of all the selected DISCOMs are given in Annexure-2.

4.4 CYMDIST Library of Modelling Tools for Photovoltaic System Study

CYME library consists of equipment details (as per actual data of feeders). DISCOMs using CYMDIST Software with Long Term Dynamics module can directly use this library for solar studies. The library is based on the study methodology using percentage increment of solar injection per DT capacity. DISCOMs utilizing the module will have to vary the equipment's technical parameters as per their requirements. However, the DISCOMs will have to model the feeders manually. If they have

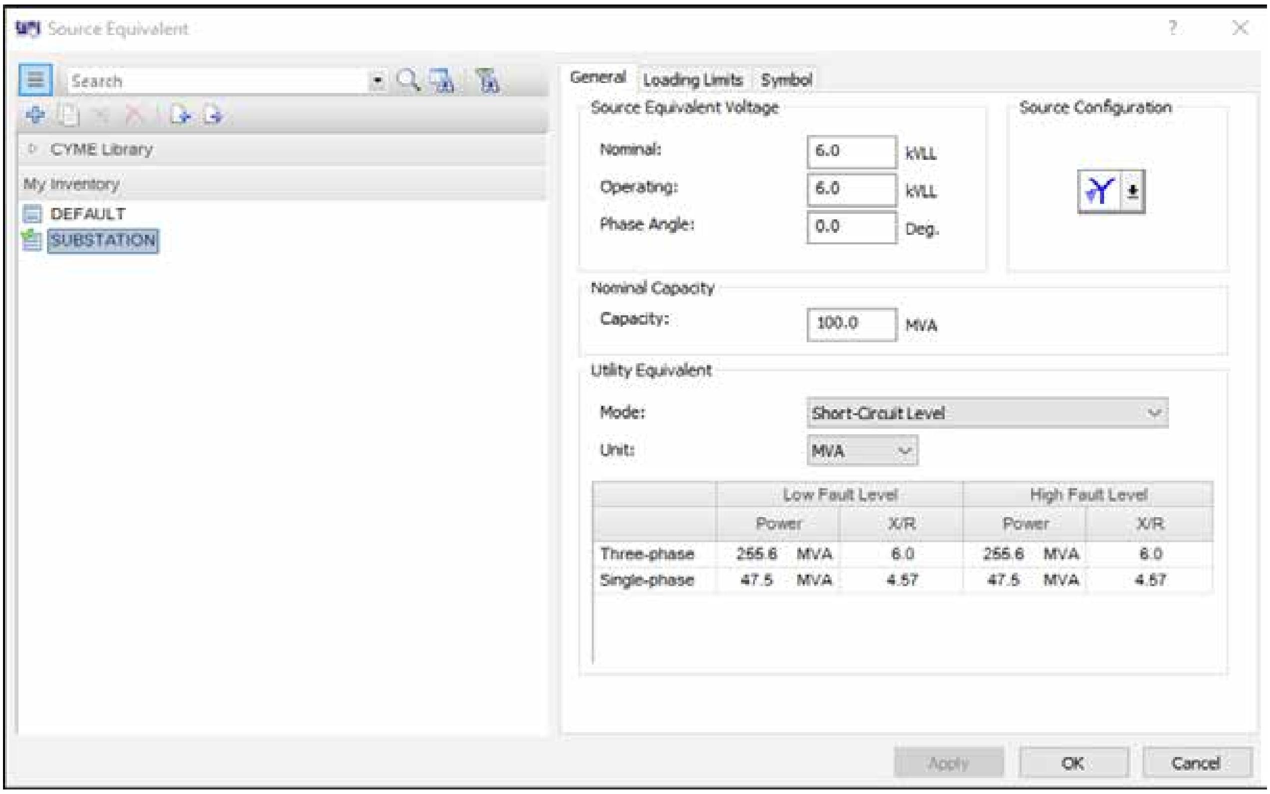


GIS data, it will benefit them for modelling the feeders.

Network diagram: Feeder files are saved in **. sxst** format in CYMDIST.

1. **Equipment library creation:** This document will provide a guideline on how to create equipment's with the CYME Software. A self-contained study file (.sxst) to use with this document is provided. The explanations below are based on the use of that file.

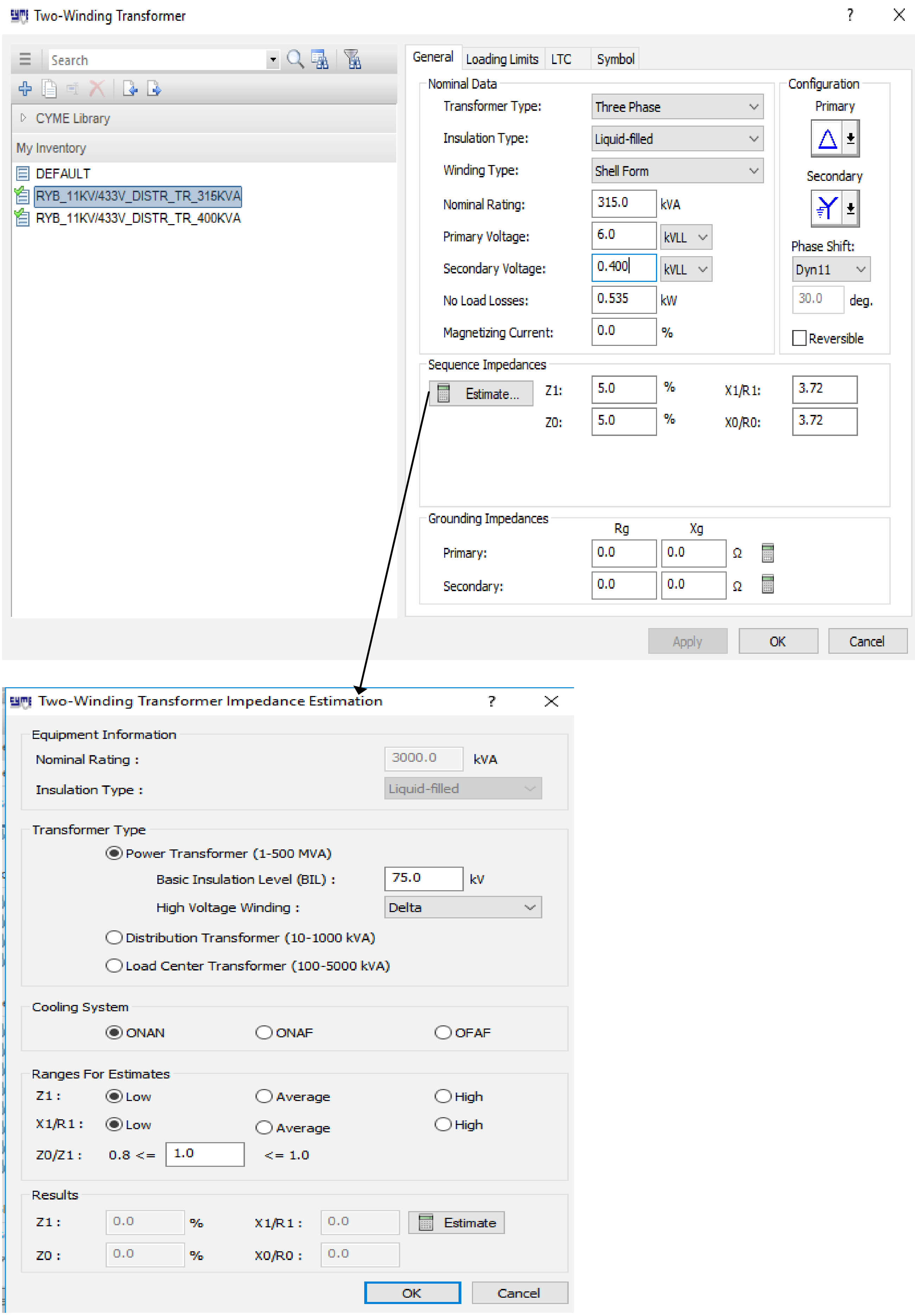
   a) **Source equivalent:** Go to equipment > source equivalent. The dialog box opens where you can create new sources and enter appropriate data values such as the capacity (to flag overload), the nominal and the operating voltage, the configuration, and the equipment impedance values.



   b) **Transformer:** Go to equipment > transformer in the menu. You have six options:

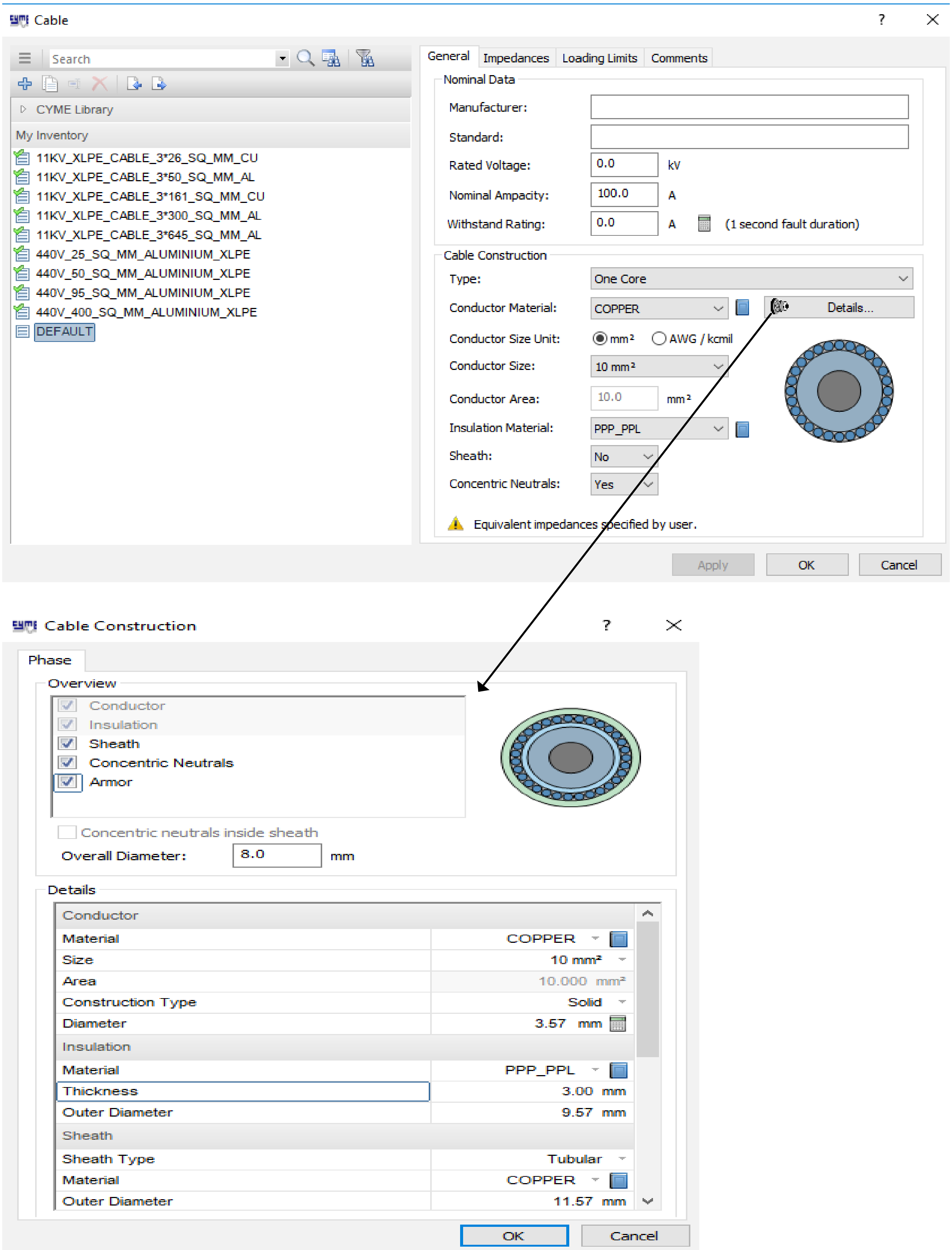
      - The two-winding transformer
      - Two - winding auto - transformer
      - Phase shifting transformer
      - Three-winding transformer
      - Three - winding auto – transformer and
      - Grounding transformer

Select two – winding transformer. Fill in the ratings of the transformer, its impedances, type and connection. Should there be any grounding impedance, they should be entered accordingly too. If the transformer has a Load Tap Changer (LTC), select the LTC tab, and check the load tap changer option.

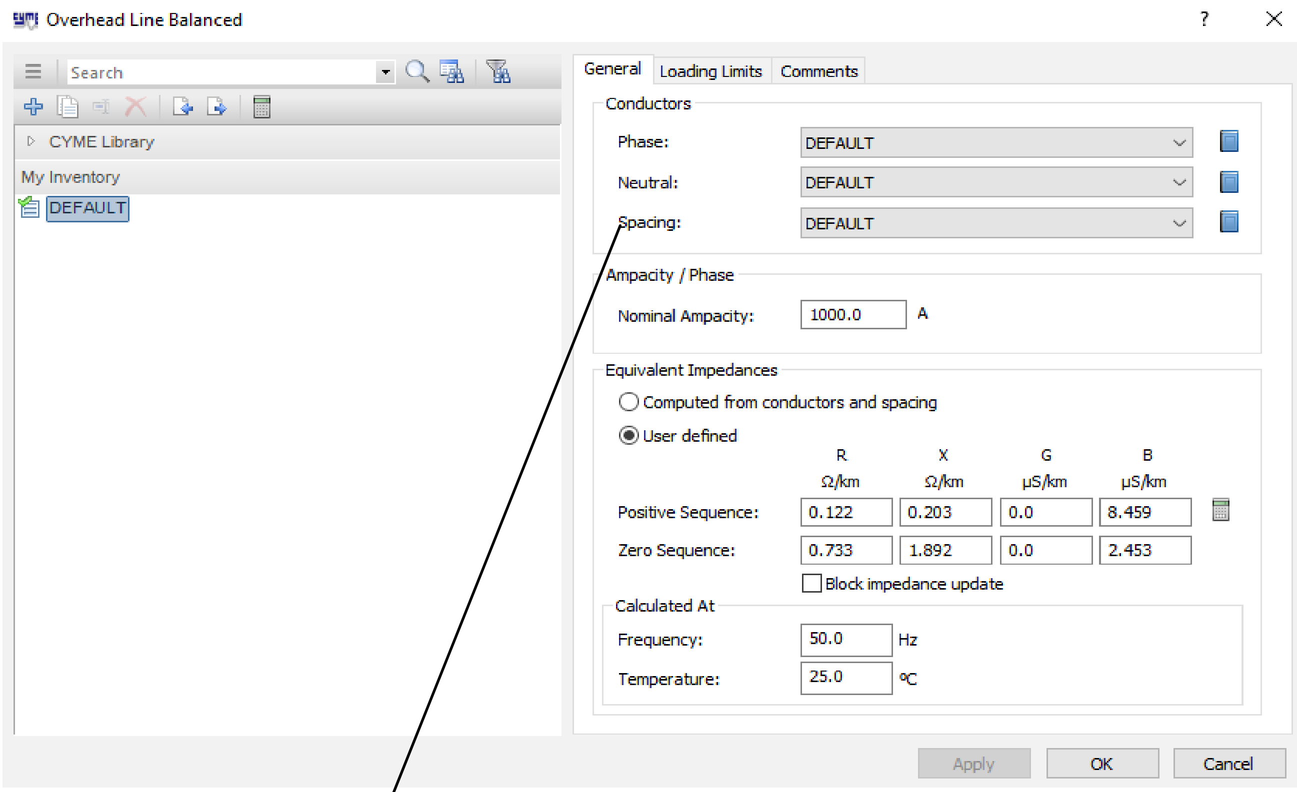


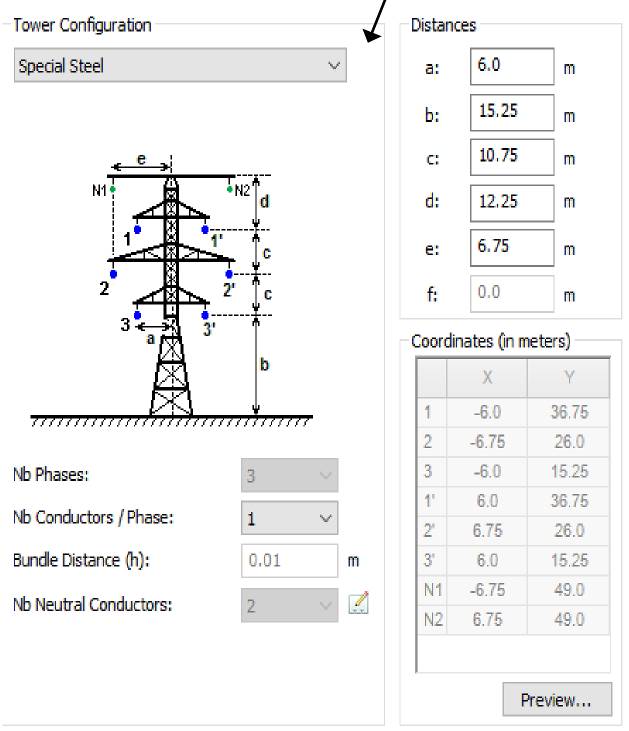
Two-Winding Transformer
General
Loading Limits
LTC
Symbol
CYME Library
My Inventory
DEFAULT
RYB_11KV/433V_DISTR_TR_315KVA
RYB_11KV/433V_DISTR_TR_400KVA
Nominal Data
Transformer Type: Three Phase
Insulation Type: Liquid-filled
Winding Type: Shell Form
Nominal Rating: 315.0 kVA
Primary Voltage: 6.0 kVLL
Secondary Voltage: 0.400 kVLL
No Load Losses: 0.535 kW
Magnetizing Current: 0.0 %
Configuration
Primary
Secondary
Phase Shift: Dyn11
30.0 deg.
Reversible
Sequence Impedances
Estimate...
Z1: 5.0 %
Z0: 5.0 %
X1/R1: 3.72
X0/R0: 3.72
Grounding Impedances
Rg
Xg
Primary: 0.0 0.0 Ω
Secondary: 0.0 0.0 Ω
Apply
OK
Cancel
Two-Winding Transformer Impedance Estimation
Equipment Information
Nominal Rating : 3000.0 kVA
Insulation Type : Liquid-filled
Transformer Type
Power Transformer (1-500 MVA)
Basic Insulation Level (BIL) : 75.0 kV
High Voltage Winding : Delta
Distribution Transformer (10-1000 kVA)
Load Center Transformer (100-5000 kVA)
Cooling System
ONAN
ONAF
OFAF
Ranges For Estimates
Z1 : Low Average High
X1/R1 : Low Average High
Z0/Z1 : 0.8 <= 1.0 <= 1.0
Results
Z1 : 0.0 %
X1/R1 : 0.0
Estimate
Z0 : 0.0 %
X0/R0 : 0.0
OK
Cancel

c) Cable: Go to Equipment > Cable to access the cable database. You can enter the parameters in the General tab of the cable if known. If the parameters are not known, click on the details button to enter cable construction details and calculate the equivalent impedances.

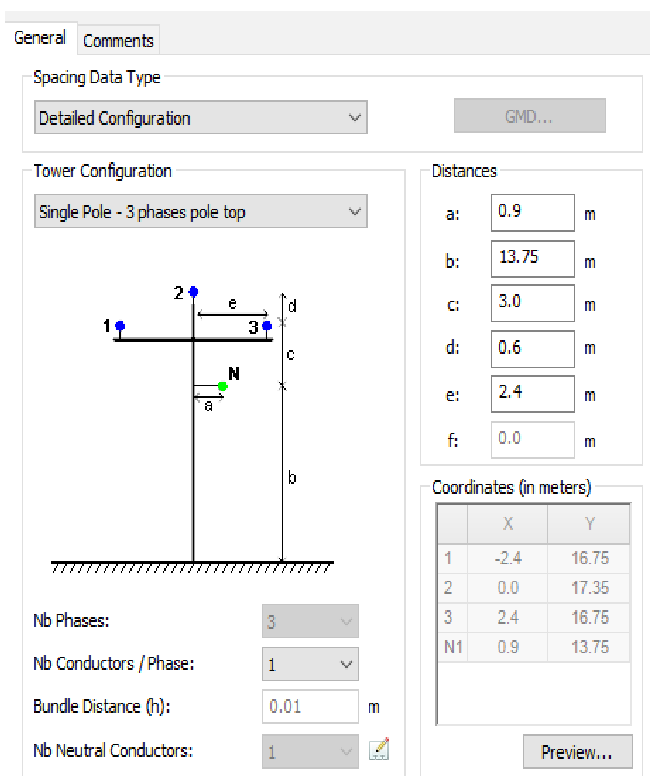


d) Overhead Line: Go to Equipment > Overhead Line > Balanced. The balanced type uses the same conductor for all phases, whereas the unbalanced type uses different conductors for each of the three phases.



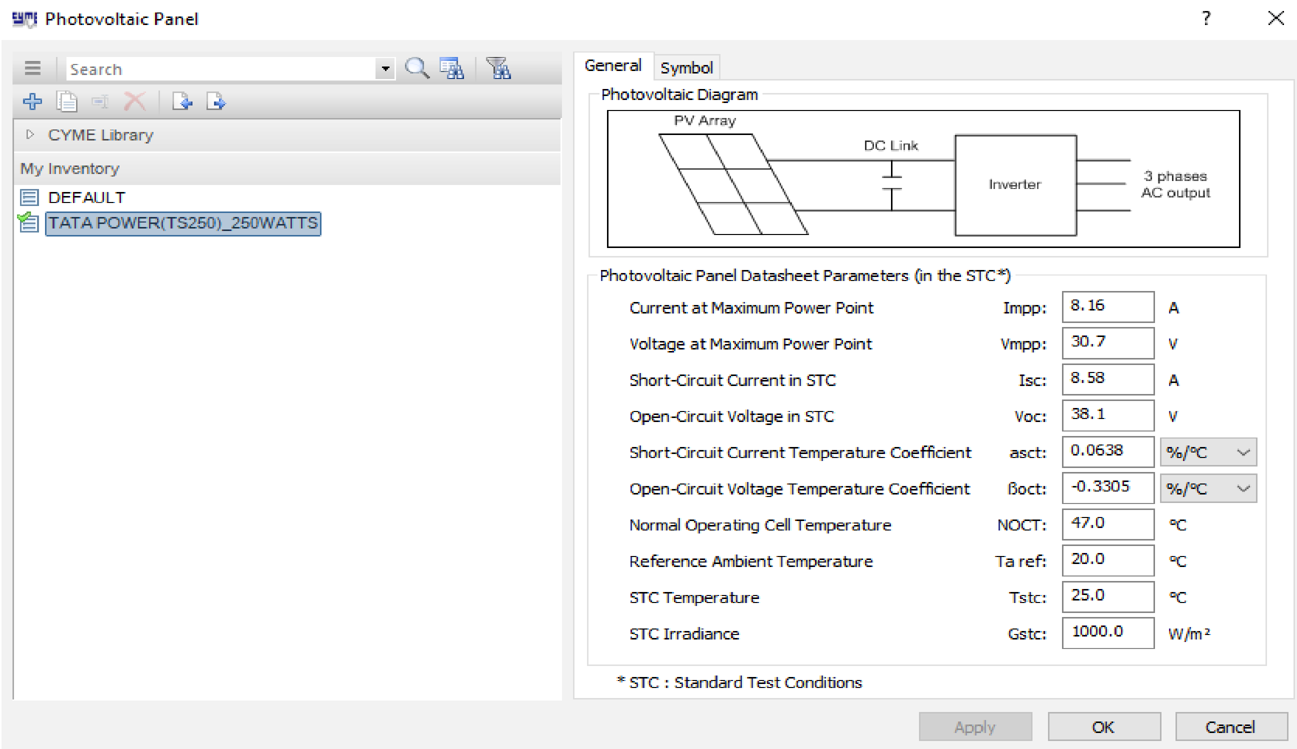


Double Circuit Spacing

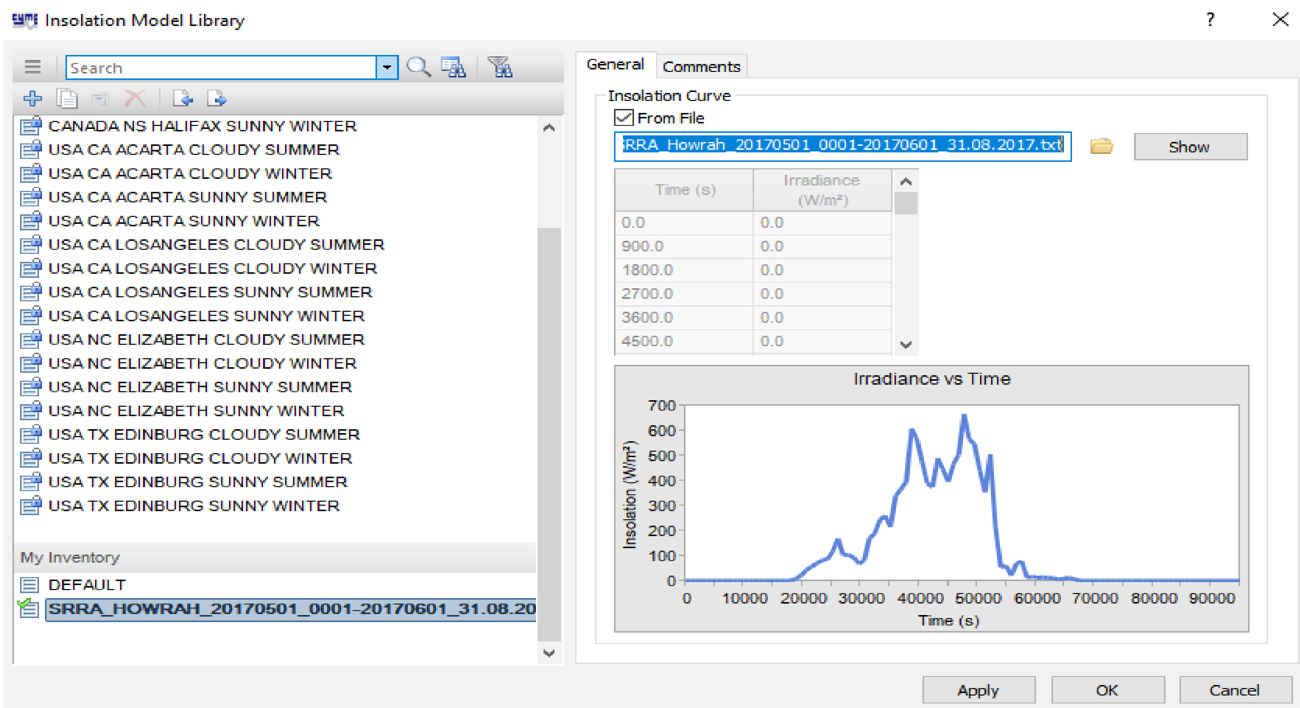


Single Circuit Spacing

e) **Photovoltaic Panel:** Go to Equipment > Photovoltaic Panel. Fill up all the required details as per the PV panel specifications as per the manufacturer's standards.



Solar Insolation Curve: For the study of solar variations throughout the day on CYME, solar insolation curve is required. As the irradiance is variable in nature, in this way, it has been thought about. The PV Module uses this curve for certain time intervals.



5 Energy Storage India Tool (ESIT)

5.1 Description and Overview

Recent improvements in performance and cost reduction of energy storage technologies have generated a strong interest in evaluating role of energy storage for helping with larger penetration of solar PV at grid and rooftop levels. However, often the optimum size of storage and right type of technologies are debated. Secondly, there is not a lot of information available on techno-commercial feasibility of integrating advanced energy storage with RTPV for applications which can provide larger savings and/or improve power quality and reliability for consumers.

Hence, to answer, whether energy storage can help RTPV penetration and to determine optimal size and to assist with technology selection, Energy Storage India Tool (ESIT) has been developed as a part of this study. The basic function of this tool is to take network load data and optimize the energy storage capacity. This tool is capable of dealing with distribution feeder and customer level analysis. For given inputs related to site and technical parameters of a potential project, ESIT has the capability to provide cost benefit assessment. The value streams captured by ESIT include both monetizable benefits and non-monetizable benefits. Monetizable benefits could be system peak shaving, diesel usage optimization for back-up power, time shifting, demand response etc. (details given in section 5.3). Whereas non-monetizable benefits include prevention of economic loss due to power cuts. ESIT has been developed considering all the parameters used by different utilities so that it can be universally used in the Indian context. Moreover, it is flexible to carry out analysis on some unknown data or broken data like load data and includes sample data which can be used by users without in-depth knowledge of many storage, power electronics and power quality equipment. This model takes annual load data as input but can also work with partial data. Any time interval load data can be directly inserted to the existing model for analysis. For ESIT inputs, there are four major categories i.e. solar, grid, storage and diesel genset (DG) for insertion of detailed values shown in Figures 23-25. In addition, grid segment has different levels like customer, feeder and Distribution Transformer (DT) level. Based on one's need, user can easily perform the analysis for different scenarios of solar PV penetration at different levels, for multiple load patterns, and load growth scenarios. Details on each segment is presented in section 5.2.

Figure 23:
Load and Irradiance data dashboard

Figure 24:
Feeder and Supply side Parameter

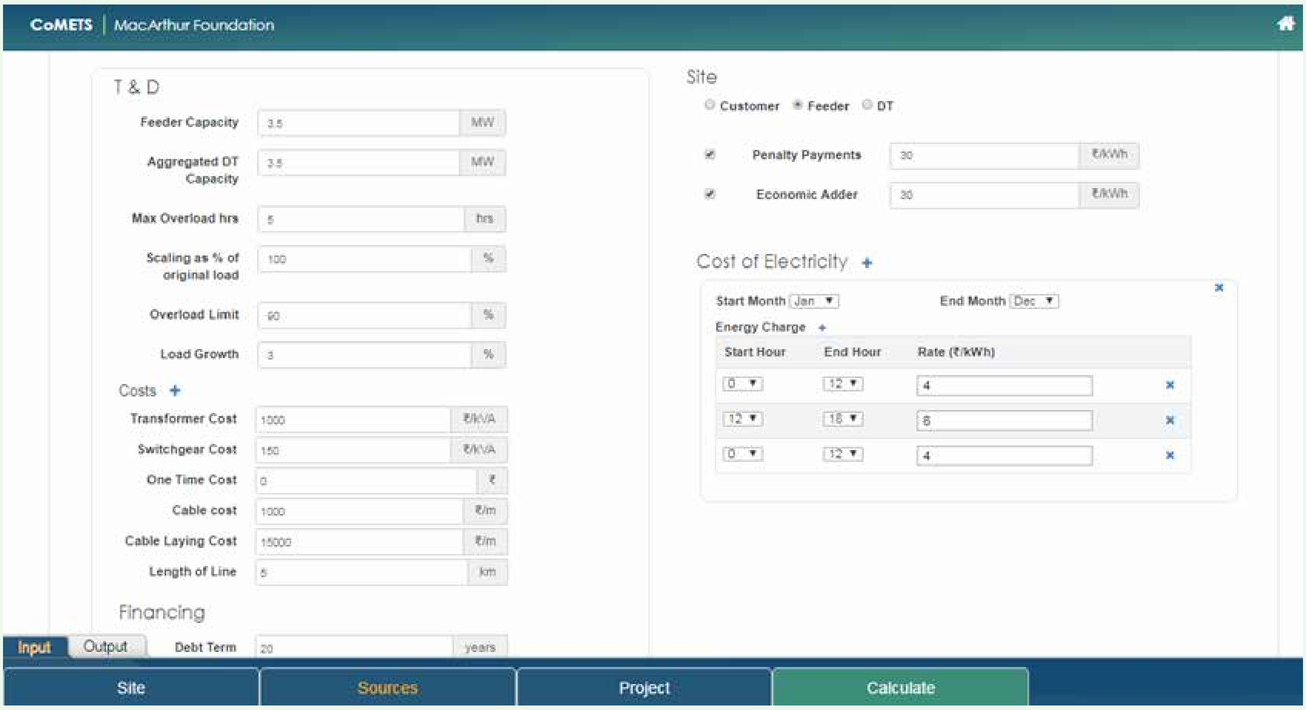
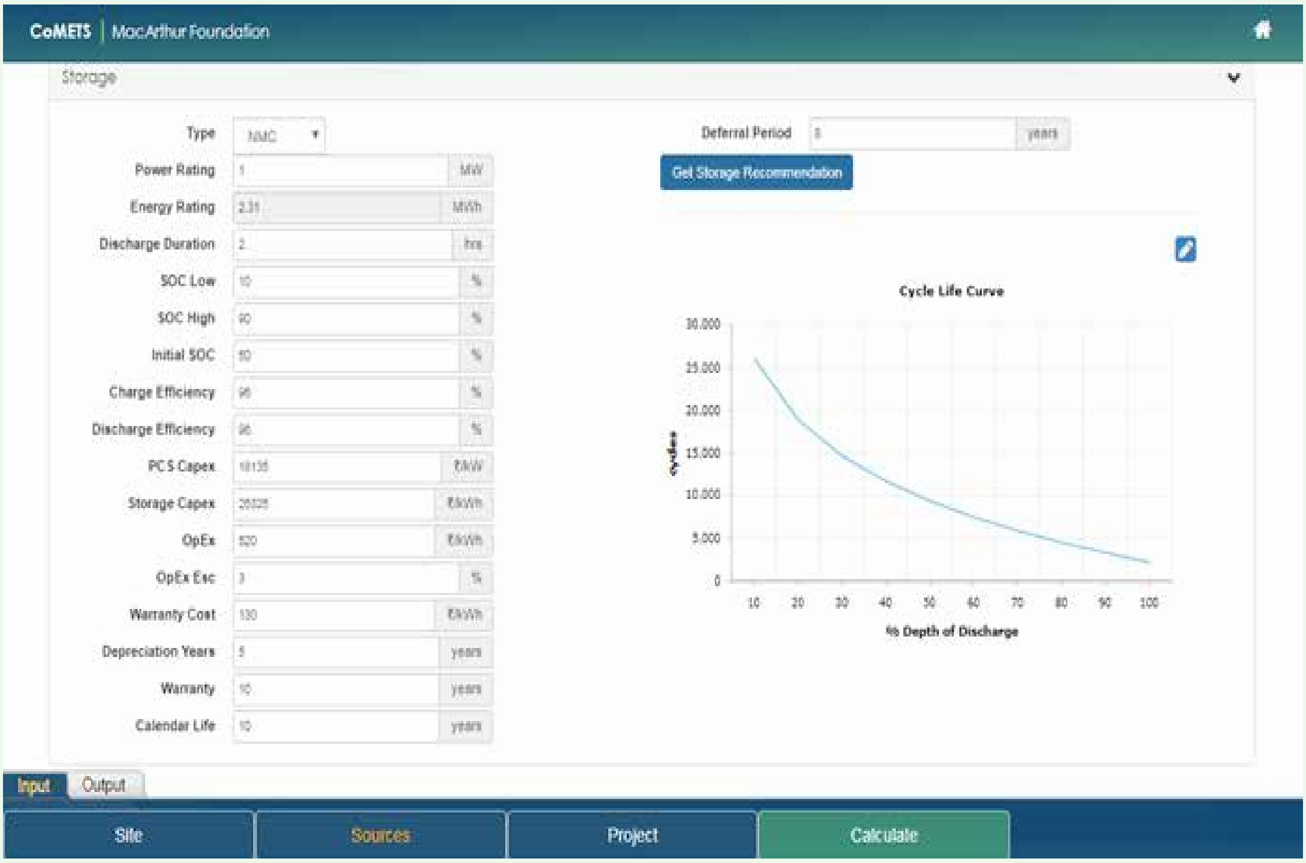


Figure 25:
Storage Parameter Dashboard



5.2 Techno-Commercial Evaluation of ESS Projects

The techno-commercial analysis for storage is done on the basis of monetizable benefits which an ESS asset can cater to at a particular level in the network. The user does not need to think or choose benefits, which are automatically selected based on the state policies and based on position of storage in the grid.

ESIT includes important features like choosing a different rate plan based on a commercial, industrial or residential customer segment. The tool also allows the user to choose the year in which they are planning to deploy energy storage and accordingly choose the load curve as per load growth estimates. Based on this ESIT also determines electricity cost for that particular year. After taking all the parameters from user, it performs simulation for a fixed time interval. The size of solar is taken as percentage of Distribution Transformer (DT) size. In case of DT side or feeder side installation of energy storage, total electricity cost represents the cost of procurement of energy. This cost is based on Time of Day (ToD) based rates and has ability to use monthly or 24-hour spot pricing. On the other hand, when ESS is located in customer premise, actual rate plan is considered as input. This rate plan includes following parameters:

- Demand Charge
  - Constraints such as minimum threshold and penalty for crossing contract demand
- Fixed charge
- Contract demand
- Slab based charge
- ToD based charges
- Value of lost load

Cost of technical components such as transformers, cables and cable laying have been considered to calculate the actual cost of upgradation of a distribution transformer.

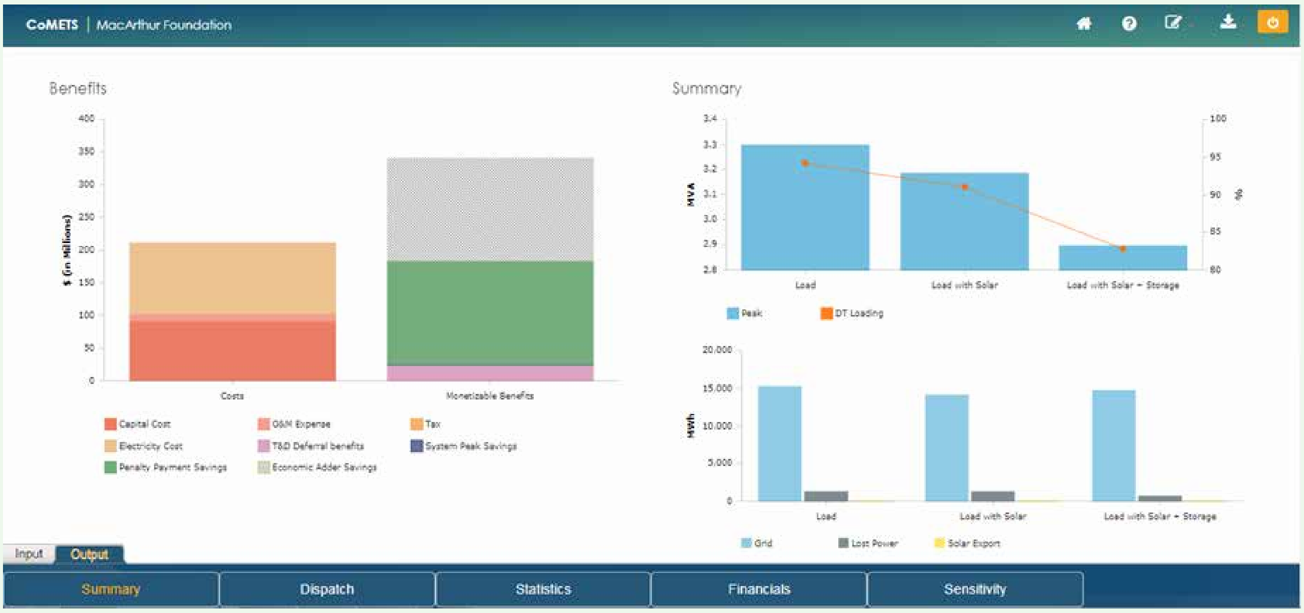
Model is capable of analysing different types of lithium ion battery chemistries as well as storage technologies like Valve Regulated Lead Acid (VRLA), Flooded Lead Acid batteries etc. Apart from energy rating, other characteristics such as power rating, state of charge, efficiency for storage can be manually inserted if someone wants to deep dive into a particular energy storage technology. The model can also recommend energy storage size based on solar penetration level and grid characteristics.

Considering all the parameters, simulations can be performed to get optimized energy storage solution. Results of model can help to calculate whether a system upgradation is required for future and how energy storage can help to defer that.

One of the most interesting results from this tool is its output with sensitivity analysis. It gives numerical as well as visual output which make this tool much more user friendly. Summary tab (shown in Figure 26) of output helps the user to understand the various value streams as well as the implication of added solar and storage on DT loading. Detailed output of non-monetizable and monetizable benefits can be visualized under this tab.

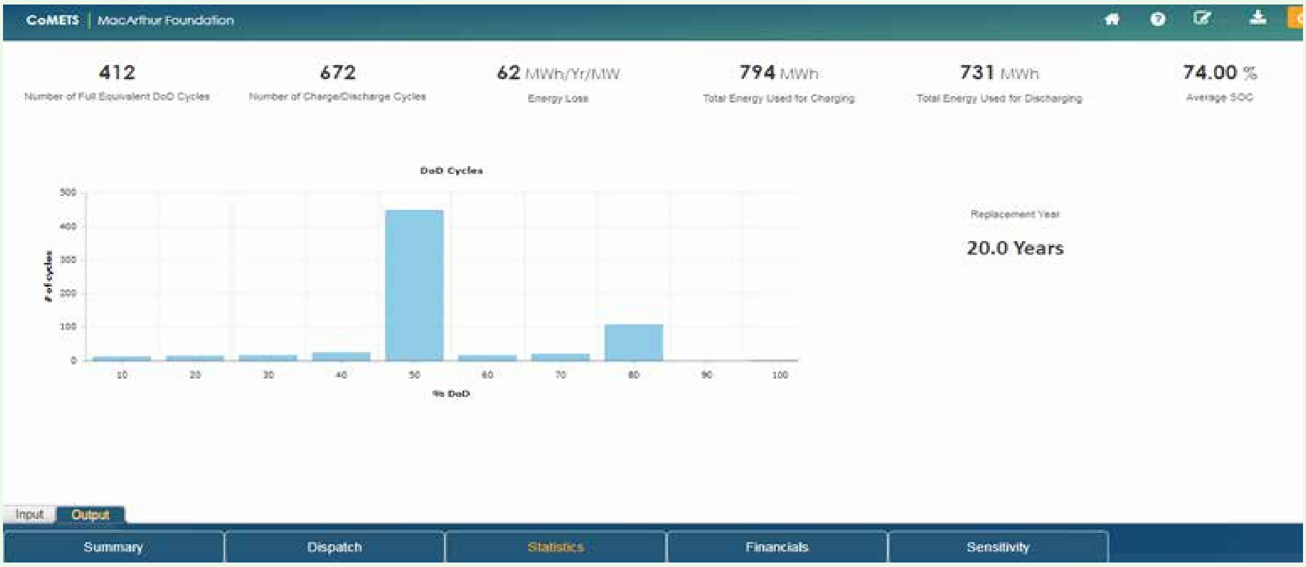
Figure 26:

Summary Tab of ESIT Model



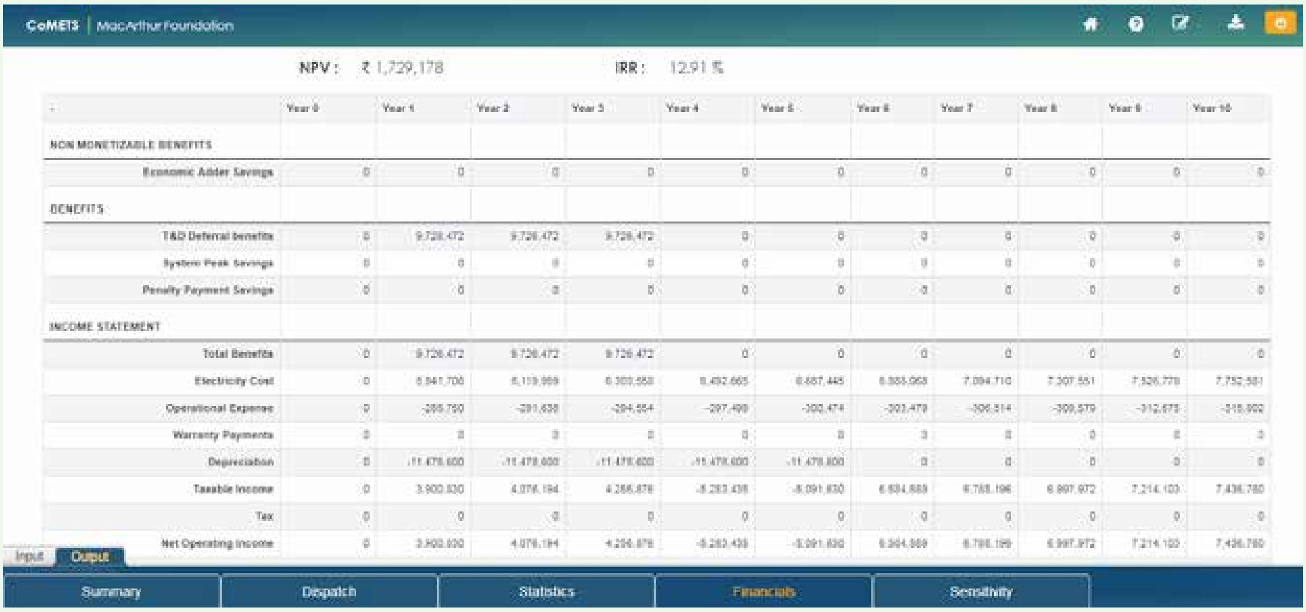
Statistics tabs (shown in Figure 27) is also provided to show cycling of energy storage system and technical parameters such as energy throughput, Avg State of Charge, etc. The replacement year of ESS is also shown here.

Figure 27:
Statistics Tab of ESIT



The financials tab (shown in Figure 28) on the other side helps to quantify all the costs and benefits for the user. The total cost of project (Capex and Opex) can be seen from financial tab. Income statement is generated to check actual profit against various expenses. Finally, cash flows section is shown from which IRR and NPV of the project is calculated. In addition to these sections, sensitivity section is also there which perform sensitivities of loading v/s different penetration levels of solar PV with and without storage.

Figure 28:
Financial Tab of ESIT



	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
NON MONETIZABLE BENEFITS											
Economic Adder Savings	0	0	0	0	0	0	0	0	0	0	0
BENEFITS											
T&D Deferral benefits	0	9,726,472	9,726,472	9,726,472	0	0	0	0	0	0	0
System Peak Savings	0	0	0	0	0	0	0	0	0	0	0
Penalty Payment Savings	0	0	0	0	0	0	0	0	0	0	0
INCOME STATEMENT											
Total Benefits	0	9,726,472	9,726,472	9,726,472	0	0	0	0	0	0	0
Electricity Cost	0	5,941,700	6,119,959	6,303,558	6,492,665	6,687,445	6,888,068	7,094,710	7,307,551	7,526,778	7,752,581
Operational Expense	0	-288,750	-291,638	-294,554	-297,499	-300,474	-303,479	-306,514	-309,579	-312,675	-315,802
Warranty Payments	0	0	0	0	0	0	0	0	0	0	0
Depreciation	0	-11,478,600	-11,478,600	-11,478,600	-11,478,600	-11,478,600	0	0	0	0	0
Taxable Income	0	3,900,830	4,076,194	4,256,878	-8,283,438	-8,091,830	6,584,889	6,788,196	6,997,972	7,214,103	7,436,780
Tax	0	0	0	0	0	0	0	0	0	0	0
Net Operating Income	0	3,900,830	4,076,194	4,256,878	-8,283,438	-8,091,830	6,584,589	6,788,196	6,997,972	7,214,103	7,436,780

5.3 Consideration of Multiple Use-Cases

The ESIT is well suited for different levels of analysis mentioned above. The monetizable benefits are listed below:

- **T&D Upgrade Deferral:** The tool deploys storage when feeder/DTs are heavily loaded (local peak shaving and reverse power flow absorption). This defers the T&D upgradation for certain period. Benefits are calculated considering savings on interest payments on upgradation costs due to deferral
- **System Peak Shavings Benefits:** System wide peak shaving benefits can be captured if a suitable program exists. Storage is deployed to reduce utility loads during system peaks (For most utilities in India this could include evening time discharge of energy storage)
- **Time Shifting:** The tool has capability to examine the power procurement cost for the utility. If energy arbitrage opportunity exists, then storage is deployed to take advantage of the price differential
- **Penalty Savings:** ESIT is able to quantify the savings on penalty payments to consumers during power cuts if storage is deployed to serve the load
- **DR Revenue:** The tool can simulate a Demand Response (DR) program. Utility DR calls can be specified. If the customer sited storage is capable of responding during those calls, the benefits are calculated
- **Energy Arbitrage:** In the rate plan for the consumer, if there exits an arbitrage, then storage is dispatched to capture those benefits
- **Diesel Minimization:** Tool can calculate the benefits due reduction in diesel consumption by DG sets if storage is utilized during power cuts

5.4 Evaluation of Monetizable and Non-Monetizable Benefits

ESIT classifies benefits from storage into two categories namely monetizable and non-monetizable benefits. The tool classifies the benefits into the aforementioned categories with respect to the current regulatory scenarios at state and central levels, barring few exceptions. For instance, in ESIT tool T&D upgrade deferral benefit is basically a financial benefit for utility by deferring the investment for certain years. The benefit reflects in the savings in interest payments for upgrade costs. Under present payment mechanisms and regulatory policies, a customer owned asset cannot realize this benefit, however, the benefit for the grid can be realized even if the asset is owned by customer. Thus, T&D upgrade deferral benefit has been considered as monetizable benefit across all the placements in ESIT. Potential benefits for different levels are captured in Table 6. Electricity savings on the other hand is also an important benefit for utility as well as consumer (For Commercial and Industrial) as storage can also perform arbitrage based on utility energy procurement cost. However, energy shifting is not a monetizable benefit for residential customers as time of day tariff does not apply to them. Acting as a customer asset in the current scenario, utility needs to pay for lost power to consumers. This can be reduced by using storage.

ESIT can show different peak saving benefits i.e. system and local. Storage can operate during system peak events. However, under present market structure storage can be only present at utility side to monetize system peak reduction.

With Demand Response programs, end customers can also get paid for responding to DR signals. Storage being a flexible asset can

Table 7:
Different Monetizable and Non-Monetizable Benefits

Different Benefits	DT	Feeder	Customer
T & D Upgrade Deferral	M	M	M
Electricity Savings	M	M	M*
System Peak Reduction	M	M	NM
Penalty Payment Savings	M	M	M
Diesel Savings	NM	NM	M
Economic Adder	NM	NM	NM
PF Correction/Reactive Power Support	M	M	M

M=Monetizable, NM=Non-Monetizable

M* = Monetizable only for commercial and industrial consumers

help in allowing consumers to participate in DR programs without changing consumption patterns. Moreover, with help of distributed storage, as mentioned earlier, utility can save by reducing local peak and thus can extend the usability of current DT/Feeder/Line configuration by deferring upgrades.

Under this study, it is felt that reliability of power is still an issue with many customers reporting almost daily short unscheduled interruptions especially in rural and semi-urban centres. Reliability and quality of power has often been quoted as a barrier for economic growth in India. There are many economic studies done in different parts of world which claim that value of voltage sags and power cuts to customers range from as low as $5 to $50 per kWh (when cost of electricity is rated close to 10-15 percent). Semiconductor fabrication manufacturing units have quoted losses of close to $500,000 per power cut event. Hence as a tool, ESIT has defined a non-monetizable benefit called economic adder, which can be chosen by the user as a multiple of tariff to quantify loss of business due to reliability issues. However, in the Indian scenario, the power outages can be monetized well at customer end, as most of customers are using diesel gensets, which is an expensive backup option in terms of operating costs. ESIT considers energy storage as a solution to optimize the use of diesel gensets during power cuts and reduction in diesel usage is considered as a cost benefit of storage when placed at the customer end. However, if the same asset is placed at utility side and is able to address the outage, there would be only partial benefit to utility apart from recovery of the T&D portion of the charges which the utility losses in case of power cut. If there are regulations in place, which can penalize the utility for loss of supply, utility owned storage can have a monetizable benefit for providing reliable supply by avoiding penalties. However, apart from Delhi, no other stated has introduced or has planned to introduce such penalty so far. And even in case of Delhi, the penalty payments are rated as INR 50 for two hours of power cut. Apart from these benefits, power quality (PF correction), is also a monetizable benefit which smart storage inverters can address. And the tool considers PF correction as a monetizable benefits.

5.5 Testing of Different Policy Incentives

While India is successfully progressing towards achieving 175 GW renewable energy targets by 2022, a few challenges still needs to be addressed such as RE integration to distribution grid, peak deficits, intermittency problems owing to RE penetration etc. In order to achieve Solar Mission objectives, interventions are still required to bring down costs borne by the utility and end user/consumer. The key challenge is to provide an enabling framework and support for entrepreneurs to develop markets.

On the other hand, many of the industrial consumers, connected to 33kV and 11kV feeders are facing severe losses during power cuts and voltage fluctuations. These consumers spend lot of amount on diesel/other sources during power deficits which itself is an additional burden on these consumers. The only demand from the consumers connected to these voltage levels is to receive uninterruptable quality power supply. This is the same case for domestic consumers as well.

For taking complete advantage of Storage + Solar PV integration, the need of the hour is to formulate appropriate regulations for successful implementation of the proposed system. The best way to test the advantages of this system is to implement a pilot project in most load facing Discom in an urban area and compare these results with only solar PV installed regions. Although few of the benefits of installing storage is not monetizable but immediately yield positive results. Testing the pilot project for a year or more can certainly show the system improvement. Creating market mechanism for demand response, ramp controls, ancillary services and power quality will definitely boost efficiency in the last mile network and also increase the reliability. Such mechanisms will also introduce flexible assets in the system like energy storage systems and smart inverters, which can bring a lot of value to the grid apart from addressing issues due to higher penetration of rooftop solar PV in Low voltage and medium voltage distribution networks.

6 Cost Benefit Analysis of Energy Storage using ESIT

6.1 Cost Benefit Analysis for Energy Storage System at Different Locations

Energy Storage India Tool (ESIT) developed as the part of this study has the capability to analyze penetration of storage and its benefits at different level namely feeder, distribution transformer (DT) and customer levels. The tool has the capability to understand techno-commercial benefits of using a storage at a particular location through different cost benefits, it can avail at a particular level in the network. However, the tool does not analyze voltage drop, voltage fluctuations and many such load flow parameters to derive this analysis. An introduction to the tool was made in Chapter 5. This chapter will further help the reader to understand quantitative assessment conducted by ESIT through a particular case.

To understand benefits of energy storage at different level, analysis for one of the feeders of CESC Kolkata has been considered in our study. The feeder covered in this study is of capacity 2.9 MVA and feeding 11 distribution transformers of 3.4 MVA cumulative capacity. This feeder is currently loaded 85%, which is high compared to other feeders. Such highly loaded feeders that are likely candidate for distribution upgrades in near future are good candidates for deployment of energy storage to capture maximum benefit. Lithium ion Nickel Manganese Cobalt (NMC) and lead acid (LA) batteries have been considered to understand effect of technology on project feasibility. With preliminary analysis of storage cycles, it was found that LiB for this particular project could last for 10 yrs. So, no replacement is required for LiB during a 10 year project evaluation. But in case of lead acid (LA) battery, it is expected to last for 3 years thus needs to be replaced up to 3 times during the 10 year evaluation period. Feeder upgrade planning is assumed to be 30 years. Some general assumptions used in the simulations are listed in Table 8.

Table 8:
Assumptions for Analysing Feeder and DT Level Data

Assumption Parameter	2020	2022	2025
Solar Penetration(Low case and High case)	20% & 50%	40% & 70%	70% & 90%
Load Scale (Considering annual load growth is 3%)	106.6%	116%	127%
Power Conversion System Cost trend($/kW)	224-405	182-328	133-239
Storage cost($/kWh)	220	184	150

Apart from those parameters, some data like transformer cost, switchgear cost, cabling cost etc. have been taken from CESC and secondary sources. Considering all these parameters, CESC cases has been analyzed for 2020, 2022 and 2025. Table 9 is summary of all the cases considering maximum level of penetration in each level. The feasibility of the project can be seen in different level. It has been found out that for CESC, installation of storage in DT level will help them to reduce peak load and also, they will get monetizable benefits.

Table 9:
Summary of Different Level Analysis

Year	Different Level	Solar Penetration	Individual Storage capacity (KW)	Total storage capacity (MW)	Storage capacity (MWh)	Project NPV	IRR
2020	Feeder	50 %	290	0.29(10% of Feeder Capacity)	0.58	-0.772	6.01 %
	DT	50 %	31.5	0.031(10% of DT Capacity)	0.031	0.076	*21.6 %[31]
	Consumer	50 %	31.5	0.031	0.031		*-8.66 %
2022	Feeder	70 %	290	0.29	0.58	-0.621	6.20 %
	DT	70 %	31.5	0.031	0.031	0.081	*27.2 %
	Consumer	70 %	31.5	0.031	0.031	-06061	*0 %
2025	Feeder	90 %	290	0.29	0.58	-0.244	8.30 *
	DT	90 %	63	0.031	0.031	0.076	*37.5 %
	Consumer	90 %	31.5	0.031	0.031	-04169	*0 %

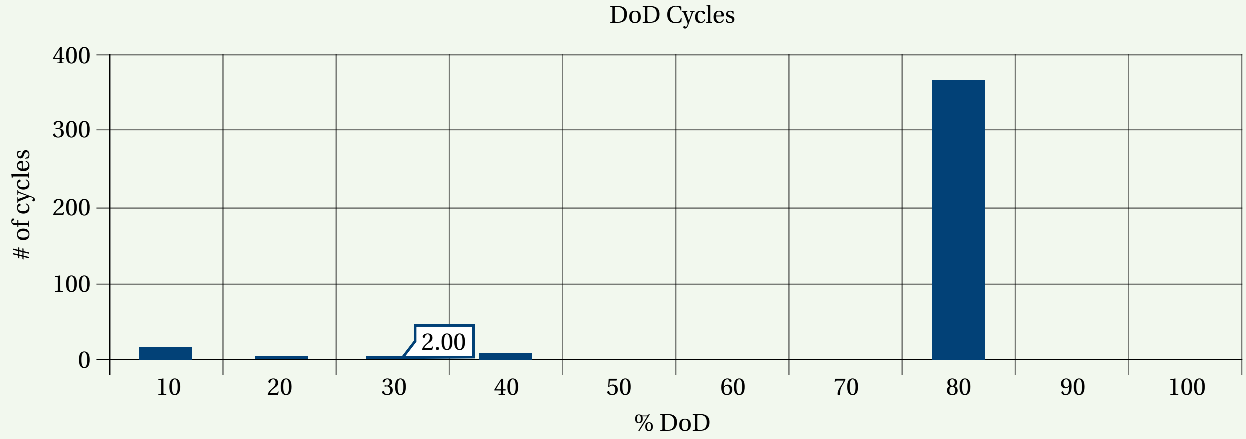
*IRR is for particular DT

6.2 Feeder Level Analysis

From the initial analysis it is found out that although lead acid battery storage option is cheaper compared to LiB; it is uneconomical due to its short life as it needs to be replaced after every 3 years. We have estimated that price of LiB's will go down below lead acid battery price in coming years. In addition to that, LiB's are more ecofriendly and can be recycled totally. This study has considered LiB as the storage option for analyzing different cases. From Figure 29 it can be seen that LiB has the capability to do more than 350 cycles each day at 80% depth of discharge (DoD). This leads to deferment of Lead-Acid battery replacement every 3 years. For this study, the replacement year for a typical DT level ESS is 15 years, which is economically viable. For this study the replacement year for DT level storage is 15 years which is quite economically viable. Different size of storage has been considered to optimize the storage size according to feeder capacity and found out different optimum storage size for different years. To make the project more feasible, IESA have considered constant storage size for every year and various levels of solar penetration. In that way, utility can think about one storage option which has capability of taking load up to 2025 as well as beneficial for them.

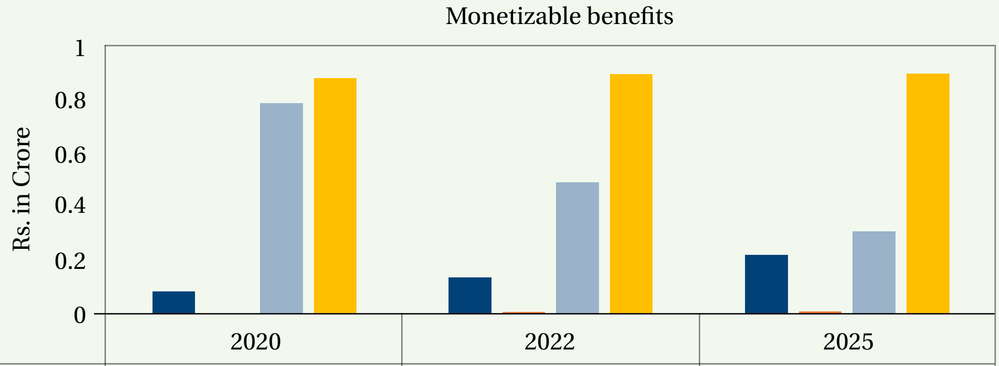
[31] Value benefits considered for this case are power factor correction, T&D deferral and electricity savings. In this particular case, value adds due to high local characteristics enabling a good return on investment.

Figure 29:
Cycles at Different Depth of Discharge



Benefits in Figure 30 Different benefits captured over different year are for maximum solar penetration with the help of storage for the above-mentioned year. Different monetizable benefits assuming constant storage size are depicted in Figure 30.

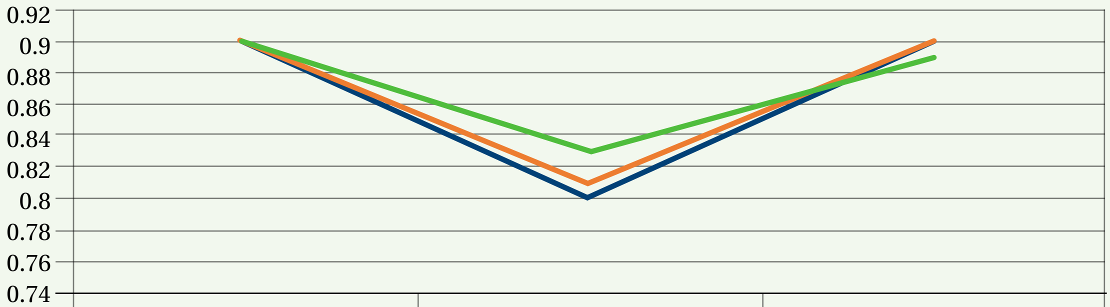
Figure 30:
Different Benefits Captured Over Different Years



	2020	2022	2025
T & D deferral benefits (Cr)	0.085	0.134	0.22
Penalty payment savings (Cr)	0.004	0.007	0.009
PF penalty savings (Cr)	0.781	0.488	0.307
Electricity Savings (Cr)	0.872	0.888	0.89

Among different benefits, penalty payment savings has the least impact compared to other benefits. T & D deferral benefits have increased from 2020 to 2025 due to the low-cost of storage. Electricity savings by considering arbitrage will be almost similar for every year. On the other hand, Power Factor (PF) penalty savings will gradually go down due to the lower tariff of electricity. Figure 31 describes how power factor is increasing with the help of storage.

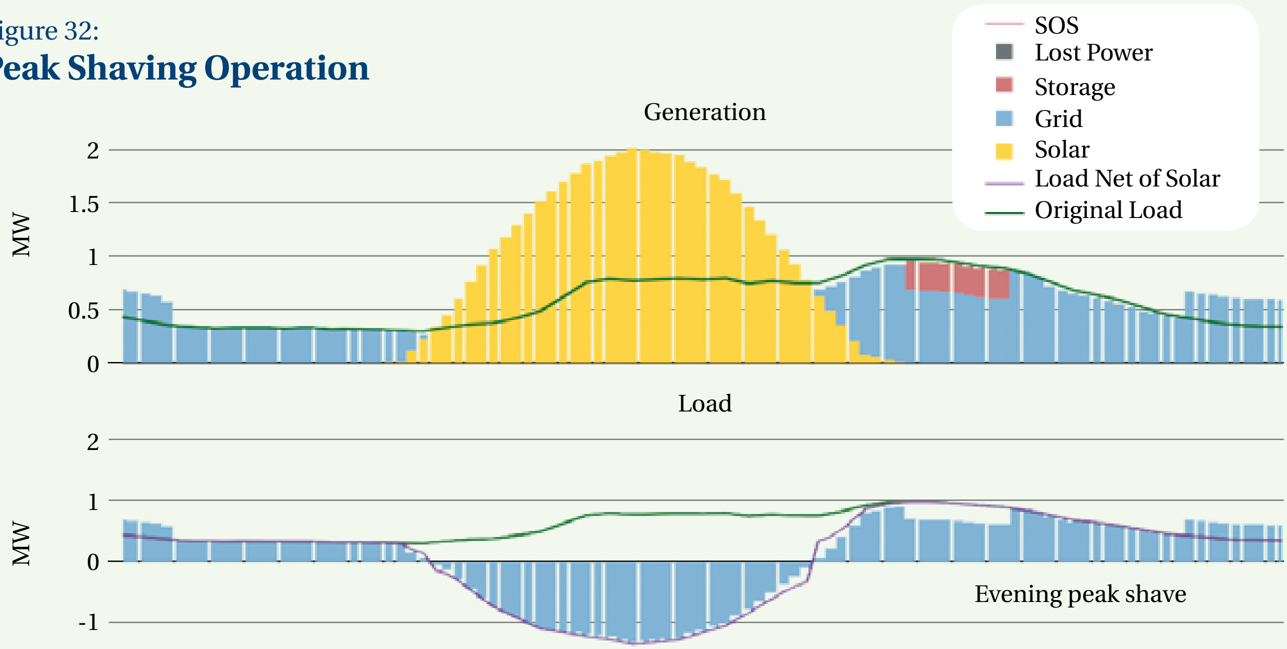
Figure 31:
Increment of PF by Using Storage



	PF of Actual load	PF of load with Solar	PF of load with Solar and storage
2020	0.9	0.8	0.9
2022	0.9	0.81	0.9
2025	0.9	0.83	0.89

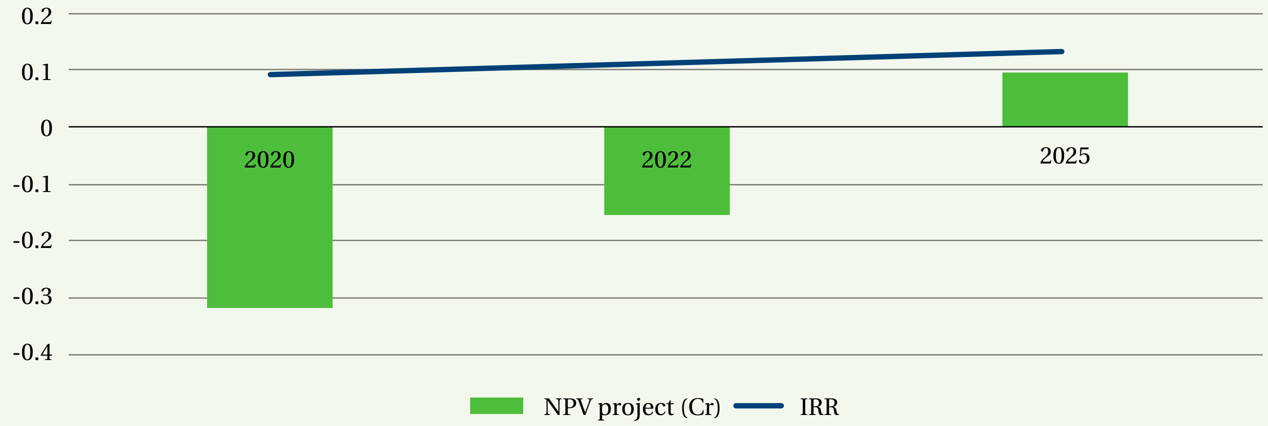
As per the data, feeder level load is having 0.9 PF but when solar comes into the grid, then PF reduces to around 0.8. Reduction in PF happens because solar is giving only active power instead active and reactive power thus ratio of apparent power to active power (i.e. PF) got reduced. With the help of storage that ratio got increased and back to its actual PF.

Figure 32:
Peak Shaving Operation



These graphs in Figure 32 shows yearly data for CESC. Also, it clearly indicates the peak shave operations. The evening peak get saved by using storage. This will eventually defer the transformer upgradation for long period.

Figure 33:
Economic Viability of the Project During Different Years



From Figure 33, it can be seen that the project is not viable in the initial years (2020 & 2022) as net present value (NPV) is negative. Battery in 2025 case is helping to reduce peak load with higher PV penetration, also giving economic benefits. But in rest of the years, storage is not helping although solar PV penetration is helping to reduce peak load. In 2025, at 90% solar PV in penetration (1.3MWp), a 0.29 MW× 2hr (10% of feeder capacity) LiB would be required to provide 2 years of T&D upgrade deferral benefit with energy time shifting. The tool has sized the storage in order to maximize T&D deferral benefits and then value from other applications are assessed. The final size is different from the recommended size for T&D upgrade benefit to arrive at maximum ROI.

As per our analysis, installation of 0.29 MW ×2hr battery in 2020 will help to reduce losses though in this year project is not economically feasible. But different monetizable benefits can be obtained and thus leading to positive internal rate of return (IRR).

6.3 Distribution Transformer (DT) Level Analysis

DT level analysis is performed on a 315 kVA DT. This DT is highly loaded among the 11 DTs on a feeder. Rest of the assumptions are similar to feeder level assumptions. Figure 34 shows different monetizable benefits for particular DT. Monetizable benefits are decreasing over the year. This could be due to the advancement of technology and low cost of storage. In addition to that, this DT is highly loaded and can be saturated after some years. Thus, installing storage in coming year will help to reduce losses with monetizable benefits. PF penalty savings are the major contributor for the monetizable benefit followed by electricity savings and T&D deferral benefit.

On the other hand, IRR of the project is increasing every year seen in Figure 33. Also, it depicts that the project is economically viable as NPV is positive. Capex of each year starting from 2020 to 2025 will reduce due to reduction in cost of Li-ion battery and hence makes the project feasible. Solar penetration in the year 2022 and 2025 also helps to reduce the original load curve. As the DT is highly loaded and if storage can be installed in 2020, then it will defer the transformer upgradation for 2 years. But if the storage is installed in 2025, then the transformer upgradation deferment year will be 1 year considering 3% growth every year. This is due to the capacity of transformer reaching maximum load. At 20% of DT capacity storage (i.e. 0.0315 MW for 1 hr) option is suitable for all the year to get maximum IRR. This result is for considering maximum solar penetration in each DT. As per ESIT, maximum IRR is driven by low storage cost.

Figure 34:
Break-up of Monetizable Benefits (INR)

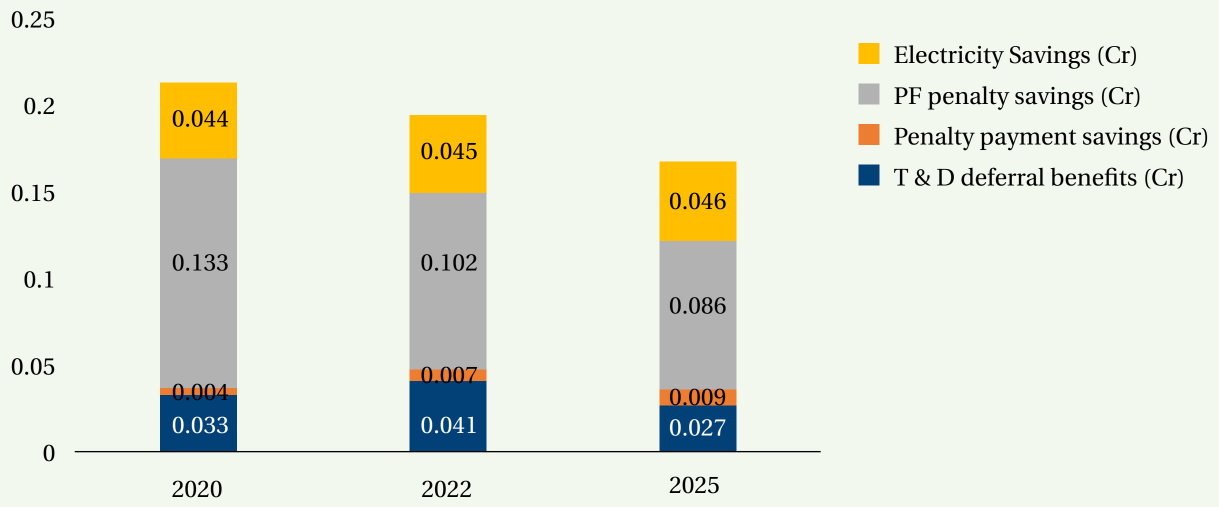
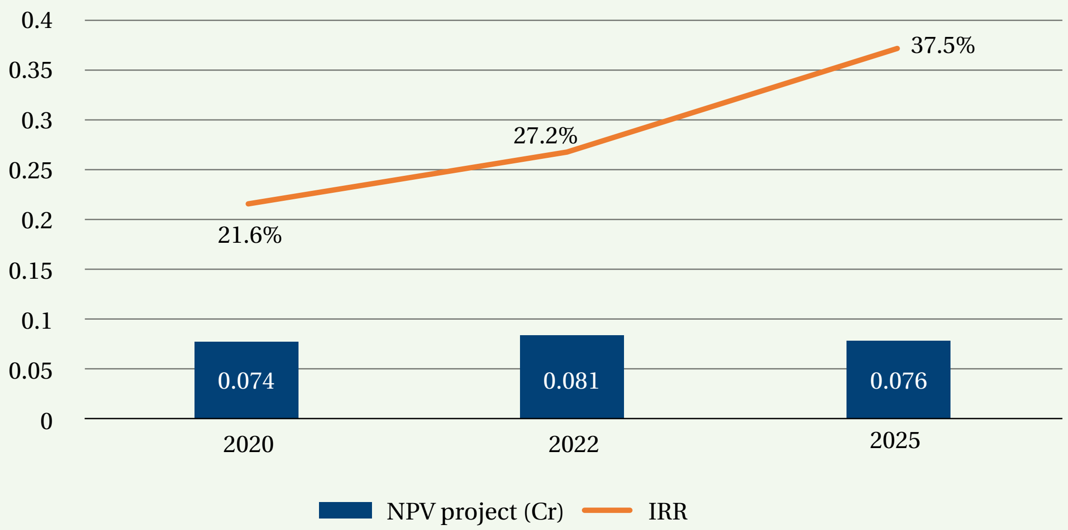


Figure 35:
Economic Feasibility of the Project



6.4 Consumer Level Analysis

Under the 315 kVA DT, all the consumers are residential. Approximately 198 consumers are associated with this DT. Rest of the assumptions are taken same as for the analysis of Feeder & DT. The Table 10 shows results from consumer level analysis. The NPV is negative for every year and hence makes the project economically unviable. Flat rate plan has been applied here thus benefit of energy shifting is not there. However, for commercial and industrial (C & I) consumers' energy shifting benefit will be there due to the time of day tariff. Thus, energy

Table 10:
Consumer Level Results

Year	Power (MW)	Duration (Hr)	NPV project (Cr)	IRR	Deferral Years
2020	0.0315	1	-0.083	-8.66%	2
2022	0.0315	0.5	-0.0551	0%	0
2025	0.0315	0.5	-0.0379	0%	0

storage will be beneficial for C&I consumers. Moreover, CESC is having very low power cut, thus diesel minimization is also very less. Currently there is no Demand Response (DR) program applicable in India. Implementation of DR program would help them to incentivize consumers for investment in energy storage.

ESIT recommends CESC to install storage at DT level to minimize cost of the project and to get maximum benefit. The above-mentioned analysis is for one particular DT. This analysis can be done for every DT for installation of storage. Thus, help to reduce the peak load as well as to defer the transformer upgradation.

7 Energy Storage Roadmap for India – 2019, 2022, 2027 and 2032

Energy Storage represents a huge economic opportunity for India. Ambitious goals, concerted strategies, and a collaborative approach could help India meet its emission reduction targets while avoiding import dependency for battery packs and cells. This could help establish India as a hub for cutting-edge research and innovation, boost its manufacturing capabilities, create new jobs, and foster economic growth. India's strengths in IT and manufacturing, its entrepreneurial and dynamic private sector, and its visionary public and private sector leadership will be key factors in realizing these ambitions. Creation of a conducive battery manufacturing ecosystem on fast track could cement India's opportunity for radical economic and industrial transformation in a critical and fast-growing global market.

This chapter presents the estimated Energy Storage System (ESS) requirements in India for the periods 2019-2022, 2022-2027 and 2027-2032 for different applications. We have examined different ESS technologies such as batteries, super capacitors, compressed air energy storage system, fly wheels, pumped hydro storage plants, etc with regard to technology maturity and price trajectory. However, the fast pace of developments taking place in the battery technologies and the consequent price competitiveness have put batteries as the first choice for most applications. Few pumped hydro storage (PHS) plants in India with total capacity of 5.7GW have been identified long time back, but these projects have not made any progress in the past two decades owing to variety of issues. Hence, the PHS plants are not considered in this report. New form of gravity storage involving large blocks of concrete/ stones is still in its infancy and not sure of achieving commercial viability before 2032; and hence, not considered in these estimates. Super capacitors, fly wheels and compressed air energy storage are far more expensive than the latest range of lithium-ion batteries (LiB) and those technologies have their own limitations with regard to size, location, cost etc. Hence, we have considered batteries as the ESS of choice for various applications in the forecast period. We have made separate projections for different ESS applications such as:

1. Energy Storage for VRE Integration on MV/LV Grid
2. Energy Storage for EHV Grid
3. Energy Storage for e-Mobility
4. Energy Storage for Telecom Towers
5. Energy Storage for Data Centres, UPS and Inverters
6. Energy Storage for DG Replacement
7. Energy Storage for other > 1 MW Applications

It is pertinent to state here that we have conducted detailed study and analysis only in the case of ESS for VRE integration on MV/LV grid. Other estimates are from best available data in the public domain. Although we have attempted to make projected ESS requirements, primarily batteries until 2032, technological breakthroughs making different ESS technologies more attractive in the forecast period is not ruled out. As in the case of any long-term roadmaps, this roadmap also should be reviewed and updated periodically considering the changes taking place both on the supply and demand sides.

7.1 Energy Storage for VRE Integration on MV/LV Grid

This estimate has been developed assuming 40 GW solar penetration connected to Medium Voltage (MV) and Low Voltage (LV) grid by 2022. In our calculations, we have split the 40 GW solar penetration into different states based on the solar potential in the state. To make it further precise, the states are divided into different segment namely Metro-Saturated, Metro-Growing, Peri-Urban and Rural. As per our analysis, maximum solar installations will be happening in Peri-Urban (80%) followed by Rural (17%) and Metro (3%) states. Further, we have analysed that Metro-Saturated have 30% potential whereas Metro-Growing has 70% potential of the total Metro potential of 3% for solar penetration. We have considered only 12 major metros in Metro segment. Rest of the Tier 2 cities have been considered under Peri-Urban category. Thus, for every state, analysis is different based on different assumptions. These segments are further divided among commercial, industrial and residential consumers. We have found out that the solar penetration for residential consumers varies between 10% and 40% whereas for commercial and industrial consumers it varies between 20% to 70% and 20% to 90% depending upon place to place.

After splitting the rooftop solar target, we have optimized the energy storage requirement based on different levels of solar penetration. To optimize the storage requirement for each state/segment, we have considered two scenarios. In one scenario, it is assumed that the solar penetration will be distributed among the grid of a particular state thus the battery requirement will be higher for the state (known as ***Base Case Scenario***). On the other scenario, it is assumed that solar penetration will be concentrated in few feeders thus requirement of storage will be less for that (***Best Case Scenario***). As per our analysis, the storage requirements for best case scenario will be around 9.4 GWh by 2022 whereas for the base case scenario, total storage requirement will be around 21 GWh.

7.1.1 ESS Requirement for 40 GW RTPV Integration by 2022

While presenting the scenario for energy storage market in the country, this chapter attempts at answering the preliminary question, that is, how much energy storage will be required to integrate 40 GW of rooftop solar PV in India by 2022. It also separates the requirement as per the type of consumer – residential, commercial and industrial; as per the area or the demography – metro cities, villages or Tier 2 cities, town centres.

To establish these results at all India level, scenario analysis was done as per utilities data and as per the effect of major parameters on storage selection. For example, high load growth scenarios allowed substation/feeder expansion deferral for less than two years, with deployment of ESS. However, a load growth of 3-5% meant that network expansion deferral is possible for close to 4 years with a commercially viable ESS. Similarly, high municipal charges for cable laying in metros, further strengthen the case for distribution asset deferral. On the other side, frequent power cuts scenario which is witnessed in rural networks, makes a really good case for diesel saving at customer end with 2 hours of ESS back-up. Based on the categories defined in the target of 40 GW of rooftop PV is split across the states.

In the estimations made, 40 GW of RTPV targets were split across different states and union territories as projected by MNRE. Split of 40 GW RTPV targets, as per customer category, is presented in the Table 12.

Table 11:
Split of Distribution Network and Solar PV Penetration into Different Categories

Category	Network Expansion Costs	Feeder/ DT Loading	Load Growth	ToD Tariff	Power Cuts (hours/year)	Connected at	Estimated PV Penetration
Metros-Saturated Residential	High	80%	3-5%	No	< 100	415 V	20%-50%
Metros-Saturated Commercial	High	80%	3-5%	Yes	< 100	11 kV	20%-50%
Metros-Saturated Industrial	High	80%	3-5%	Yes	< 100	11 kV	20%-90%
Metros-Growing -Residential	High	50%	5-7%	No	< 100	415 V	20%-50%
Metros-Growing -Commercial	High	80%	5-7%	Yes	< 100	400 V	20%-70%
Metros-Growing-industrial	High	80%	5-7%	Yes	< 100	11 kV	20%-90%
Rural Residential	Low	80%	7-9%	No	< 1000	415 V	20%-70%
Rural Commercial	Low	80%	7-9%	No	< 1000	415 V	20%-70%
Rural 11 kV	Low	80%	7-9%	No	< 1000	11 kV	20%-90%
Peri-Urban/Tier2 Centres R*	Medium	50%	5-7%	Yes	< 300	415 V	20%-70%
Peri-Urban/Tier2 Centres C*	Medium	50%	5-7%	Yes	< 300	415 V	20%-70%
Peri-Urban/Tier2 Centres I*	Medium	50%	5-7%	Yes	< 300	11 kV	20%-90%

(* R-Residential, C-Commercial, I-Industrial; ~Distribution Transformer)

Source: IESA Analysis

Table 12:
40 GW Rooftop Target Split for Different Types of States

RTPV Split - Categories	Commercial (MW)	Industrial (MW)	Residential (MW)	Total (MW)
Metros-Saturated	850	680	170[32]	1,700
Metros-Growing	1,720	2,150	430	4,300
Rural Residential	3,400	4,250	850	8,500
Peri-Urban/Tier2 Centres	7,650	15,300	2,550	25,500
TOTAL	**13,620**	**22,380**	**4,000**	**40,000**

[32] To accommodate 170 MW of rooftop solar PV, network capacity required will be 850 MW as this scenario considers 20% penetration of RTPV (as explained in Figure 36). Hence, as ESS is sized 10% of the network capacity, the requirement for ESS will be 85 MW (10% of network capacity) and as 1 hour storage is considered, requirement in MWh will be 85 MWh.

Further to the bifurcation of rooftop solar across different areas in the country, this report highlights an interesting observation, that is the requirement for ESS for integration for 40 GW RTPV will also depend on concentration of solar PV across the distribution networks. Higher concentration of RTPV in distribution network can lead to lesser requirement for ESS, while the requirement for storage will be higher if RTPV installation is more spread out. Hence, it is important to identify feeders where RTPV can be integrated easily and penetration of solar PV can be much higher than 50%. Installation of storage can be done predominantly in those feeders to support the higher penetration and capturing those values.

Using the Energy Storage India Tool (ESIT), the requirement for ESS was determined for rooftop PV integration. Rooftop Solar PV integration is estimated to have only 8% share of the total energy storage during 2019-2027 in India. Over 2/3rd of the deployments in this case will be required at the grid scale, which can capture many of the network issues like power quality, peak shaving, and distribution asset deferral apart from rooftop PV integration. Rest of the installations will make commercial sense at behind the meter as it can save electricity cost using ToD tariff and save diesel for backup generation in rural and peri-urban areas which are still affected by frequent power cuts.

On the other hand, according to data compiled by IESA, electric vehicle industry, consumed over 5 GWh of batteries in 2018 in India. This number is likely to be over 36 GWh by 2025. During 2019-2027, the EV sector is estimated to consume about 257 GWh of batteries. Some of these can be used through V2G (Vehicle to Grid) technologies to meet flexibility needs of the electricity distribution network. Large requirement for ESS across the applications will help in reduction of costs. Lastly, new installations of ESS for distribution grid and rooftop PV integration can be reduced if the network planning can be done around leveraging V2G and some of existing back-up battery systems.

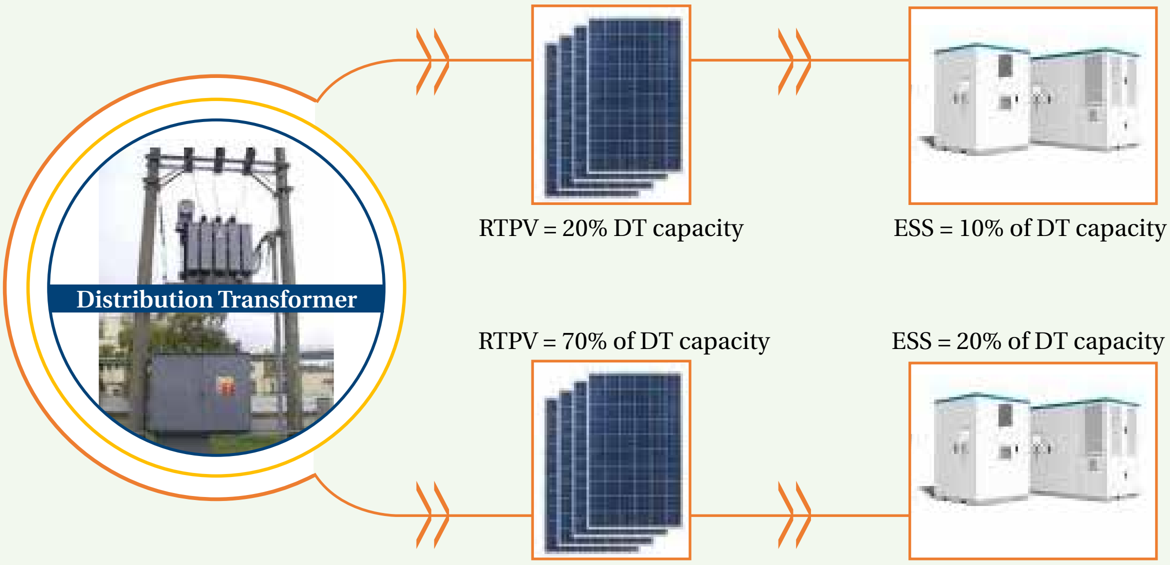
In the following four scenarios of RTPV installations, a potential requirement for ESS has been derived.

Metro-Saturated Scenario: In this particular case, where load is growing less than 5% year on year, networks are saturated, power reliability is quite good, power factor penalties are high, ESS support of around 10% of feeder/distribution transformer (DT) capacity will be required if RTPV penetration is up to 50% of the feeder/DT capacity. As RTPV penetration exceeds 20%, ESS requirement will be doubled in terms of MW/MVA for this scenario, as power factor issues and possibility of reverse power flow might demand larger size ESS. Requirement of duration of ESS will be 1-2 hours depending upon different cases.

In this scenario, power factor penalty savings, especially for industrial customers would be the biggest savings. Increase of solar PV penetration has created a marked decline in power factor across low and medium voltage levels, often leading to solar PV curtailment in states where PF penalties are high.

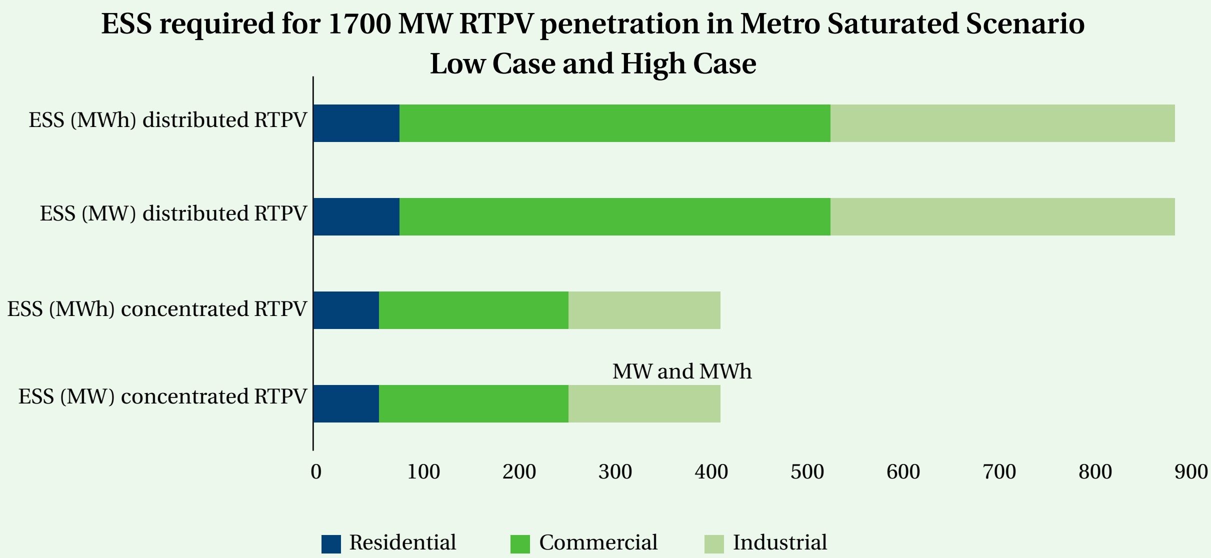
Electricity savings and T&D deferral will also be substantial in some of these metros where a decent time-of-day (ToD) tariff has been introduced and distribution infrastructure upgrade deferral savings were also high in cases where a long stretch (over 1 km) of distribution cable laying is required for an upgrade. These savings can be really substantial for top four metros where municipal charges for excavation are in the range of INR 10,000-15,000 per meter. As evaluated in ESIT, ESS of over 10% of substation/feeder capacity is required for 20% of RTPV penetration in the particular feeder or substation. In case of a higher penetration like above 50% RTPV capacity, ESS of size of 20% of network capacity will be required. As it can be observed, for higher penetration of RTPV,

Figure 36:
ESS requirement (as percentage of DT capacity) in Metro Saturated Scenario with different solar PV penetration (IESA Analysis)[33]



the increase in requirement of ESS is marginal (Figure 36). Hence, it can be inferred that if RTPV's installations are more concentrated, requirement of storage in this scenario level will be higher than the case of a more spread out installations of RTPV. At All India level, for low case and high case penetrations, ESS requirement estimation is provided in chart below (Figure 37).

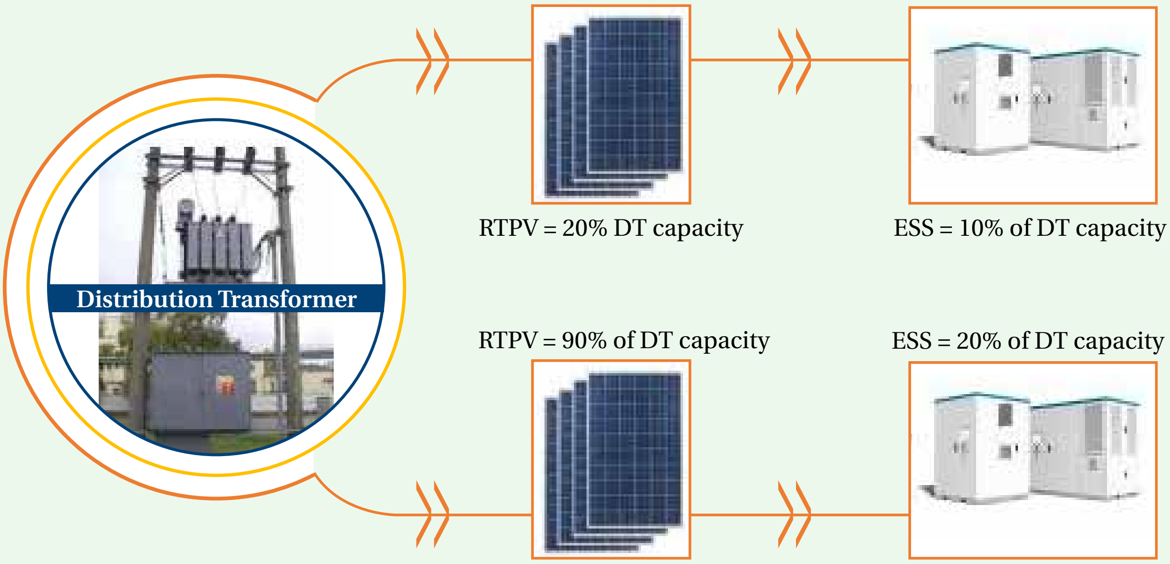
Figure 37:
ESS required for different RTPV scenario at Metro Saturated Segment



[33] The sizing of BESS has been done on the basis of monetizable economic value of the BESS functions (cut-off/near NPV neutral) using the ESIT tool. Should battery prices drastically reduce further, or if ancillary services market improve, or if tariffs rise dramatically, this equation for BESS sizing will grow larger relative to DT ratings.

Figure 38:

ESS requirement (as percentage of DT capacity) in Metro Growing Scenario with different solar PV penetration (IESA Analysis)

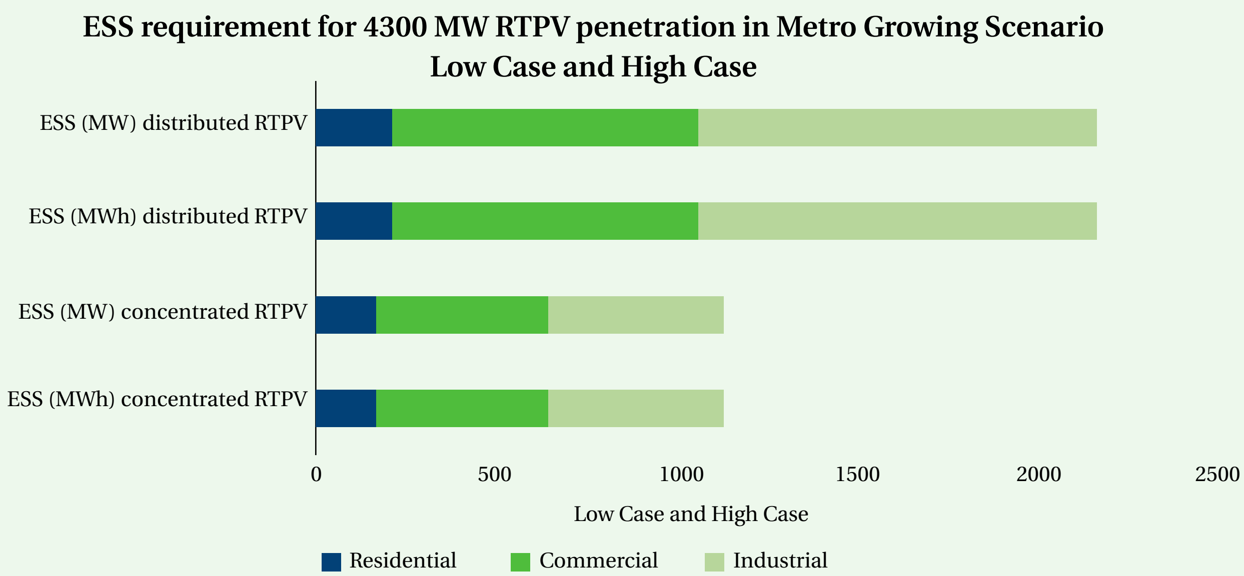


Metro-Growing Scenario:

In Metro Growing Scenario, load growth is comparatively higher (around 5-7% year on year) compared to saturated scenario. Power reliability is better in this area than in case of tier 2 cities. ESS support of around 10% of feeder/ distribution transformer (DT) capacity will be required only if RTPV penetration approach 40%. As RTPV penetration exceeds 40% and beyond, ESS requirement will be doubled in terms of MW/ MVA for this scenario, as power factor issues and possibility of reverse power flow might demand a larger size battery. To make it economically

Figure 39:

ESS required for different RTPV Scenario at Metro Growing Segment



feasible, requirement of ESS is recommended for 1 hour for most of these cases.

Electricity savings and T&D deferral savings in the case will be similar to that of Metro-Saturated category. As evaluated in ESIT, ESS of over 10% of substation/feeder capacity is required for 40% of RTPV penetration in the particular feeder or substation (Figure 38). In case of a higher penetration over 40% of RTPV penetration, ESS size of 20% of network capacity will be required. As it can be again observed in Figure 39, for higher penetration of RTPV, the increase in requirement of ESS is marginal.

Tier 2 Urban/Peri-Urban Scenario:

Tier 2 cities and their Peri-urban centres are heavy load pockets of the country as the industrialization and population density in these areas are quite high. As per CES analysis, load growth in this sector is high as these areas are developing rapidly. The annual load growth is around 5-7% in most of the cases and in some places, it goes even in the range of 8-10%.

Power reliability is not good in this area as both short and long power cuts are witnessed in Tier 2 cities with generally power cuts causing over 300 hours of interruptions in a year. ESS support of around 10% of feeder/distribution transformer (DT) capacity will be required from 20% to up to 90% of solar PV penetration for the given feeders.

T & D deferral benefit in these areas can be a weaker case, due to lower cost of upgrade and high growth rate. On the other hand, power factor penalties are generally high in the southern and western states for commercial and industrial customers. However, utilities have realized need for power factor correction in residential feeders too as there has been recently a dip in the power factor in these feeders, due to increase in electronics and LED usage, which is further going to be affected due to penetration of solar PV in the feeders.

Figure 40:

Requirement of ESS in Peri- Urban Scenario with low solar PV penetration (IESA Analysis)

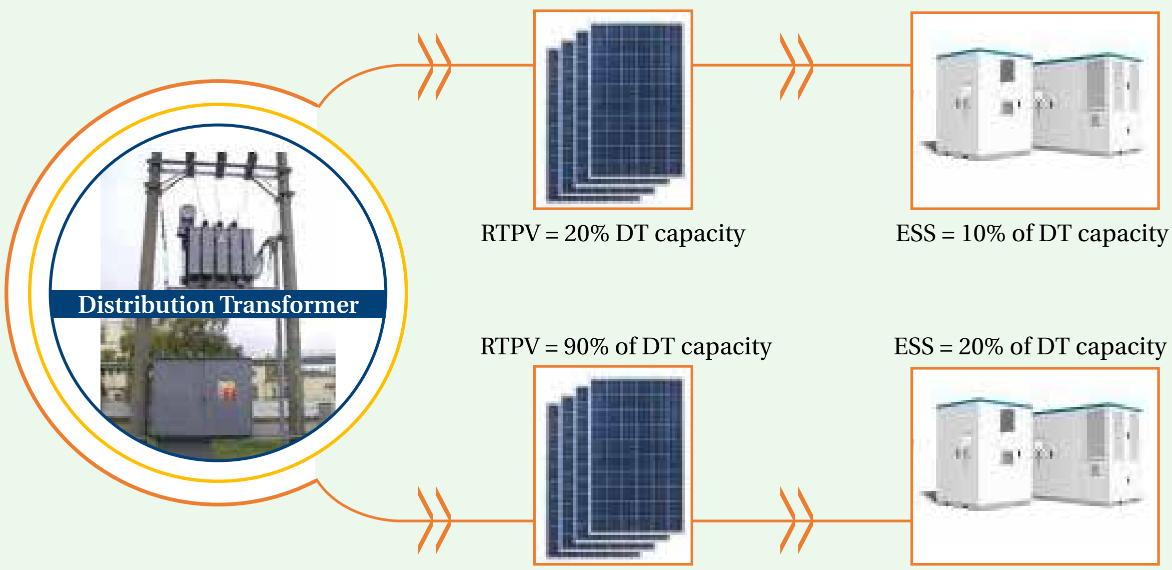
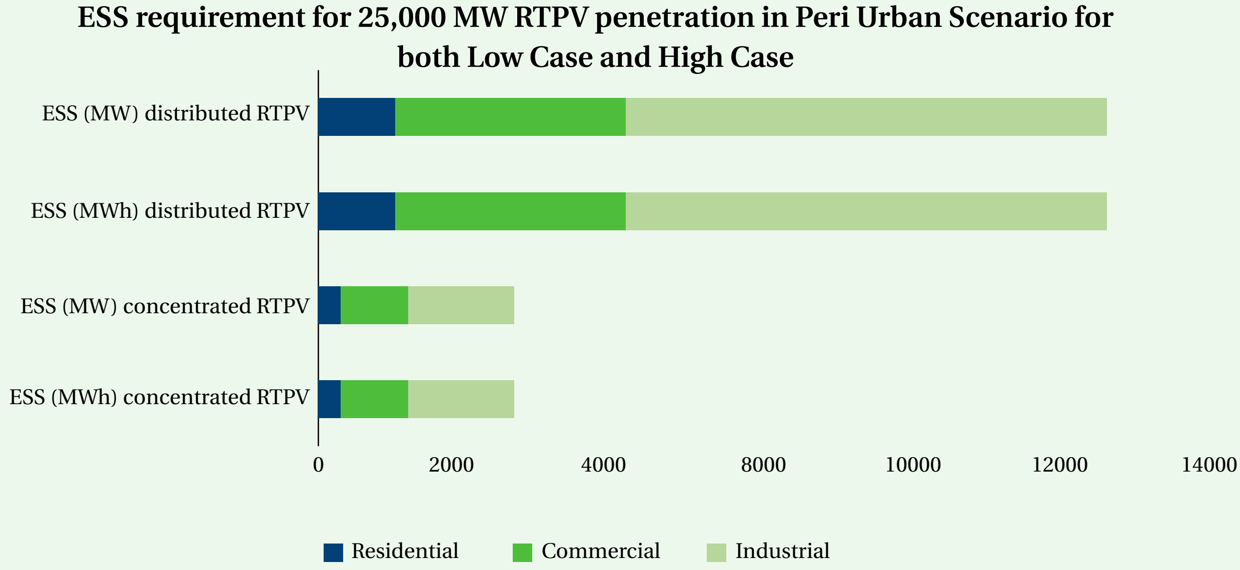


Figure 41:
ESS required for different RTPV Scenario at Peri-Urban Segment



Rural Feeder Scenario:

The annual load growth in most of the rural feeders studied was in range of 7-9%. Power reliability in this area is a major concern. As witnessed through utility data, there are over 100 hours of power cuts per month during several months in a year, especially in the northern and eastern regions. ESS support of around 10% of feeder/distribution transformer (DT) capacity will be required for RTPV penetration up to 40%. As RTPV penetration exceeds 40% and beyond, ESS requirement will be double in terms of MW/MVA for this scenario, (Figure 42). To make it economically feasible, requirement of ESS will be for 2 hours for most of these cases which will give benefits from avoided diesel usage.

Electricity savings for industrial consumer are high here compared to other benefits as these areas experiencing highest number of power cuts in a year.

Figure 42:

Requirement in Rural with Low Solar PV Penetration (IESA Analysis)

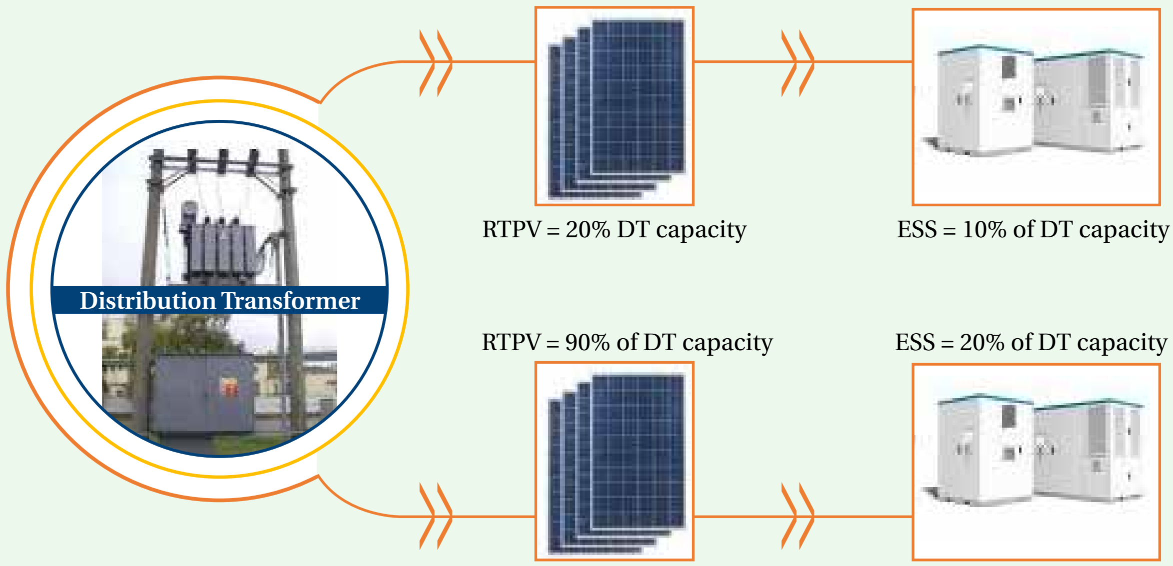
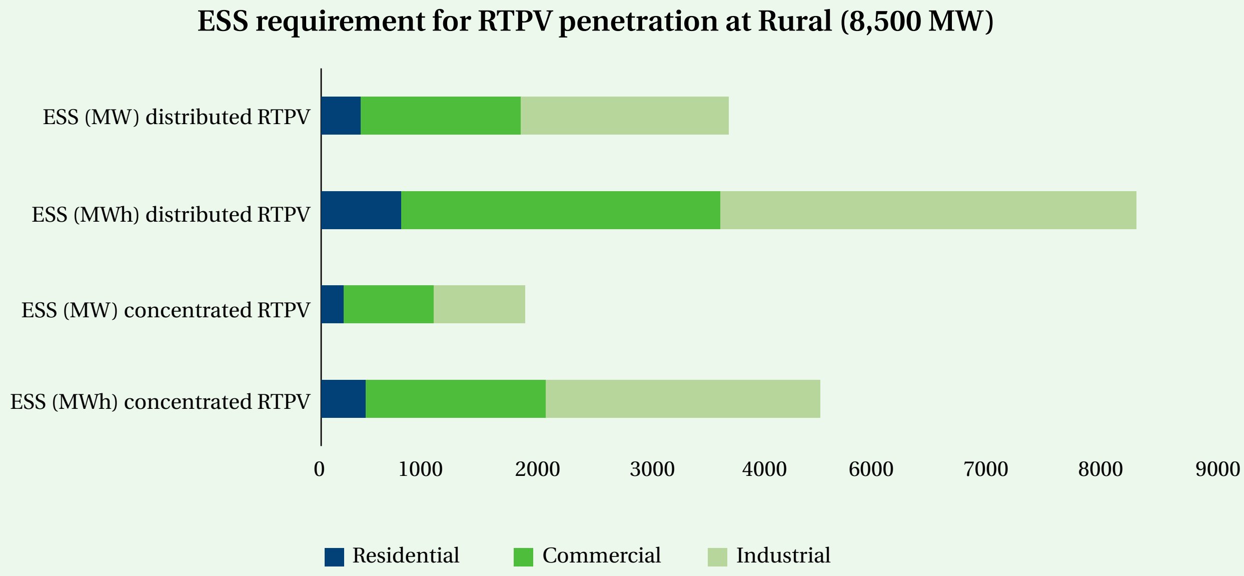


Figure 43:

ESS required for different RTPV Scenario in the Rural Segment



7.1.2 40 GW RTPV on MV/LV Grid by 2022

Total ESS estimated for Integration of 40 GW RTPV by 2022 is 9.4 GWh. State wise break up given in the Figure 44.

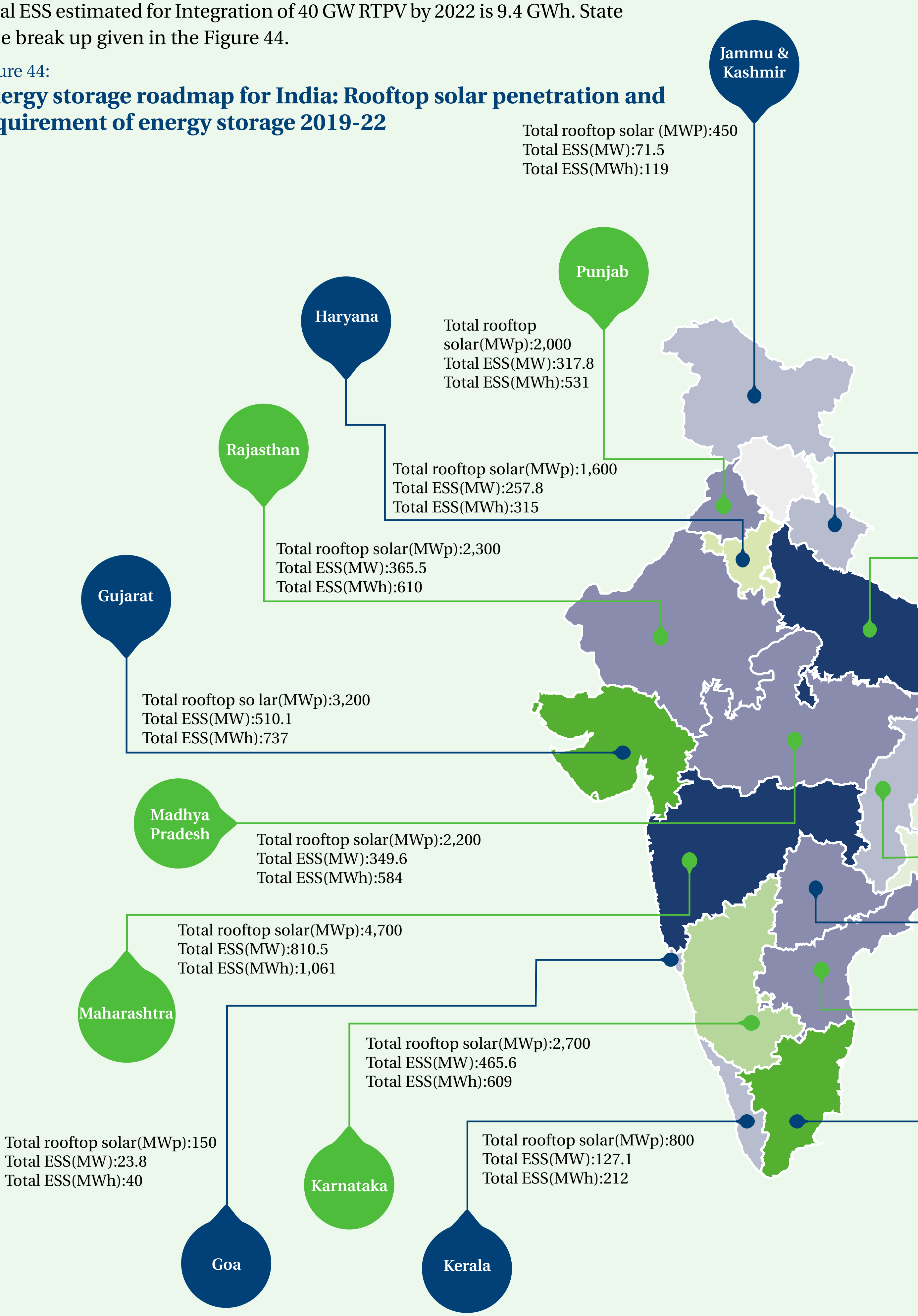
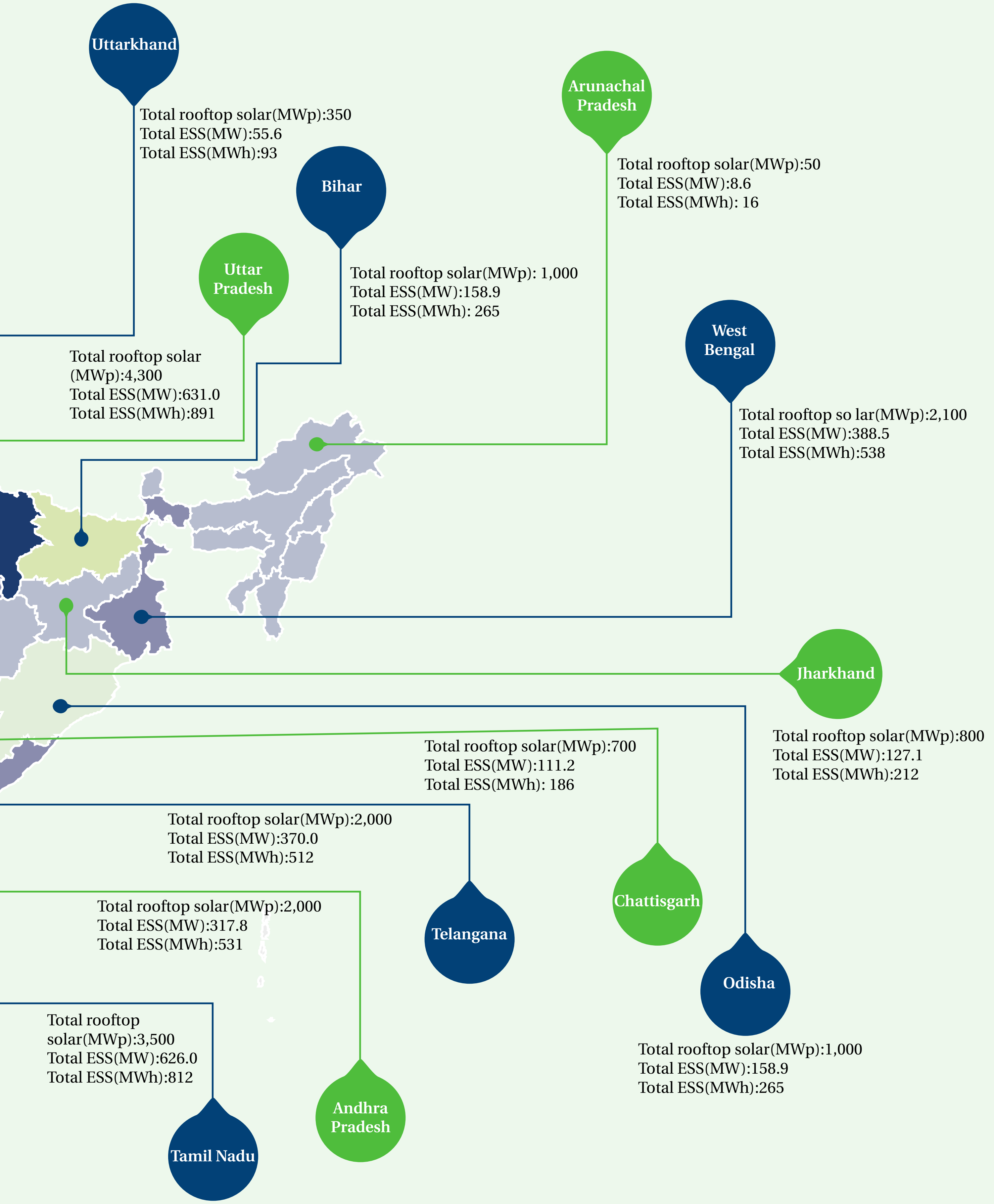


Figure 44:

Energy storage roadmap for India: Rooftop solar penetration and requirement of energy storage 2019-22



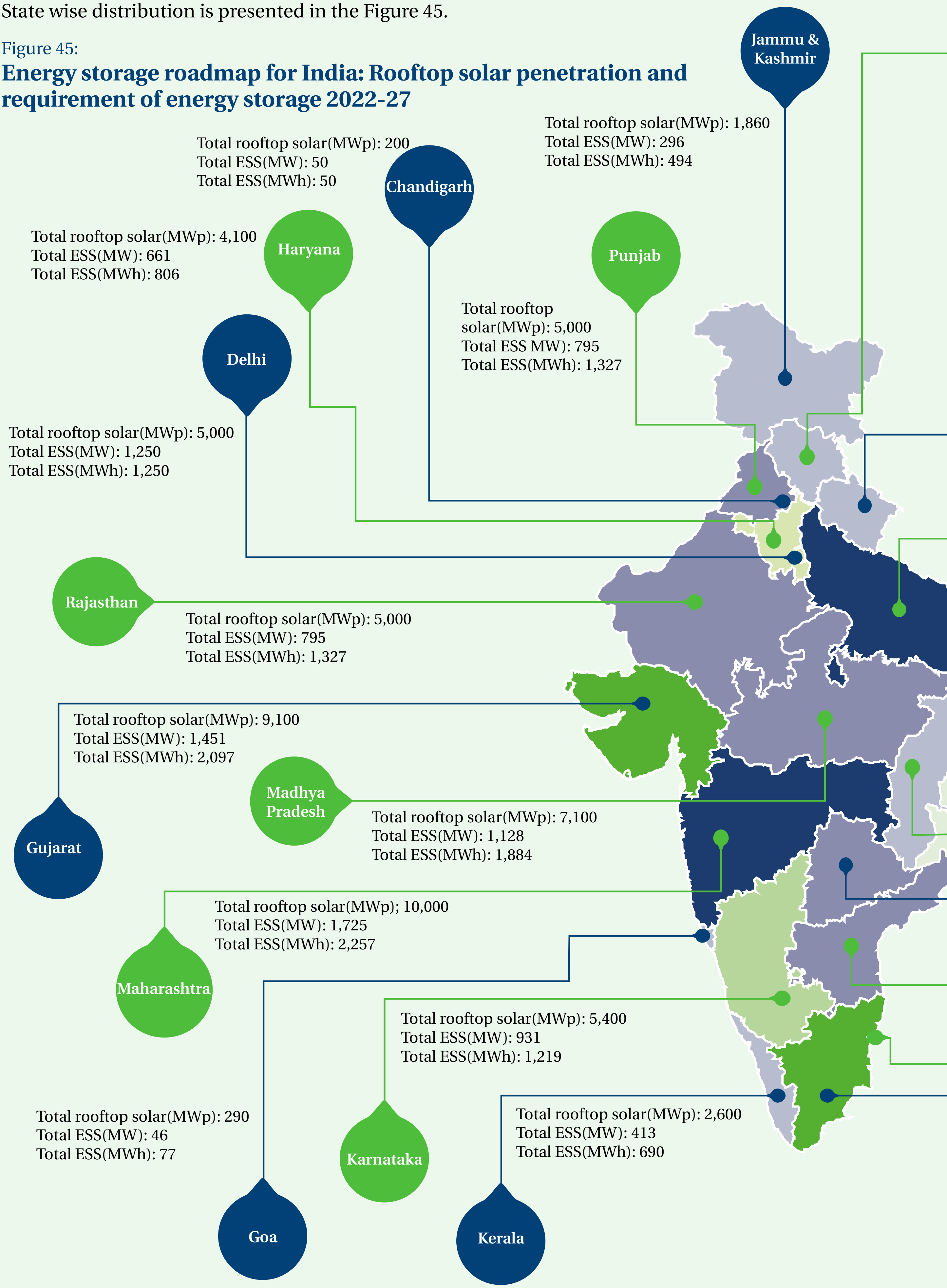
Uttarkhand
Total rooftop solar(MWp):350
Total ESS(MW):55.6
Total ESS(MWh):93
Arunachal Pradesh
Total rooftop solar(MWp):50
Total ESS(MW):8.6
Total ESS(MWh): 16
Bihar
Total rooftop solar(MWp): 1,000
Total ESS(MW):158.9
Total ESS(MWh): 265
Uttar Pradesh
Total rooftop solar (MWp):4,300
Total ESS(MW):631.0
Total ESS(MWh):891
West Bengal
Total rooftop so lar(MWp):2,100
Total ESS(MW):388.5
Total ESS(MWh):538
Jharkhand
Total rooftop solar(MWp):800
Total ESS(MW):127.1
Total ESS(MWh):212
Total rooftop solar(MWp):700
Total ESS(MW):111.2
Total ESS(MWh): 186
Chattisgarh
Total rooftop solar(MWp):2,000
Total ESS(MW):370.0
Total ESS(MWh):512
Telangana
Total rooftop solar(MWp):2,000
Total ESS(MW):317.8
Total ESS(MWh):531
Andhra Pradesh
Total rooftop solar(MWp):3,500
Total ESS(MW):626.0
Total ESS(MWh):812
Tamil Nadu
Odisha
Total rooftop solar(MWp):1,000
Total ESS(MW):158.9
Total ESS(MWh):265

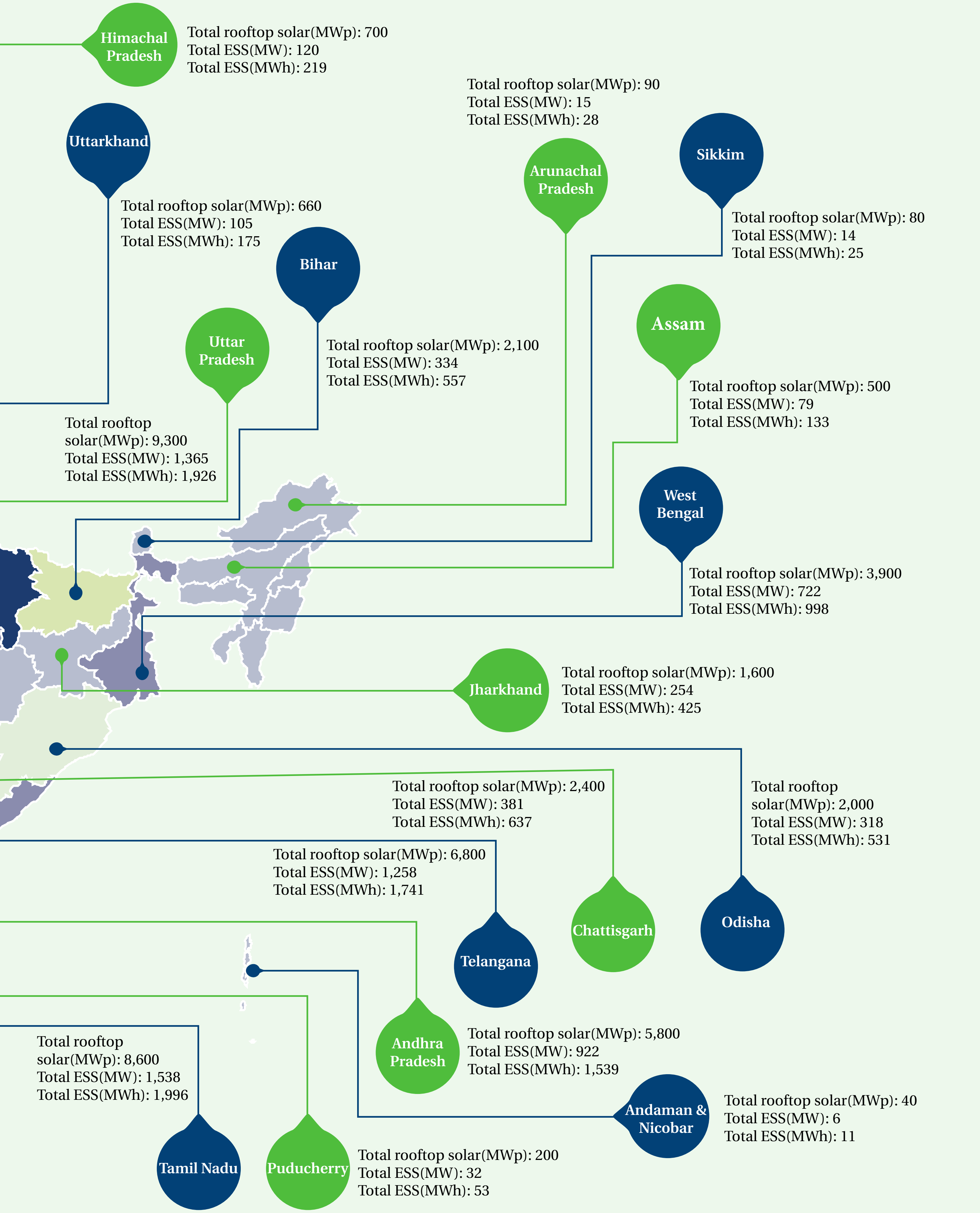
7.1.3 100 GW RTPV on MV/LV Grid by 2027

Total ESS estimated for Integration of 100 GW RTPV by 2027 is 23.01 GWh. State wise distribution is presented in the Figure 45.

Figure 45:

Energy storage roadmap for India: Rooftop solar penetration and requirement of energy storage 2022-27



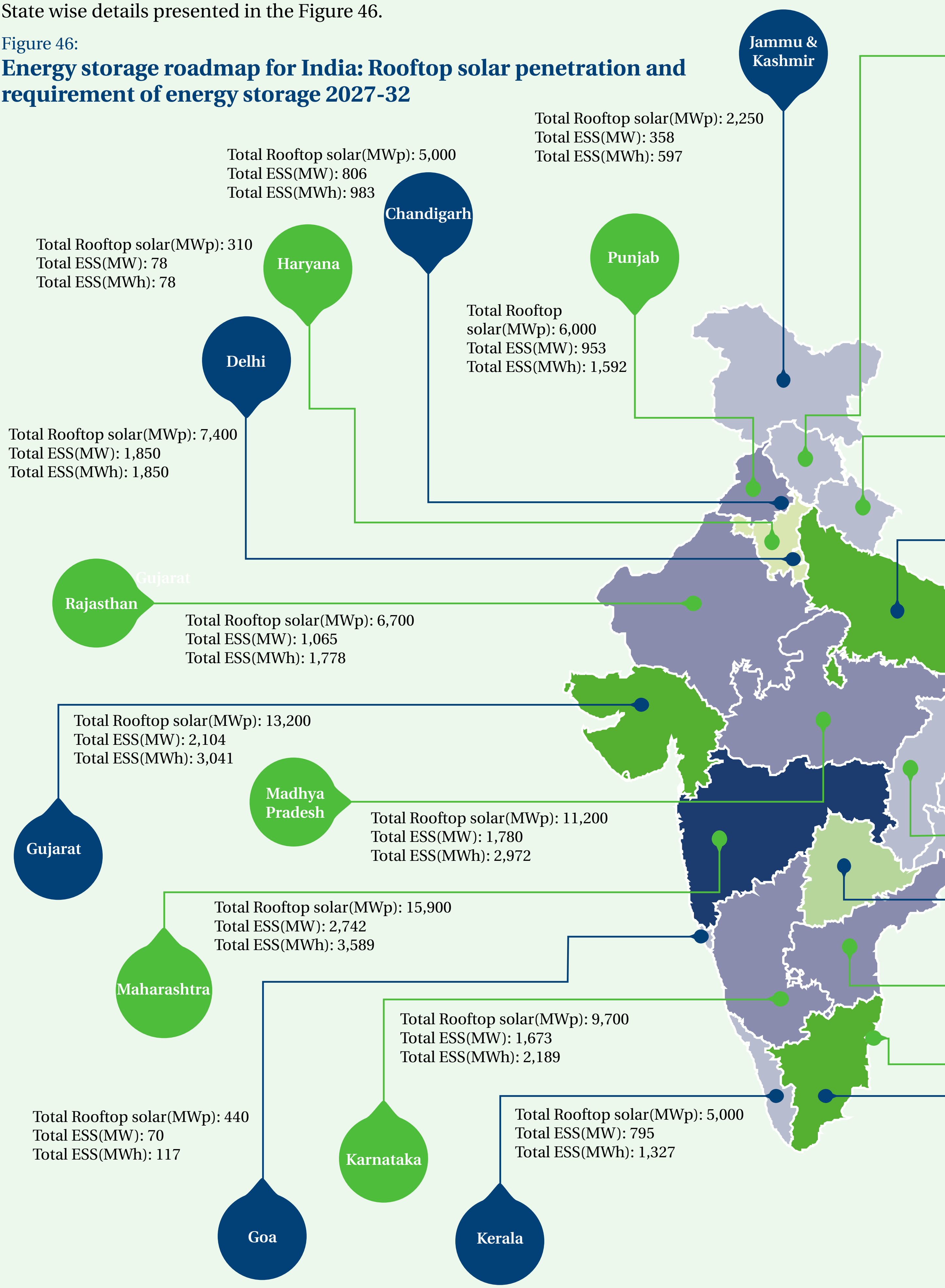

Himachal Pradesh
Total rooftop solar(MWp): 700
Total ESS(MW): 120
Total ESS(MWh): 219
Total rooftop solar(MWp): 90
Total ESS(MW): 15
Total ESS(MWh): 28
Arunachal Pradesh
Uttarkhand
Total rooftop solar(MWp): 660
Total ESS(MW): 105
Total ESS(MWh): 175
Sikkim
Total rooftop solar(MWp): 80
Total ESS(MW): 14
Total ESS(MWh): 25
Bihar
Total rooftop solar(MWp): 2,100
Total ESS(MW): 334
Total ESS(MWh): 557
Uttar Pradesh
Total rooftop solar(MWp): 9,300
Total ESS(MW): 1,365
Total ESS(MWh): 1,926
Assam
Total rooftop solar(MWp): 500
Total ESS(MW): 79
Total ESS(MWh): 133
West Bengal
Total rooftop solar(MWp): 3,900
Total ESS(MW): 722
Total ESS(MWh): 998
Jharkhand
Total rooftop solar(MWp): 1,600
Total ESS(MW): 254
Total ESS(MWh): 425
Total rooftop solar(MWp): 2,400
Total ESS(MW): 381
Total ESS(MWh): 637
Chattisgarh
Total rooftop solar(MWp): 2,000
Total ESS(MW): 318
Total ESS(MWh): 531
Odisha
Total rooftop solar(MWp): 6,800
Total ESS(MW): 1,258
Total ESS(MWh): 1,741
Telangana
Andhra Pradesh
Total rooftop solar(MWp): 5,800
Total ESS(MW): 922
Total ESS(MWh): 1,539
Andaman & Nicobar
Total rooftop solar(MWp): 40
Total ESS(MW): 6
Total ESS(MWh): 11
Total rooftop solar(MWp): 8,600
Total ESS(MW): 1,538
Total ESS(MWh): 1,996
Tamil Nadu
Puducherry
Total rooftop solar(MWp): 200
Total ESS(MW): 32
Total ESS(MWh): 53

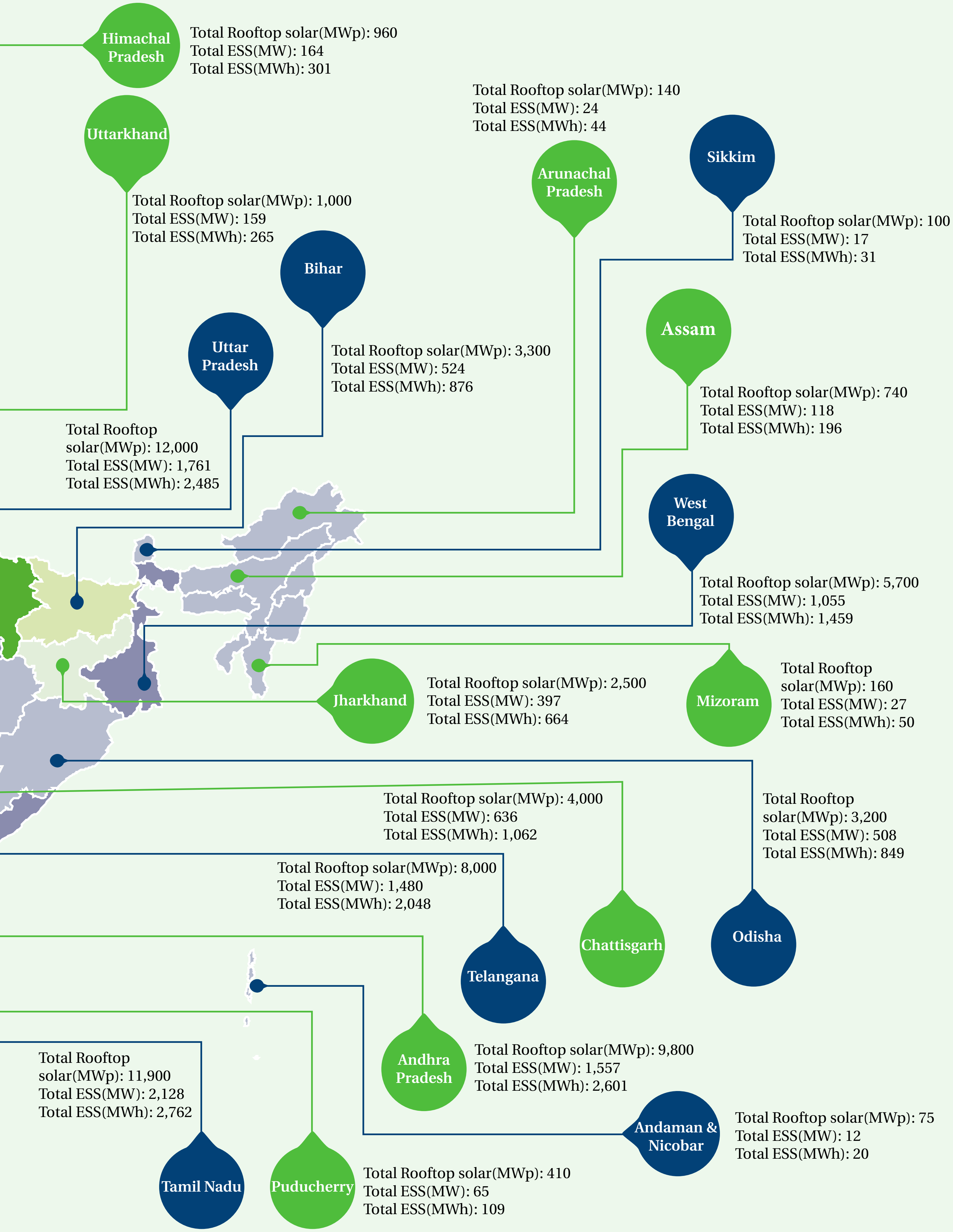
7.1.4 150 GW RTPV on MV/LV Grid by 2032

Total ESS estimated for Integration of 150 GW RTPV by 2032 is 32.675 GWh. State wise details presented in the Figure 46.

Figure 46:

Energy storage roadmap for India: Rooftop solar penetration and requirement of energy storage 2027-32





Himachal Pradesh
Total Rooftop solar(MWp): 960
Total ESS(MW): 164
Total ESS(MWh): 301
Uttarkhand
Total Rooftop solar(MWp): 1,000
Total ESS(MW): 159
Total ESS(MWh): 265
Arunachal Pradesh
Total Rooftop solar(MWp): 140
Total ESS(MW): 24
Total ESS(MWh): 44
Sikkim
Total Rooftop solar(MWp): 100
Total ESS(MW): 17
Total ESS(MWh): 31
Bihar
Total Rooftop solar(MWp): 3,300
Total ESS(MW): 524
Total ESS(MWh): 876
Uttar Pradesh
Total Rooftop solar(MWp): 12,000
Total ESS(MW): 1,761
Total ESS(MWh): 2,485
Assam
Total Rooftop solar(MWp): 740
Total ESS(MW): 118
Total ESS(MWh): 196
West Bengal
Total Rooftop solar(MWp): 5,700
Total ESS(MW): 1,055
Total ESS(MWh): 1,459
Jharkhand
Total Rooftop solar(MWp): 2,500
Total ESS(MW): 397
Total ESS(MWh): 664
Mizoram
Total Rooftop solar(MWp): 160
Total ESS(MW): 27
Total ESS(MWh): 50
Total Rooftop solar(MWp): 4,000
Total ESS(MW): 636
Total ESS(MWh): 1,062
Chattisgarh
Total Rooftop solar(MWp): 3,200
Total ESS(MW): 508
Total ESS(MWh): 849
Odisha
Total Rooftop solar(MWp): 8,000
Total ESS(MW): 1,480
Total ESS(MWh): 2,048
Telangana
Andhra Pradesh
Total Rooftop solar(MWp): 9,800
Total ESS(MW): 1,557
Total ESS(MWh): 2,601
Andaman & Nicobar
Total Rooftop solar(MWp): 75
Total ESS(MW): 12
Total ESS(MWh): 20
Total Rooftop solar(MWp): 11,900
Total ESS(MW): 2,128
Total ESS(MWh): 2,762
Tamil Nadu
Puducherry
Total Rooftop solar(MWp): 410
Total ESS(MW): 65
Total ESS(MWh): 109

Battery market in India for renewable energy applications has been growing steadily with increasing renewable penetration across different segments. Adoption of batteries in solar segment is largely restricted due to high cost of generation of power from solar plus battery system. As the grid tariff surpasses cost of generation from solar plus battery system, consumers tend to be captive user of solar electricity with battery backup instead of feeding the excess power to grid. This shift is expected to begin in as early as 2020. Industries and commercial consumers will be early adopters of batteries under this shift. These early adopters of batteries in industrial segment will be from the states of Maharashtra, Odisha, Delhi, West Bengal, Tamil Nadu, Uttar Pradesh and Karnataka. The adoption of solar PV with batteries, in residential segment will be primarily in Uttar Pradesh, Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra, Jharkhand and Kerala. Though the solar segment offers a huge market opportunity for advanced battery technologies, manufacturers have some ground to cover in addressing technical limitations of batteries such as charging characteristics, thermal performance and requirement of boost current to charge deep cycle batteries. Also, since solar companies may directly procure batteries from manufacturers and require after sale services and technical support, battery companies should have wider presence to address these expectations.

Table 13 presents the ESS requirement for MV/LV grid based on estimated penetration of solar PV (both Ground Mounted and Rooftop) likely to be connected to the MV and LV grid.

Table 13:
Energy Storage Estimations for MV/LV Grid

Estimations	2019	2022	2027	2032
Generation (GW)				
Thermal	209	NA	NA	NA
Hydro	43	NA	NA	NA
Nuclear	6	NA	NA	NA
Solar	26	107	244	349
Ground Mounted Solar	24	68	148	206
RTPV	1.5	40	98	144
Connected to EHV	14	34	66	94
Connected to MV	11	35	84	112
Connected to LV	2	40	98	144
Wind	35	NA	NA	NA
Small Hydro	4.5	NA	NA	NA
Biomass & Biopower	10	NA	NA	NA
Peak Load (GW)	192	333	479	658
Energy (BUs)				
Annual Energy	1192	1905	2710	3710
Storage Recommended (MWh)				
Battery (LV)	241	5908	14617	21484
Battery (MV)	1054	3482	8393	11191
Total (MWh)	**1295**	**9390**	**23010**	**32675**
Approximate (GWh)	**1 GWh**	**10 GWh**	**24 GWh**	**33 GWh**

Note: In congruence with the RE target of 175 GW by 2022, the calculations were done on the basis of 100 GW Solar, out of which 40 GW is RTPV, 20 GW is medium size installations and 40 GW is from large solar parks. Similarly, for 2027 and 2032, the ratio of RTPV was taken in accordance with the 2022 targets constituting of 40% RTPV of the total solar installed capacity. All the values for 2027 and 2032 have been forecasted using the best available data in public domain.

7.2 Energy Storage for EHV Grid

Large solar and wind farms are connected to the extra high voltage (EHV) transmission grid. In the Green Corridor Report prepared by POWERGRID in 2013, it was recommended to have 500 MWh energy storage for integration of 31,000 MW of renewable energy. Thereafter, no detailed studies have been conducted by POWERGRID or CEA on ESS requirements at EHV grid level. IESA estimates ESS for EHV grid support is presented in Table 14.

Table 14:
Energy Storage e-Mobility Applications (IESA Estimates)

Year	Renewable Energy Generation connected to EHV Transmission Grid (GW)	ESS Requirements (Estimate) (GWh)
2022	120	7
2027	150	38
2032	200	97
Total upto 2032	**470**	**142**

Note: No detailed modelling studies have been conducted yet for this segment.

7.3 Energy Storage for Electric Mobility

With the launch of National Mission for Transformative Mobility, India is anticipated to witness significant growth in EV penetration in next decade. Already, the market is witnessing significant penetration of Electric 3W vehicles in Tier 2 and Tier 3 cities as they offer greater economic returns to the commercial vehicle operators. India has also in past couple of years started to see growing interest in commercial electric 2W and 4W operations for segments such as employee transport and logistics.

Till 2022, E3W segment driven by e-Rickshaws will lead the demand for batteries for EVs in India. With the rapid cost reductions anticipated due to global scaling up of LiB manufacturing capacity as well as anticipated launch of Giga-scale LiB factories in India, it is expected that this trend will accelerate from 2023 as the reduced total cost of ownership for most user segments will drive adoption of EVs in the country. If the current trend continues, then beyond 2025, even the upfront cost of the new EVs for 4W category might match or beat the cost of ICE vehicles. Table 15 presents projections developed by IESA for various EV categories. The market projections are done with respect to various policy uncertainties.

Table 15:
Energy Storage for Electric Mobility Applications[34] (IESA Estimates)

Applications	Battery Requirement for EV (GWh)			
	2019-2022	2022-2027	2027-2032	Total by 2032
E2W	4	51	441	496
E3W	26	43	67	136
E4W	8	102	615	725
Electric Bus	2	11	44	57
Total Electric Vehicles (GWh)	**40**	**207**	**1167**	**1414**

[34] Different electric vehicles were presumed to penetrate sales for 2030 and 2032. For E2W, it is presumed that sales will penetrate by 40% by 2030, while the penetration by 2032 will be around 60%. The penetration of sales in the event of E3W is presumed to be 45% by 2030. The sales penetration will be comparable for the E4W and e-Bus instances, i.e. 50%. Sales penetration for E3W, E4W and Buses will rise up to 70 percent as a result of advancing technology and consciousness among individuals, according to the CES analysis.

7.4 Energy Storage for Telecom Towers

India is the second largest wireless phone market with over 1.19 billion users in the country as per data released by Telecom Regulatory Authority of India (TRAI) in 2018. Total telecom towers installed in the country crossed 550,000 in 2018. Indian government intends to improve the tele-density in the rural areas to over 70%. Telecom companies are planning to expand their services in rural areas, where the dependence on DG sets for power backup is a significant cost for the telecom companies. With the growing grid availability in rural areas, telecom companies are expected to rely more on the ESS installations and use DG sets only for extended outages.

Telecom market will also witness mixed growth scenarios with reducing the size of the backup batteries through introduction of advanced ESS systems as well as due to improving grid availability in urban and semi urban areas. At the same time, the growing tele densities and move for more data services will require higher number of 4G and 5G telecom tower deployment, thus increasing the number of ESS units sold to the telecom sector.

Table 16 provides projections developed by IESA on the expected market size for telecom tower segment.

7.5 Energy Storage for Data Centers UPS and Inverters

The market for inverter back-up power witnessed a consistent growth from 2013 till 2017. In 2018, this segment held the highest market share of nearly 13 GWh of energy storage in India. With urban market getting stagnant mainly on the residential front, major market growth is expected in Tier 2 and Tier 3 cities as well as rural areas. Small commercial activities and residential demand, which is not big at present but is surely making the major battery players divide their attention towards rural and remote areas. This market segment is currently dominated by various lead acid technologies and its growth is attributed to the power deficit/ unreliability scenario in the country.

The market for UPS back-up power has witnessed a consistent growth of around 8% per year in the last decade and held a market share of 2.7 GWh in 2018. During the past year, grid supply reliability has improved which has affected the rate of growth of this market segment but has not dwindled the size. The UPS is mainly considered for critical situations where a miss of micro-second in supply could cause larger losses. IT enabled and Data Center segment continue to be the largest user for UPS. Increasing use of IOT in the manufacturing sector is booming, and this is contributing to the increased application of UPS back up, besides, the introduction new manufacturing technologies in the evolving Industry 4.0 era.

Recent and anticipated cost reduction of advanced storage technologies as well as improved energy densities is opening up opportunities for advanced energy storage technologies for particularly UPS applications in C&I segment. We anticipate that overall this market will remain a steady market for ESS as the growing user base will be balanced by

Table 16:
Energy Storage Telecom Applications (IESA Estimates)

Applications	Energy Storage (GWh)			
	2019-22	2022-2027	2027-2032	Total by 2032
Telecom Towers	25	51	78	154

reduction in the backup duration and also the size of ESS systems due to abilities of newer ESS technologies for deeper cycling (thus reducing the effective size of the system required for backup). Also, improved cycle life of newer technologies can also result in reducing the market for replacement of batteries by allowing UPS batteries to last for 5-10 years versus the life of 3 to 5 years for lead acid battery.

Table 17 provides summary of the projections made by IESA for ESS applications in data centers, UPS and Inverters segments.

Table 17:

Energy Storage for Data Centres, UPS and Inverters Applications (IESA Estimates)

Applications	Energy Storage (GWh)			
	2019-22	2022-2027	2027-2032	Total by 2032
Data Centres, UPS and inverters	80	160	234	474

7.6 Energy Storage for DG Set Replacement

With the growing concern about rising cost of power from diesel generating sets (DG sets) as well as associated air pollution, Commercial & industrial (C&I) customers depending on DG sets for reliability can switch over to renewables with storage. Falling solar module and battery storage prices can accelerate this decision making. Presently, ATM booths, petrol bunks, road toll plaza's and off grid industrial units are considered as the potential users who are likely to switchover to the storage technology in the short term.

Although growing reliability of electricity distribution networks due to increased supply can reduce usage of DG sets, there are other opportunities emerging for ESS for C&I customers. The Levelized Cost of Electricity (LCOE) from RE + Storage for C&I customers is expected to become lower than the grid tariff for C&I electricity tariffs in many states in the country in coming 5-10 years.

We anticipate that in most cases, customers may still retain the DG set for backup for unforeseen longer duration outage, but the usage of these assets can reduce substantially from the current levels of 500-1000+ hours/year for many users.

Table 18 provides summary of projections developed by IESA for ESS potential for DG Usage Minimization.

If new policies ban usage of DG sets in urban areas and enforce its implementation strictly, there will be huge opportunities for ESS which will be in excess of 100 GWh.

Table 18:

Energy Storage DG Applications (IESA Estimates)

Applications	Energy Storage (GWh)			
	2019-22	2022-2027	2027-2032	Total by 2032
DG Usage Minimization	0.5	3.5	10.5	14.5

7.7 Energy Storage for Other >1MW Applications

Apart from the key applications discussed, there are various additional user segments such as Railways, Rural Electrification that will generate additional demand for energy storage in India.

We also anticipate need for thermal storage solutions to meet the growing usage of Heating Ventilation and Air Conditioning (HVAC) in India, particularly for urban areas as well as for cold storage facilities around the country.

Below is a summary of anticipated demand for ESS for these segments as estimated by IESA.

Table 19:

Energy Storage Miscellaneous Applications (Railways, Rural Electrification, and HVAC applications)

Applications	Energy Storage (GWh)			
	2019-2022	2022-2027	2027-2032	Total by 2032
Miscellaneous Applications (Railways, rural electrification, HVAC application)	16	45	90	151

7.8 Consolidated Energy Storage Roadmap for India

Table 20:

Consolidated Energy Storage Roadmap

	Consolidated Energy Storage Roadmap					
	Applications		Energy Storage (GWh)			
	2019-2022		2019-2022	2022-2027	2027-2032	Total by 2032
Stationary Storage	Grid Support	MV/LV	10	24	33	67
		EHV	7	38	97	142
	Telecom Towers		25	51	78	154
	Data Centres, UPS and inverters		80	160	234	474
	Miscellaneous Applications (Railways, rural electrification, HVAC application)		16	45	90	151
	DG Usage Minimization		-	4	11	14
	Total Stationary (GWh)		138	322	543	1,002
Electric Vehicles	E2W		4	51	441	496
	E3W		26	43	67	136
	E4W		8	102	615	725
	Electric Bus		2	11	44	57
	Total Electric Vehicles (GWh)		40	207	1,167	1,414
Total Energy Storage Demand (GWh)			**178**	**529**	**1710**	**2416**

8 Policy and Tariff Design Recommendations

The benefits of grid-level energy storage cover a wide gamut of services—energy time-shift, ancillary services, making renewable energy dispatchable, deferring transmission and distribution upgrades, and others. These benefits cannot be realized unless investments in energy storage can yield returns that are commensurate with similar investments in the power sector. Return on investments can be obtained only if policies related to tariff, licensing, and other aspects of the power sector are in place.

Tariffs

Sustainable development of energy storage will not occur unless tariffs for the various services provided by energy storage are established, and the tariffs are sufficient for energy storage investors to recover cost and make an acceptable return on investment. Each type of service provided by energy storage should have a tariff. Setting tariff is a difficult problem requiring the balance between the quantifiable benefit of a service and the cost of the service. For example, the benefit of peak-shaving can be quantified in terms of the following factors:

- Tariff for electricity hour-by-hour at peak time, amount of energy supplied to grid by energy storage hour-by-hour at peak time
- Tariff for electricity hour-by-hour at off-peak time, amount of energy used for charging of energy storage hour-by-hour at off-peak time

If an energy storage project can provide reactive power (voltage support) services and frequency support services, in addition to peak-shaving service, then the benefits-based tariff approach to energy storage projects may be financially feasible. Since the number of hours each service is provided is different and tariffs of each service are different, the financial model is complex.

The intention of this benefits-based tariff approach is to demonstrate that policy makers must consider the totality of services that energy storage can provide and assign tariffs for each service because an energy storage tariff for a single service is unlikely to make projects feasible.

An approach to determining the value of energy storage as a sum of operational and capacity values is proposed by the National Renewable Energy Laboratory, USA. The operational value is determined by comparing the difference in production costs with and without storage, which is done by using production simulation software like PLEXOS, PROMOD or PROSYM. There are three components to the operational value of energy storage: ***regulation reserves, spinning reserves, and load levelling (energy price arbitrage)***. In general, regulation reserve has highest value followed by spinning reserves, while load levelling has the lowest value; however, the relative value is grid-specific. Although in general, regulation reserve has the highest value, the market potential is smaller because the need is for fewer hours.

Capacity value, the second component of the value of energy storage, on the other hand, cannot be estimated using simulation because the value of providing firm system capacity cannot be accounted for in a simulation. Note that capacity value depends on the need for additional capacity to provide adequate planning reserve margin: If a system has sufficient planning reserve margin, then the capacity value of energy storage would be zero. However, this is rarely the case in developing markets, where demand exceeds supply during peak hours. In such cases, energy storage provides an alternative to construction of new peaking resource. Overall, the National Renewable Energy Laboratory report concludes that the value of energy storage is largely dependent on it obtaining a capacity value, even if the device is providing higher-value reserve services.

Table 21:
Components of Benefits of Energy Storage

Benefit of Energy Storage	Method of Estimation
Operational Value	
Load Levelling (Energy Arbitrage)	Use dispatch simulation to calculate operational savings—fuel cost and avoid unit starts. Subtract cost of energy used to charge energy storage and losses
Spinning Reserve	
Regulation Reserve	
Capacity Value	Avoided cost of adding reserve capacity

This approach would set the tariff for storage based on accounting of the benefits (sum of operational and capacity values) to the grid of the services provided by energy storage. The following benefits should also be added to compute the overall benefits:

- Avoided cost of greenhouse gas emissions, which would be in grids with renewable energy. The accounting of this would need to be done with care to avoid counting the benefits twice—renewable energy generation and energy storage. One approach is to assign a benefit to energy storage only when there is curtailment of renewable energy generation
- Local environmental benefit, which would be in grids with renewable energy. Same considerations apply as the avoided cost of greenhouse gas emissions
- Energy security, when energy storage enables a grid to use the energy source with the lowest marginal cost of production and avoid use of the highest marginal cost source. For this reason, energy storage cushions the grid from increases in fuel prices that contribute to the highest marginal cost of production

A tariff for energy storage that is less than or equal to the sum of the benefits would be economically prudent.

It is worth noting that there is a lack of research and data related to value of energy storage in grids with a large penetration of renewable energy.

Role of Government and Regulators

Often there is resistance among traditional utilities to transition to new technologies and new methods of operating and managing the grid, which is required with high penetration of variable generation. The push therefore has to come from policy makers and regulators. The imperative for push is further accentuated by the fact that although there are substantial benefits of energy storage to the grid, they are often difficult to quantify; For example, improvement to power quality, reliability, resiliency, energy security, and efficiency gains. The case for governments and regulators to play a leading role in development of policies is therefore clear.

Guidelines for Policies

The following policy prescriptions are recommended for encouraging deployment of energy storage:

i. Integrate energy storage into overall energy master plan and energy strategy. This clarifies the role of energy storage and begins the conversation about competing methods to provide the multitude of services required by the grid
ii. Enable energy storage to qualify for multiple streams of revenue for the individual services it provides to the grid
iii. Introduce time-of-use tariffs, pay-for-services tariff, and others to eliminate price distortions and increase price transparency
iv. Incentivize development and financing of energy storage and distributed renewable energy projects
v. Support in a targeted manner, demonstration projects and first movers with loan guarantees, low interest loans, grants, and others. A note of caution: policies and incentives should not be technology-specific

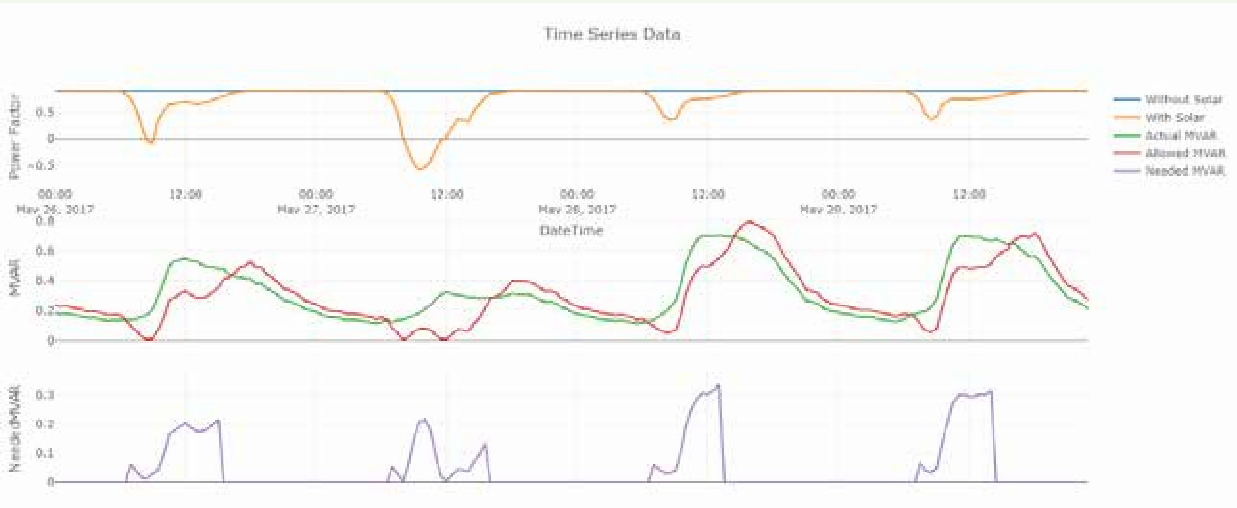
8.1 Power Factor Correction

PF correction has been a challenge so far as all the RTPV are injecting power at 1 PF (unity power factor), which accounts for lowering of real net load (only in terms of kW, with reactive load remaining constant). Allowing offsetting of power factor for rooftop PV can help both in reduction of losses and voltage control.

Germany, California and Australia – have introduced requirements for RTPV to be able to operate at offset power factors. In Germany, for example, units above 3.68 kWp must be able to realize power factors between 0.95 capacitive and 0.95 inductive and adhere to a Q(U) characteristic which is set by the grid operator based on the grid characteristic.[35]

Requirement of reactive power from ESS can be much lesser in case RTPV is allowed to inject power at 0.95 or 0.9 lag power factor. The effect of injection of solar generation at unity power factory can be seen in Figure 47. As seen in Figure 48, the requirement for MVAR is almost halved

Figure 47:
Solar Injection at Unity Power Factor (Source: CES analysis)



[35] Analysis of Indian Electricity Distribution Systems for the Integration of High Shares of Rooftop PV report (by GIZ)

Figure 48:
Solar Injection at 0.95 Power Factor (Source: CES analysis)

from 0.2 MVAR to 0.1 MVAR as the injection of RTPV is changed from unity power factory to 0.95 lagging power factor. In the following cases the size of solar RTPV is considered as 70% of the peak load.

In India, Maharashtra, Tamil Nadu, Gujarat and Karnataka are paying a large amount for PF penalty as these states strict mandate on PF.

It can be observed from Table 22 that how much PF penalty customers in these particular states are paying .The PF penalty charges are either linked to per unit electricity charges at different power factor slabs or are linked to kVAR consumed by customers if the power factor is lower than a specific target. Thus, installation of storage can help these states to maintain a constant PF after penetration of solar.

Table 22:
Savings on PF penalty

Peri-Urban industrial	Penalty per 0.01 change in PF *	Assumed Feeder Capacity (MVA)	Assumed RTPV (in MW) 20% of feeder capacity#	Target PF	ESS Required as % of Feeder capacity	PF penalty savings (INR Cr)
Maharashtra	1% of per unit tariff	2.9	0.58	0.9	10%	0.979
Gujrat	1% of per unit tariff	2.9	0.58		10%	0.428
Tamil Nadu	1% of per unit tariff	2.9	0.58		10%	0.823
Karnataka	3 Paise per kVARh	2.9	0.58		10%	0.027

*If PF is less than 0.9; #RTPV injection is assumed at unity power factor

As seen from Table 22, PF penalty is highest in industrial states of Maharashtra, Gujarat and Tamil Nadu. Hence, as most of the other states would experience reduction in PF with increase in inductive and electronic load, they would need to adopted similar power factor penalties. Increment in penetration of RTPV would only make the case worse in all these states. Hence, a review of power factor at which RTPV is generating is very much required which can be followed by adoption of smart inverters and ESS.

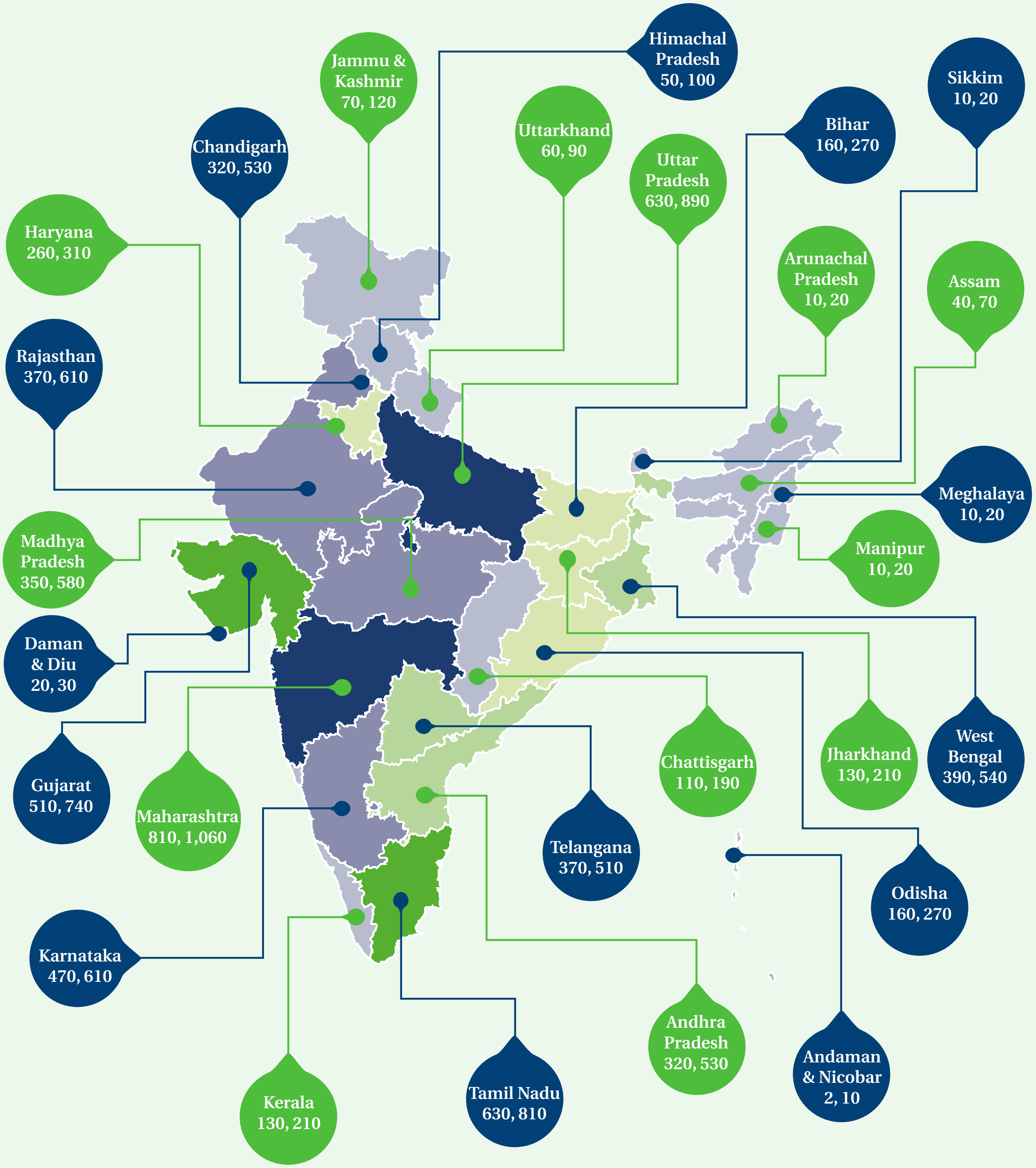
Figure 49:

India roadmap for solar and storage for concentrated penetration of solar PV

ESS MW, ESS MWh

RTPV Penetration

10 — 4,700



8.2 Energy Storage Roadmap for 40 GW RTPV Integration

Achieving RTPV targets will have a lot of challenges across the nation. However, with a little planning and defining right feeders which can take higher penetration of RTPV, a lot of the challenges can be tackled. Germany on its way to 43 GW solar PV by end of 2017, had 98% of the capacity connected to distribution grid[36], a similar story will be witnessed by India on its way to 40 GW RTPV installation. As the grid was seeing effects of high solar PV penetration in distribution grid in Germany, many interventions had to be made like derating of generation below 10 kW to 70% of the rated capacity, firmware upgrade of over 10 GW of inverters to respond to new grid codes, which had budget implications of over 300 million Euros on the country and lastly introduction of smart inverters. It is understood that one out every second house to install RTPV in Germany in Q1 2019, also installed energy storage.

As per Government target, Maharashtra has highest percentage of solar penetration followed by Uttar Pradesh and Tamil Nadu. This study has assumed that solar penetration for residential feeder or DT will vary in 10%-40%, due to rooftop space constraints whereas for commercial and industrial consumer it can vary between 20%-70% and 20%-90% depending upon metro or non-metro scenarios, considering lower FSI and low peak power to roof space ratio in non-metro spaces allowing possibility of higher penetration in these rooftops.

After splitting the rooftop solar target, the report has optimized the energy storage requirement based on low and high feeder penetration of solar penetration in all the different cases. (Figure 50). On the other scenario, it is assumed that solar penetration will be concentrating to one place thus requirement of storage will be more for that. As per CES analysis, the storage requirement for base case scenario will be around 6 MW/9MWh whereas for best case scenario, total storage requirement will be around 19 MW/21 MWh.

8.3 Regulatory Changes and Suggestions to Maximize RTPV

The availability and usage (and hence value) of rooftops differ widely between industrial, commercial and residential consumers. The following variables impact RTPV investments (with or without storage) on a given rooftop:

- Economic benefits (tariffs) to self-consume, shave peaks, time-shift or sell to grid
- Available free rooftop space (potential RTPV capacity)
- Other uses of the rooftop (e.g. multifamily and social uses in residential rooftops)
- Consumer load pattern
- Grid power quality requirements
- Capital cost of investments
- Operating costs of investments

The industrial sector which has the largest unencumbered rooftop space and coupled with a strong focus on profitability/economic benefits, becomes the best candidate to maximize RTPV. Further, given their light steel structures, the rooftop cannot be used for most alternatives/secondary uses. This bodes well for RTPV.

The commercial sector has large rooftop space as well, but sees competing economic benefits for its use. For example, malls have outdoor rooftop restaurants, hotels have pools/bars/outdoor cafes on their rooftop. In hospitals, the many HVAC units, breaks up contiguous space for RTPV. Others have rooftop parking. So, while the commercial segment has large rooftop space and is strongly focused on economic benefits, the RTPV needs to show them a better ROI.

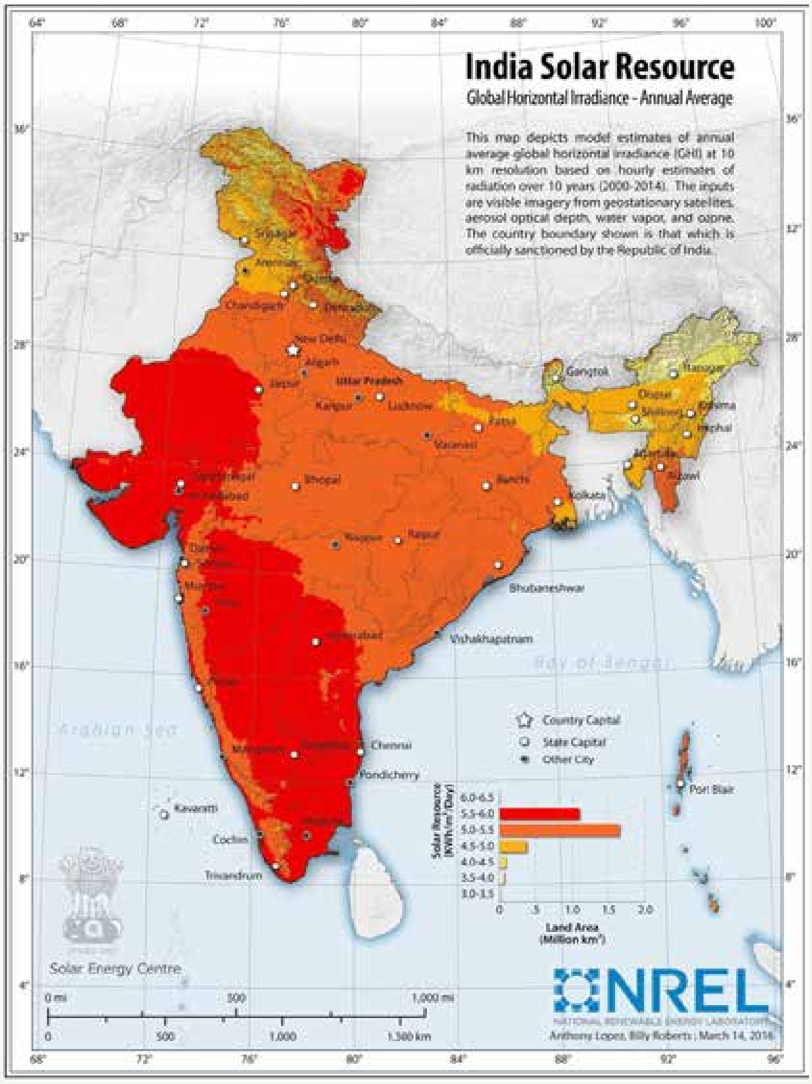
[36] Recent Facts about Photovoltaics in Germany by Fraunhofer ISE

The residential sector has the scarcest rooftop space and hence values its ***"barsati"*** as premium outdoor space for social/family uses (cool summer evenings and warm winter daytime). Only a minimal area is occupied by water tanks (a key household requirement). The rest is free open social space. The RTPV has to compete (both qualitatively and economically) against this value stream. Also, its design features need to incorporate ***"movability"*** (when not needed), so that the open social space can be enjoyed. The residential sector is the most challenging for RTPV penetration/incentivization for this reason and other power quality issues outlined in earlier sections.

Any and all regulatory changes to incentivize RTPV (with or without storage) must recognize these aspects and provide sectoral incentives if RTPV is to me maximized. No one-size fits all approach will work is required.

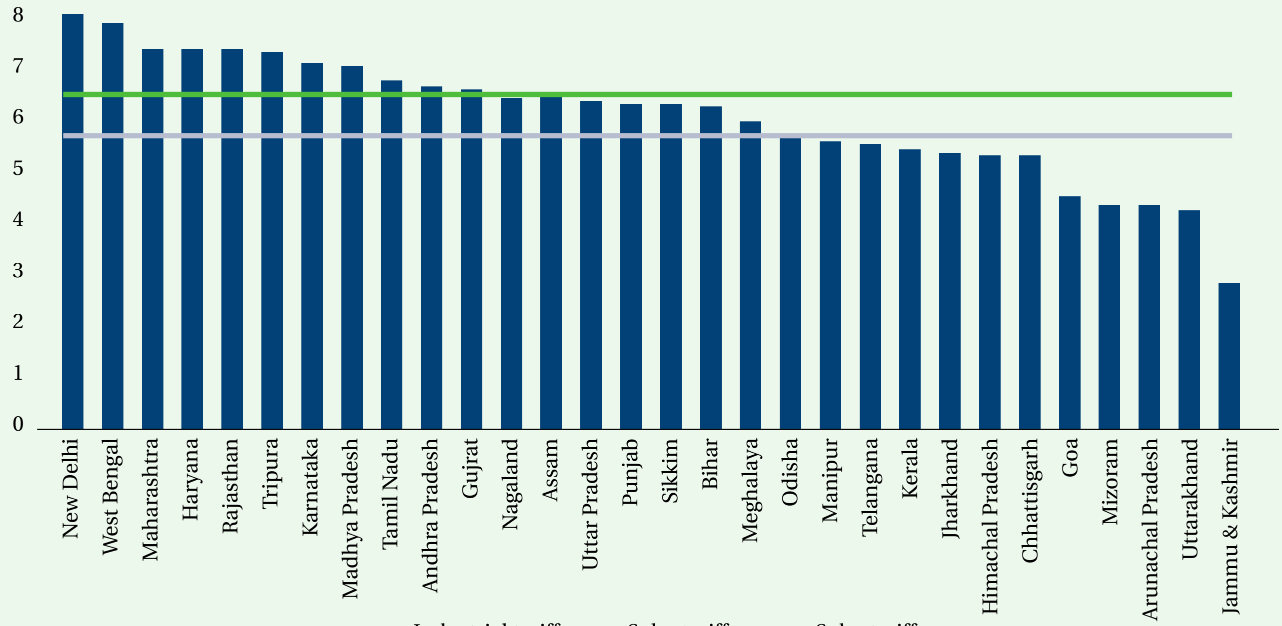
The regulatory incentives (just merely from an electricity tariff perspective) leaves much more work to be done. The alignment between (1) Tariff structures (industrial, commercial, residential); (2) The structure (Feed-in-tariff, Net Metering, Demand Charge, Time-of-Use, Peak Pricing, other); (3) The available country solar resource; (4) Urban concentration; and (4) The per capita consumptions (by State) are not aligned to maximize RTPV. The following graphs illustrate these.

Figure 50:
Global Horizontal Irradiance of India



Case 1:

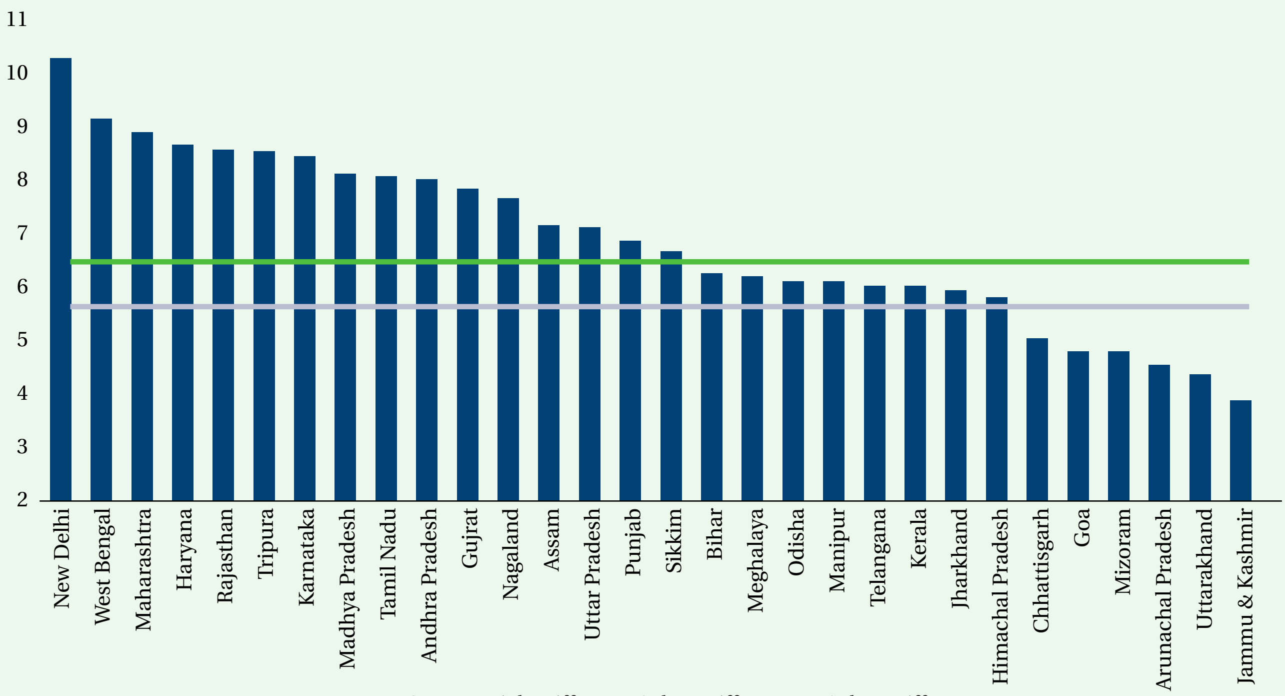
Industrial Consumers-Utility Tariff & Rooftop Solar Energy Tariff



The high industrial tariff is not high enough to attract RTPV except in a few states and certainly non commensurate with available solar resources.

Case 2:

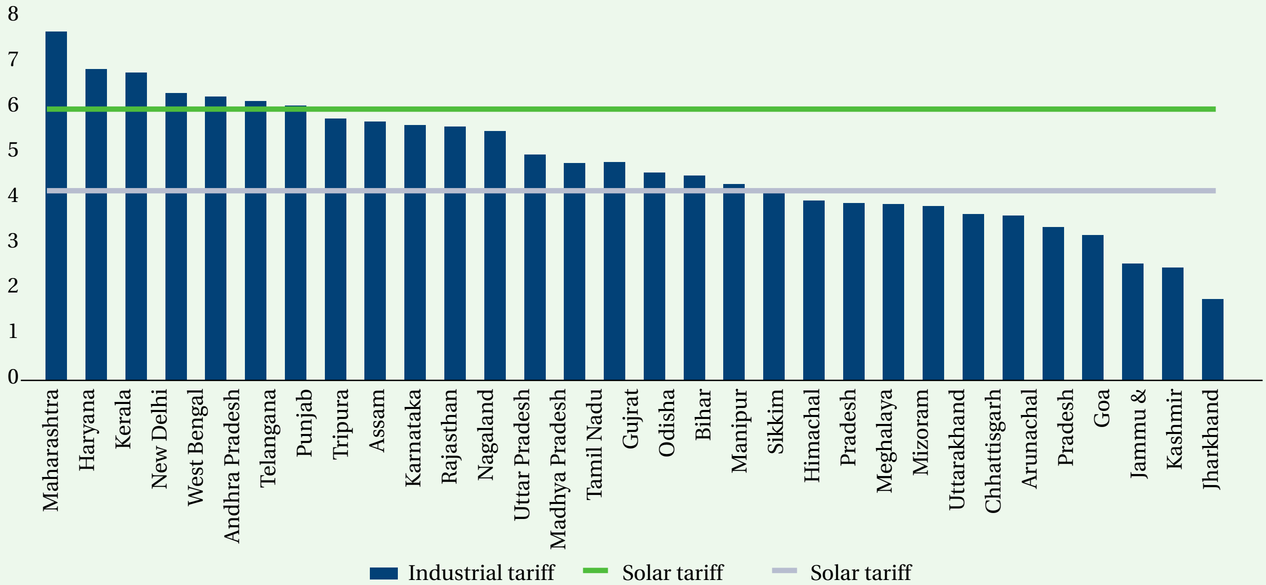
Commercial Consumers-Utility Tariff & Rooftop Solar Energy Tariff



The high commercial tariff offers the best incentives for net metering, load displacement and time-shifting but Maharashtra and Gujarat are not incentivized enough despite having excellent solar resources.

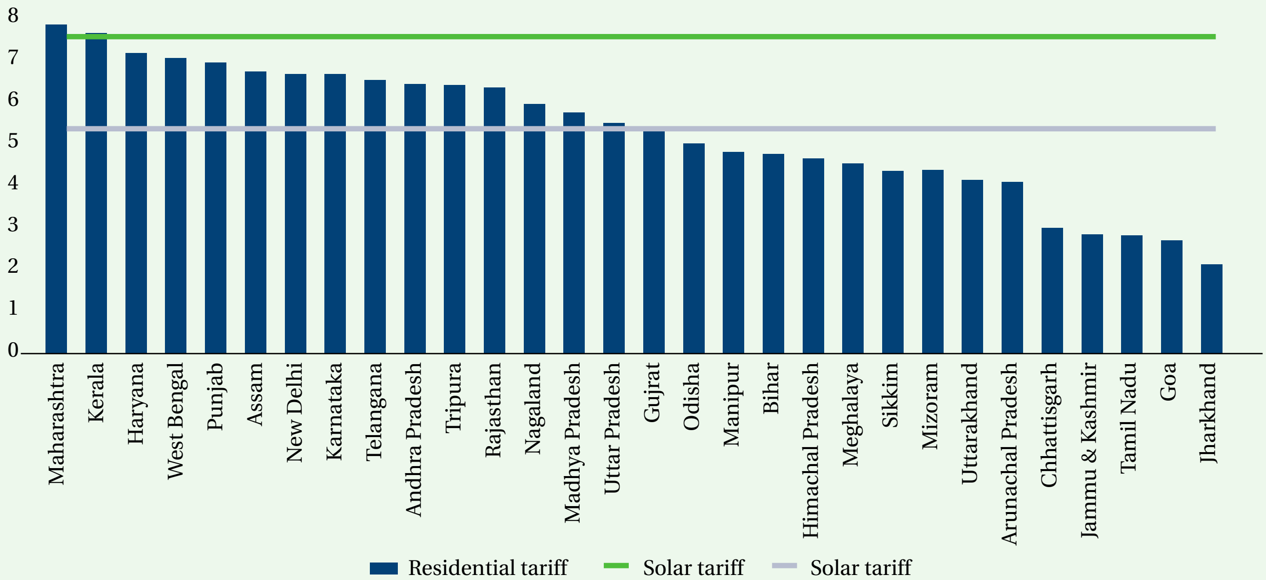
Case 3:

Residential Consumers<1000 units-Utility Tariff & Rooftop Solar Energy Tariff



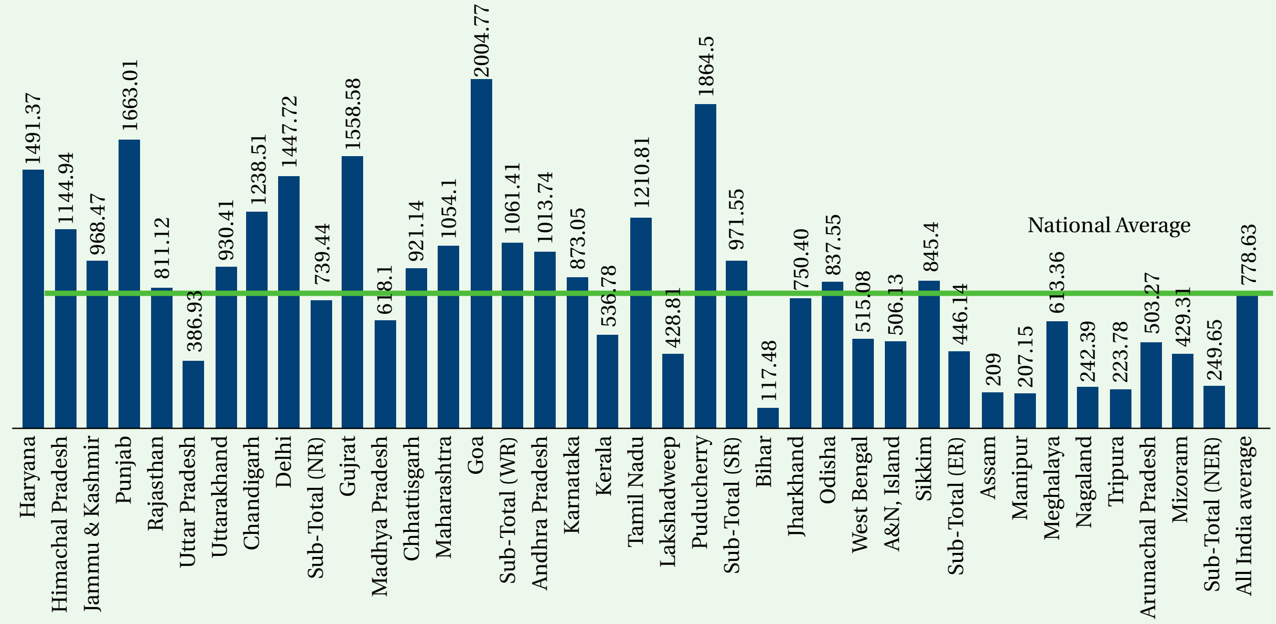
Case 4:

Residential Consumers<500 units-Utility Tariff & Rooftop Solar Energy Tariff



Case 5:

Per Capita Consumption of Electricity (kWh)



The residential sector offers tremendous room for innovative regulatory reforms for incentivizing RTPV.

The high per capita consuming states/union territories that coincide with high solar resource are Goa, Puducherry, Tamil Nadu, Maharashtra, Gujarat, Chandigarh and Delhi. Except for Delhi and Maharashtra, all the others have lower energy tariffs than solar tariffs thereby offering no incentives for self-consumption (or net metering). The best incentive in such cases is perhaps to offer feed-in-tariff incentives (to sell all their RTPV solar power at a higher price).

In majority of these categories of RTPV, across period of 2020-2025, adding energy storage is making sense commercially, as it is able to capture multiple value benefits namely:

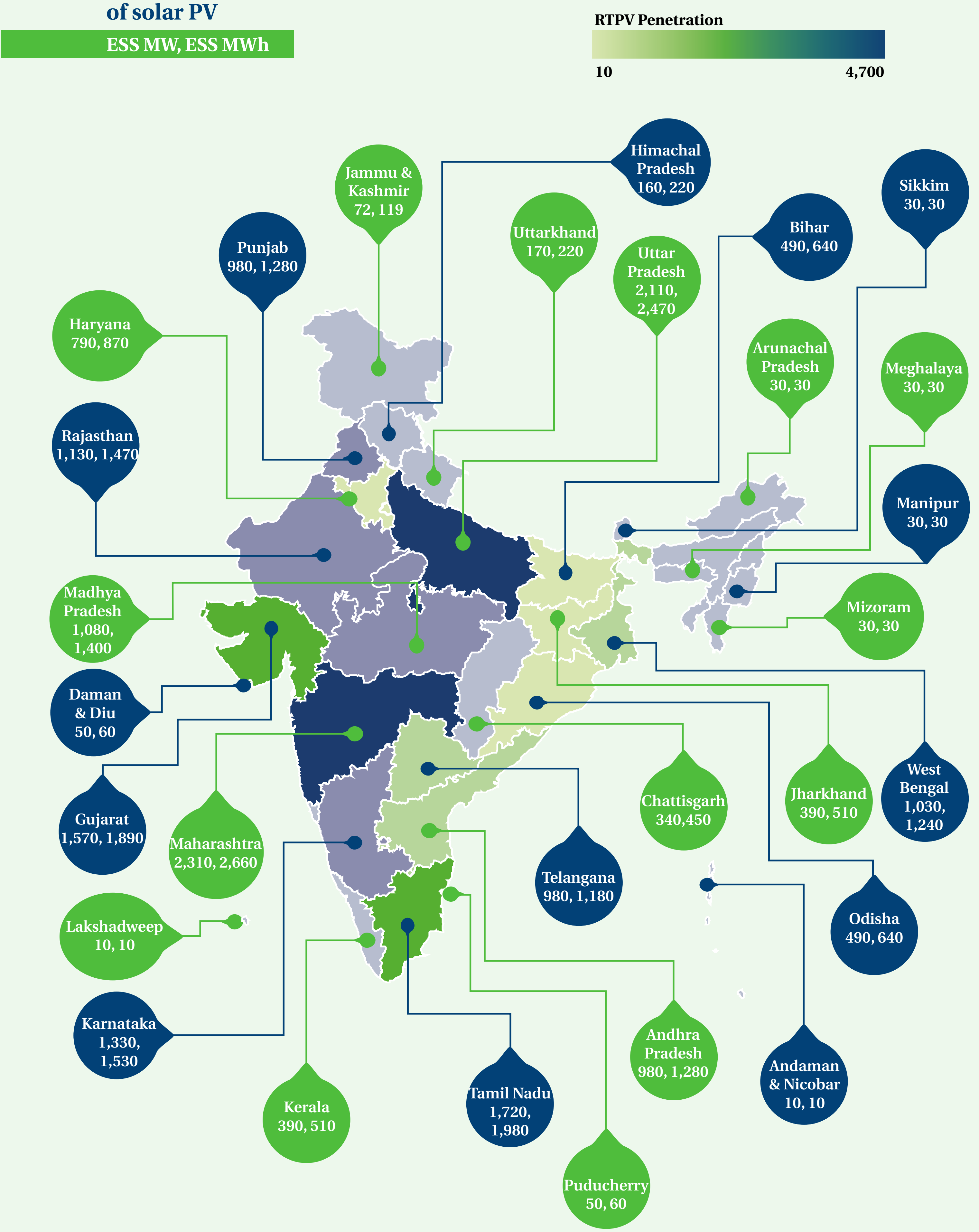
- Distribution deferral,
- Power factor correction,
- Electricity savings and
- Diesel optimization/Penalty savings (as there is a likelihood of distribution companies getting penalized for reliability issues).

However, only Li ion technologies like Lithium NMC and Lithium Iron Phosphate (LFP) are making commercial sense as they are available at competitive prices in the Indian market along with promising warranties and performance parameters.

Figure 51:

India roadmap for solar and storage for distributed penetration of solar PV

ESS MW, ESS MWh



8.4 Business Models for ESS Operations (Regulated and Non-Regulated Behind the Meter Applications)

Asset Owner/Operator/Service business models have been around in power systems for some time now. These include both within the regulated utility area as well as in the non-regulated industrial/commercial (behind the meter).

For example, the utilities regulated area include Meter Service Providers (MSP), Station Maintenance, energy aggregators, DSM providers, and merchant transmission line owners/operators. Examples in the non-regulated area include industrial plant maintenance, independent power producers, ESCOs, energy efficiency providers, etc.

In each of the above business models, one or more of the following chain-link relationship is offered with the rest de-risked through partnerships:

In the past, all these functions (except equipment manufacturing) was all in the sole hands of vertically integrated utilities. This was true for large conglomerates as well. This all-inclusive control allowed for better management of these assets. All these changed in the late nineties with the rise of specialist businesses who were able to offer better value streams on a disaggregated basis than before. It began with asset-based lending and quickly moved to services as well.

The regulatory system has come to recognize and accept these newer business models and have framed rules since the early 2000s for the active participation of these player. The Meter Service Providers (MSP), Field O&M services, Energy Aggregators, DSM Aggregators, and Energy Efficiency (ESCO services) are some of the largest areas in the regulated space. The non-regulated (behind the meter assets), have traditionally outsourced O&M services for captive industrial plants.

Regulated ESS Business Models:

Energy Storage Systems (ESS) is just one more power class asset added to the list, but it comes with a few twists:

- It requires both Generation and Consumer licenses (charge-discharge functions) to own/operate these in generation, transmission and distribution
- Operate under a two-part tariff system to discharge (generator) and charge (load)
- Get paid only when they are discharged for energy/ancillary functions (no insurance premiums)
- Not being able to recover their investment in 8-10 years but over 20-25 years
- Be at the whim of regulatory rate-setting and revenue recovery time cycles
- Be patiently waiting till existing 20-25-year contracts reach end-of-life

The above challenges are still winding its way through regulatory acceptance globally to recognize a ***"new class of assets (ESS)"*** and recognizes them for what value streams they bring. But this pace is dismally slow. Thus, given the higher price of the ESS technology (albeit it falling rapidly), the market penetration of ESS is very low in utility scale sizes. Most are deployed as a part of pilot scale utility projects.

However good progress is being made in congested transmission (i.e. PJM) and older ancillary markets in the developed countries (USA, EU, Canada) which are willing to pay a premium for a much faster ramp-rate than traditional gas turbines (thereby requiring a lower capacity reserve).

The challenge lies in the dis-aggregated, distributed and disparate value streams that ESS bring, that cannot be easily quantified particularly in the T&D verticals (where carriage and content is separate) during regulatory assessment.

The most business models in this regulated space takes the form of a developer-owner who finances the ESS equipment and outsources the EPC and O&M to third party entities.

Non-Regulated (Behind the Meter) ESS Business Models:

These offer the best growth prospects albeit a retail model targeting the industrial, commercial and residential segments. The ESS value propositions can be targeted to suit the customer (as opposed to a generic utility functions) and such solutions bring about quick returns in savings to the customer as:

- Reducing or eliminating demand charge and associated penalties
- Store RTPV power for time-shifting based on TOU rates arbitrage
- React to dynamic pricing models
- EV charging during best low tariff hours
- Battery swapping opportunity in a few segmented EV markets
- Fast charging stations that require ESS support
- Enable participation in subscription-based (paid) DSM and DM offers by utilities
- Standby Insurance against frequent power outages

The best opportunities are likely to come when the ESS assets are deployed on a fully asset-leased basis, i.e. fully financed to align with the attractiveness to the business owner, and then fully O&M managed for their entire asset life. This de-risks the owner from adopting new and sophisticated ESS asset class.

Since the capex and O&M costs of the ESS systems are quite high (compared to RTPV), their purchase, installation, and serviced by a third-party service provider (much like industrial/commercial HVAC, Industrial DM/RO Water and in the residential sector ISP internet service providers and residential RO water systems for the kitchens).

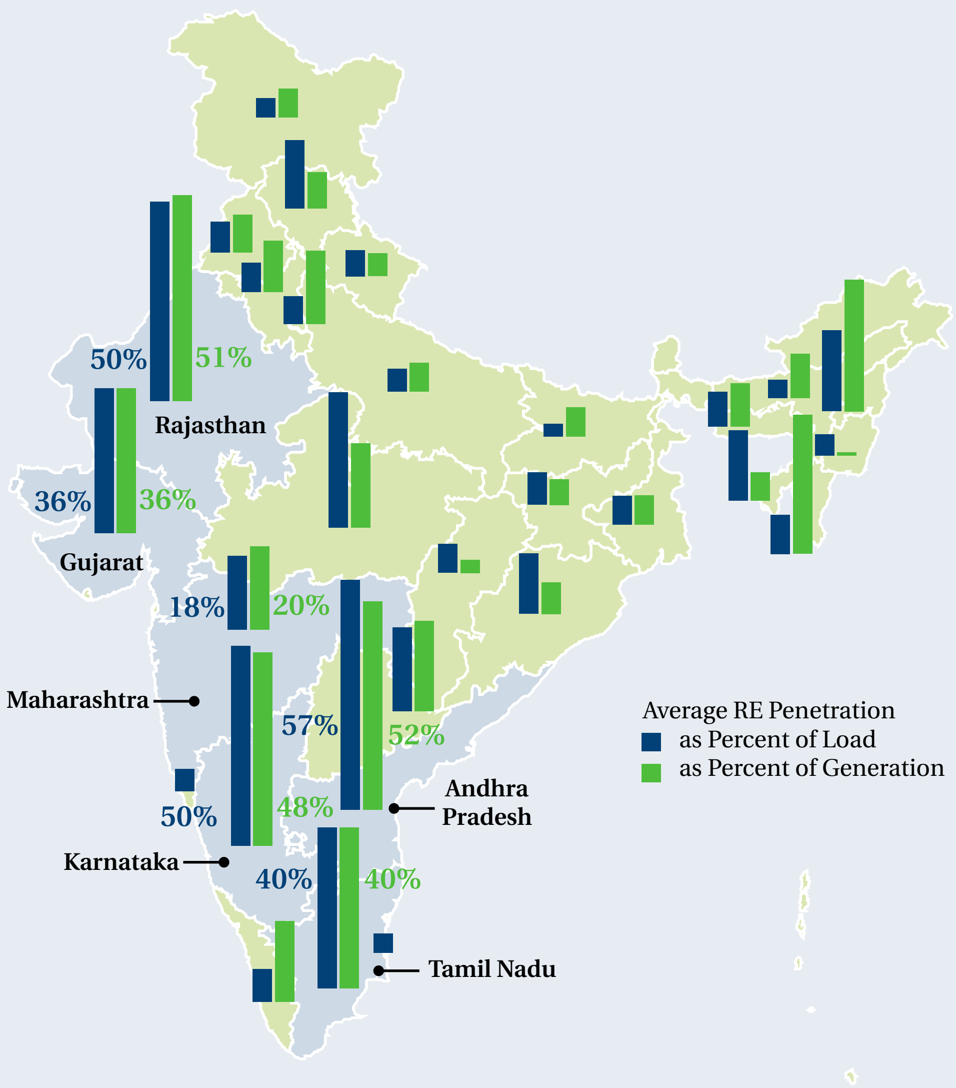
For this model to work well, banks and non-banking financial institutions (NBFI) as well as backend maintenance service providers need to be well established with trust worthy credentials. So, a brand building effort (much like internet service and RO water service) will need to be built.

Annexure 1: 175 GW RE: Status and Estimates

Annexure 1.1: RE Penetration in States as Percentage of Demand

Figure 52:

RE penetration as percentage of Generation and Load



Annual RE penetration exceeds 50% of load in 3 states

Source: Bridge To India

Annexure 1.2: State and UT Wise Targets and Installed Capacities of Renewable Energy

Table 23:

State and UT wise Targets and Installed Capacity

S. No	State	RE Targets 2022	Installed Capacity as of Feb 2019 (MW)			
			State	Private	Central	Total
1	Delhi	2,762	-	176.21	-	176.21
2	Haryana	4,376	69.30	340.19	5.00	14.49
3	Himachal Pradesh	2,276	256.61	608.50	-	865.11
4	Jammu & Kashmir	1,305	129.03	64.38	-	193.41
5	Punjab	5,066	127.80	1154.62	-	1282.42
6	Rajasthan	14,362	23.85	7216.91	344.00	7584.76
7	Uttar Pradesh	14,221	25.10	2829.83	30.00	2884.93
8	Uttarakhand	1,797	67.87	523.72	-	591.59
9	Chandigarh	153	-	32.40	-	32.40
Northern Region Total		**46,318**	**699.56**	**12946.76**	**379.00**	**14025.32**
10	Goa	358	0.05	1.69	-	1.74
11	Gujarat	17,133	49.10	7787.50	243.30	8079.90
12	Chhattisgarh	1,808	11.05	524.30	-	535.35
13	Madhya Pradesh	12,018	83.96	3990.13	300.00	4374.09
14	Maharashtra	22,045	388.13	8790.43	123.00	9301.55
15	D&N Haveli	449	-	5.46	-	5.46
16	Daman & Diu	199	-	14.47	-	14.47
Western Region Total		**54,010**	**532.29**	**21113.98**	**666.30**	**22312.56**
17	Andhra Pradesh	18,477	56.18	7223.03	250.0	7529.21
18	Telangana	2,000	41.22	3927.96	10.00	3979.18
19	Karnataka	14,817	193.89	12833.06	-	13026.94
20	Kerala	1,970	172.90	190.11	50.00	413.01
21	Tamil Nadu	21,508	122.70	11717.83	231.90	12072.43
22	Puducherry	246	-	1.80	-	1.80
Southern Region Total		**59,018**	**586.88**	**35893.79**	**541.90**	**37022.57**
23	Bihar	2,762	70.70	255.45	-	326.15
24	Jharkhand	2,005	4.05	32.41	-	36.46
25	Odisha	2,377	26.30	469.00	10.00	505.30
26	West Bengal	5,386	121.95	346.11	-	468.06
27	Sikkim	86	52.11	0.01	-	52.12
Eastern Region Total		**12,616**	**275.11**	**1102.98**	**10.00**	**1388.09**

S. No	State	RE Targets 2022	Installed Capacity as of Feb 2019 (MW)			
			State	Private	Central	Total
28	Assam	688	5.01	22.75	25.00	52.76
29	Manipur	105	5.45	3.23	0.00	8.68
30	Meghalaya	211	31.03	0.12	0.00	31.15
31	Nagaland	76	30.67	1.00	0.00	31.67
32	Tripura	105	16.01	0.09	5.00	21.10
33	Arunachal	539	107.10	5.39	0.00	112.49
34	Mizoram	97	36.47	0.50	-	36.97
North Eastern Region Total		**1,821**	**231.74**	**33.08**	**30.00**	**294.82**
35	Andaman & Nicobar	27	5.25	1.46	5.10	11.81
36	Lakshadweep	4	-	0.75	-	0.75
Islands Total		**31.0**	**5.25**	**2.21**	**5.10**	**12.56**
37	Others	720				
All India Total		**174,534.0**	**4661.67**	**142185.6**	**3264.6**	**149711.8**

Source: MNRE

Annexure 1.3: 175 GW Targets Year-Wise and Technology-Wise Capacity Addition till 2022

Table 24:
175 GW targets Year-Wise and Technology-Wise Capacity Addition till 2022

Year	Rooftop Solar (GW)	Ground-Mounted Solar (GW)	Solar (GW)	Wind (GW)	Small Hydro (GW)	Biomass (GW)	Total (GW)
Cumulative installed capacity by 2014-15			3	24	4.1	4.4	35.5
2015-16	0.2	1.8	2	3.2	0.14	0	5.3
2016-17	4.8	7.2	12	3.6	0.14	0.9	16.7
2017-18	5	10	15	4.1	0.14	0.9	20.2
2018-19	6	10	16	4.7	0.14	0.9	21.8
2019-20	7	10	17	5.4	0.14	0.9	23.5
2020-21	8	9.5	17.5	6.1	0.14	0.9	24.7
2021-22	9	8.5	17.5	8.9	0.14	0.9	27.5
Total	**40**	**60**	**100**	**60**	**5.08**	**9.98**	**175**

Source: MNRE

Annexure 1.4: 175 GW Break-up of Targets

Table 25:
175 GW Break-up of Targets

State/UT's	Solar (MW)	Wind (MW)	SHP (MW)	Biomass (MW)
Delhi	2,762			
Haryana	4,142		25	209
Himachal Pradesh	776		1,500	
Jammu and Kashmir	1,155		150	
Punjab	4,772		50	244
Rajasthan	5,762	8,600		
Uttar Pradesh	10,697		25	3,499
Uttarakhand	900		700	197
Chandigarh	153			
Northern Region	**31,120**	**8,600**	**2,450**	**4,149**
Goa	358			
Gujarat	8,020	8,800	25	288
Chhattisgarh	1,783		25	
Madhya Pradesh	5,675	6,200	25	118
Maharashtra	11,926	7,600	50	2,469
D &N Haveli	449			
Daman & Diu	199			
Western Region	**28,410**	**22,600**	**125**	**2,875**
Andhra Pradesh	9,834	8,100		543
Telangana	5490	2,000		
Karnataka	5,697	6,200	1,500	1,420
Kerala	1,870		100	
Tamil Nadu	8,884	11,900	75	649
Pondicherry	246			
Southern Region	**26,531**	**28,200**	**1,675**	**2,612**
Bihar	2,493		25	244
Jharkhand	1,995		10	
Orissa	2,377			
West Bengal	5,336		50	
Sikkim	36		50	
Eastern Region	**12,237**		**135**	**244**
Assam	663		25	
Manipur	105			

State/UT's	Solar (MW)	Wind (MW)	SHP (MW)	Biomass (MW)
Meghalaya	161		50	
Nagaland	61		15	
Tripura	105			
Arunachal Pradesh	39		500	
Mizoram	72		25	
North Eastern Region	**1,205**		**615**	
Andaman & Nicobar Islands	27			
Lakshadweep	4			
Other (New States)		**600**		**120**
All India	**99,533**	**60,000**	**5,000**	**10,000**

Source: MNRE

Annexure 1.5: 40 GW RTPV Break up of Targets

Table 26:
State-Wise Cumulative RTPV Installation Target (MW)

State	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	Total	Target Capacity under Proposed Scheme (Indicative only)
Andhra Pradesh	10	240	250	300	350	400	450	2,000	68
Bihar	5	120	125	150	175	200	225	1,000	34
Chhattisgarh	4	84	88	104	120	140	160	700	24
Delhi	5	132	138	165	190	220	250	1,100	37
Gujarat	15	385	400	480	560	640	720	3,200	108
Haryana	5	200	200	235	280	320	360	1,600	54
Himachal Pradesh	2	38	40	48	56	64	72	320	10
Jammu & Kashmir	2	54	55	74	80	90	95	450	15
Jharkhand	4	96	100	120	140	160	180	800	27
Karnataka	10	275	290	344	403	460	518	2,300	78
Kerala	4	96	100	120	140	160	180	800	27
Madhya Pradesh	10	265	275	330	385	440	495	2,200	74
Maharashtra	20	565	588	704	823	940	1060	4,700	160
Orissa	5	120	125	150	175	200	225	1,000	34
Punjab	10	240	250	300	350	400	450	2,000	68
Rajasthan	10	275	288	344	403	460	520	2,300	78
Tamil Nadu	15	420	438	524	613	700	790	3,500	118
Telangana	10	240	250	300	350	400	450	2,000	68
Uttarakhand	2	42	44	52	60	70	80	350	12
Uttar Pradesh	20	510	538	650	752	860	970	4,300	145
West Bengal	10	252	263	315	370	420	470	2,100	70
Arunachal Pradesh	2	5	5	8	10	10	10	50	2
Assam	4	30	30	38	42	50	56	250	8
Manipur	4	3	6	8	9	10	10	50	2
Meghalaya	1	6	6	8	9	10	10	50	2
Mizoram	1	6	6	8	9	10	10	50	2

State	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	Total	Target Capacity under Proposed Scheme (Indicative only)
Nagaland	1	6	6	8	9	10	10	50	2
Sikkim	1	6	6	8	9	10	10	50	2
Tripura	1	6	6	8	9	10	10	50	2
Chandigarh	1	12	12	14	18	20	23	100	3
Goa	1	20	20	22	23	30	34	150	5
Dadra & Nagar Haveli	1	24	25	30	35	40	45	200	7
Daman & Diu	1	12	12	14	18	20	23	100	3
Pondicherry	1	12	12	14	18	20	23	100	3
Andaman & Nicobar	1	2	2	2	5	4	4	20	1
Lakshadweep	1	1	1	1	2	2	2	10	1
Total	**200**	**4,800**	**5,000**	**6,000**	**7,000**	**8,000**	**9,000**	**40,000**	**1350**

Source: MNRE

Annexure 1.6: List of Solar Parks Sanctioned under the Solar Park Scheme

Table 27:
List of Solar Parks Sanctioned under the Solar Park Scheme

S. No	State	Name of the Solar Park	Capacity (MW)	Name of the Solar Park Developers	Name of the Area
1	Andhra Pradesh	Ananthapuramu-I Solar Park	1500	AP Solar Power Corporation Pvt.Ltd., JVC of SECI, APGENCO and NREDCAP	NP Kunta of Ananthapuramu & Galiveedu of Kadapa Districts
2		Kurnool Solar Park	1000		Gani and Sakunal village of Kurnool District
3		Kadapa Solar Park	1000		Vaddirala, Thalamnchi, Pannampalli, Ramachandrayapalli, Konna Ananthapuramu and Dhidium villages in Mylavaram Mandal, Kadapa District
4		Ananthapuramu-II Solar Park	500		Talarichruvu & Aluru Villages, Tadipathri Mandal, Ananthapuramu District
5		Solar Wind Hybrid Park	160		Kanaganapalli Mandal, Ananthapuramu District
6	Arunachal Pradesh	Lohit Solar Park	30	Arunachal Pradesh Energy Development Agency (APDEA)	Tezu Township in Lohit District
7	Assam	Solar Park in Assam	80	APGCL	Amguri in Sibsagar District

S. No	State	Name of the Solar Park	Capacity (MW)	Name of the Solar Park Developers	Name of the Area
8	Chhattisgarh	Rajnandgaon Solar Park	250	Chhattisgarh Renewable Development Agency	Dhaba Rengakathera, Amlidih, Dundera and Kohka villages of (100 MW) and Tolagaon, Odarband, Gatatola, Girgaon, Gugwa, Salhe villages of Dongargadh Tehsil, Rajnandgaon Dist.
9	Gujarat	Radhnesada Solar Park	700	Gujarat Power Corporation Ltd.	Radhnesada, Vav, District Banaskantha
10		Harsad Solar Park	500	Gujarat Power Corporation Limited	Villages-Harsad and Navapara, Taluka-Suigam, District-Banaskatha
11	Haryana	Solar Park in Haryana	500	Saur Urja Nigam Haryana Ltd (SUN Haryana)	Bugan in Hisar district, Baralu and Singhani in Bhiwani district and Daukhera in Mahindergarh district
12	Himachal Pradesh	Solar Park in Himachal Pradesh	1000	HP State Electricity Board Ltd.	Spiti Valley of Lahaul & Spiti District
13	Jammu & Kashmir	Solar Park in J & K	100	Jammu and Kashmir Energy Development Agency	Mohagarh and Badla Brahmana, District-Samba
14	Karnataka	Pavagada Solar Park	2000	Karnataka Solar Power Development Corporation Pvt. Ltd.	Villages- Valluru, Rayacharlu, Balasamudra, Kyathaganacharlu, Thirumani of Pavagada Taluk, Tumkuru dist.
15	Kerala	Kasargod Solar Park	200	Renewable Power Corporation of Kerala Limited	Paivalike, Meenja, Kinanoor, Kraindalam and Ambalathara villages of Kasargode district

S. No	State	Name of the Solar Park	Capacity (MW)	Name of the Solar Park Developers	Name of the Area
16	Madhya Pradesh	Rewa Solar Park	750	Rewa Ultra Mega Solar Limited	Gurh tehsil, District Rewa, MP
17		Neemuch-Madsaur Solar Park	700	Rewa Ultra Mega Solar Limited	Neemuch site: Under identification; and Mandsaur site: Runija and Gujjarkhedi villages in Suwasra Tehsil, Mandsaur district
18		Agar-Shajapur-Rajghar Solar Park	1050	Rewa Ultra Mega Solar Limited	Agar, Shajapur and Rajgarh district
19		Morena (Chambal) Solar Park	250	Rewa Ultra Mega Solar Limited	Morena, (Chambal)
20	Maharashtra	Sai Guru Solar Park	500	M/s Sai Guru Mega Solar Park Pvt. Ltd. (formerly M/s Pragat Akshay Urja Ltd.)	Bhamer Village, Taluka-Sakri, Dhule District
21		Dondaicha Solar Park	500	Maharashtra State Electricity Generating Company Ltd. (MAHAGENCO)	Villages- Vikhran & Methi, Taluka-Dondaicha, district Dhule, Maharashtra
22		Patoda Solar Park	500	M/s Paramount Solar Power Pvt. Ltd. (formerly M/s K. P. Power Pvt. Ltd.)	Villages Tambarajuri, and Wadzari, Taluka Patoda, Dist. Beed
23	Manipur	Bukpi Solar Park	20	Manipur Tribal Development Corp. Ltd.	Bukpi Village, Pherzawl District in Manipur
24	Meghalaya	Solar Park Meghalaya	20	Meghalaya Power Generation Corporation Ltd (MEPGCL)	Thamar, West Jaintia Hills & Suchen, East Jaintia Hills districts

S. No	State	Name of the Solar Park	Capacity (MW)	Name of the Solar Park Developers	Name of the Area
25	Mizoram	Vankal Solar Park	20	Zoram Energy Development Agency (ZEDA)	Vankal, Mizoram
26	Nagaland	Solar Park Nagaland	23	Directorate of New & Renewable Energy, Nagaland	Ganeshnagar (12 MW) of Dimapur and Jalukie (11 MW) of Peren districts
27	Odisha	Solar Park Odisha	1000	Green Energy Development Corporation of Odisha Limited	Balasore, Keonjhar, Deogarh, Boudh, Kalahandi and Angul
28	Rajasthan	Bhadla-II Solar Park	680	Rajasthan Solar Park Development Company Ltd.	Village-Bhadla, Jodhpur Dist., Rajasthan
29	Rajasthan	Bhadla-III Solar Park	1000	Surya Urja Company of Rajasthan Ltd	Village-Bhadla, Jodhpur Dist., Rajasthan
30		Phalodi- Pokaran Solar Park	750	M/s Essel Surya Urja Company of Rajasthan Limited	Villages Ugraas, Nagnechinagar & Dandhu, tehsil Phalodi, dist. Jodhpur (450 MW) and villages Lavan & Purohitsar, tehsil Pokaran, dist. Jaisalmer (300 MW)
31		Bhadla-IV Solar Park	500	M/s Adani Renewable Energy Park Rajasthan Limited	Village-Bhadla, Jodhpur Dist., Rajasthan
32		Fatehgarh Phase – IB Solar Park	421	M/s Adani Renewable Energy Park Rajasthan Limited	Fatehgarh & Pokaran, Jaisalmer, Rajasthan
33		Nokh solar Park	1000	Rajasthan Solar Park Development Company Ltd.	Village-Nokh, Pokaran, Jaisalmer, Rajasthan

S. No	State	Name of the Solar Park	Capacity (MW)	Name of the Solar Park Developers	Name of the Area
34	Tamil Nadu	Solar Park in Tamil Nadu	500	To be finalized	Initially proposed in Ramanathapuram district. Site under revision
35		Kadaladi Solar Park	500	Tamil Nadu Electricity Board (TNEB) Ltd	Narippaiyur and nearby villages, Kadaladi Taluk in Ramanathapuram District
36	Uttar Pradesh	Solar Park in UP	440	Lucknow Solar Power Development Corporation Ltd.	Orai & kalpi Tehsils of Jalaun, Meja tehsil of Allahabad, Chaanbe tehsil of Mirzapur and Akbarpur tehsil in Kanpur Dehat districts
37	Uttarakhand	Solar Park in Uttarakhand	50	State Industrial Development Corporation Uttarakhand Limited (SIDCUL)	Sitarganj and Khurpia farm in US Nagar district
38	West Bengal	Solar Park in West Bengal	500	West Bengal State Electricity Distribution Company Ltd.	East Mednipur, West Mednipur, Bankura
Total			**21,194**		

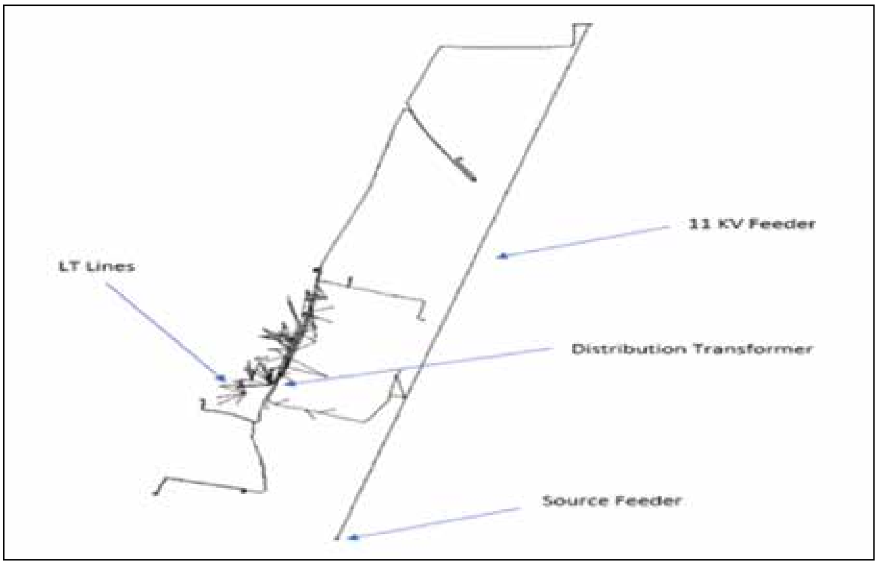
Source: MNRE

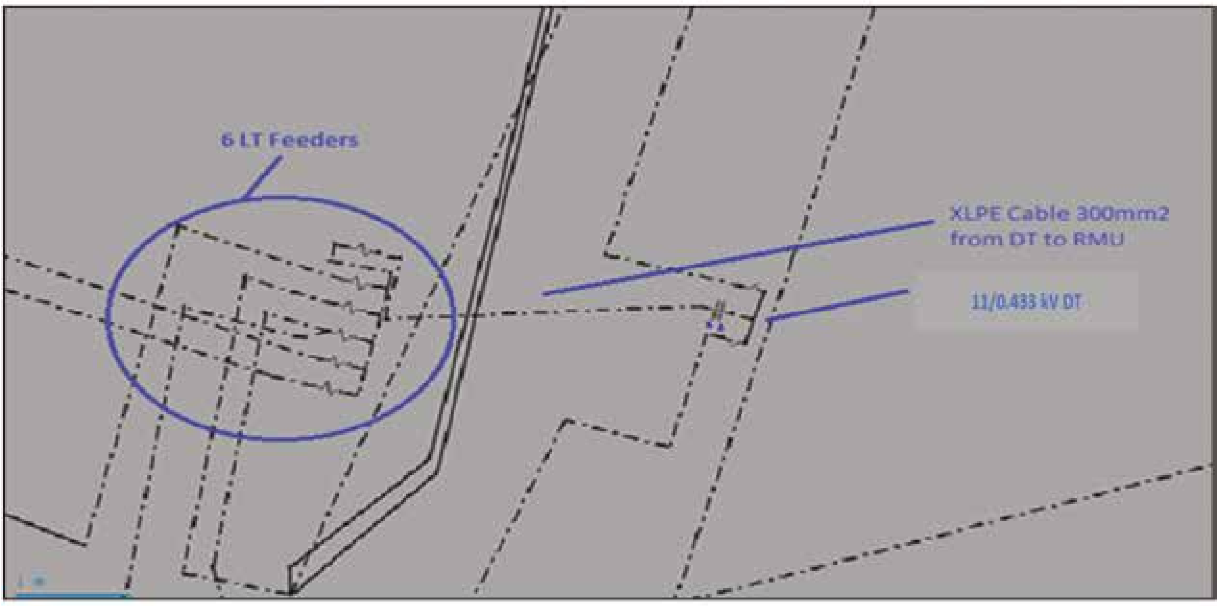
Annexure 2: Load Flow Studies and Analysis of RTPV Integration

Annexure 2.1: Load Flow Analysis of Tata Power Delhi Distribution Limited (TPDDL) Feeder

Feeder details:

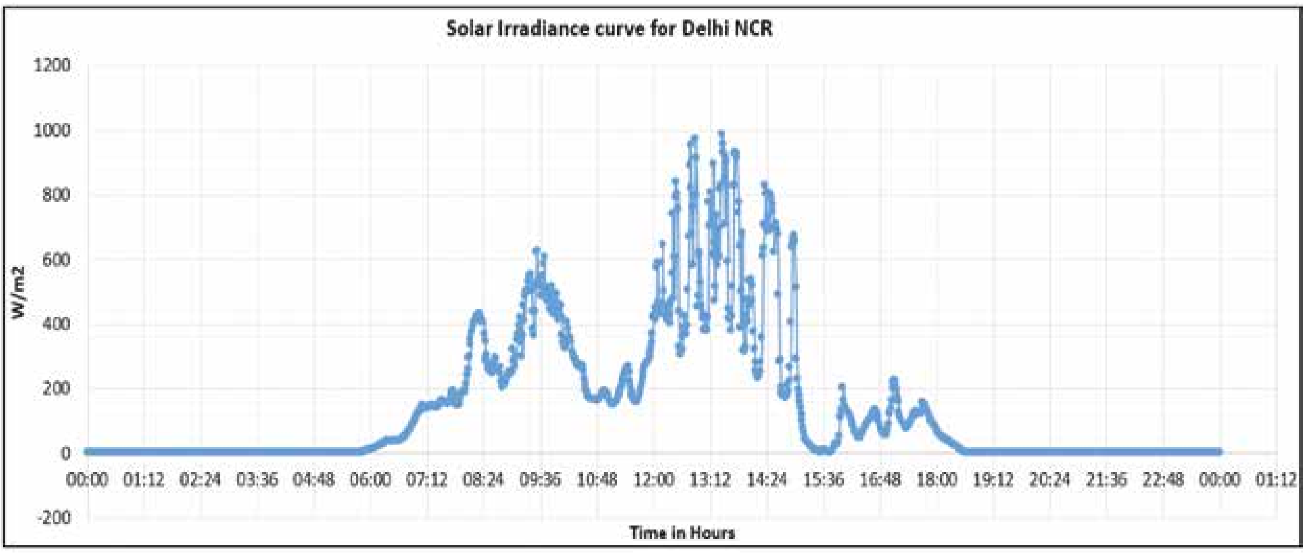
- Distribution Transformer (DT): 630 kVA
- Voltage level: 11 kV/433 V
- Length of feeder: 5.38 km
- Number of consumers: 181
- Number of solar rooftop PV: 3 (Solar PV: 70 kWp)





Solar Irradiance Curve:

The Solar Insolation (W/m^2) with respect to time, this data is collected from National Institute of Wind Energy for Minute & Hourly basis for 03 May 2017.



Load Flow Scenarios:

Scenario 1:

In every scenario solar rooftop connection is increased to observe the behaviour of 11 kV Feeder and LT network.

Objective of Study:

- To analyze the effect of11 kV feeder & LT network by increasing RTPV injection

Software Tool:

- CYME (CYMDIST)

Time slots and % incease in DT capacity:

Day	Time slot	11 kV feeder					
		Time	R-Phase current	Y-Phase current	B-Phase current	Average current	Max
03-05-2017	Slot 2	08:15:00	63.030	59.790	66.930	63.25	100.81
		08:30:00	63.030	69.490	66.930	66.48	
		08:45:00	67.420	69.540	66.930	67.96	
		09:00:00	72.150	69.540	69.470	70.39	
		09:15:00	73.760	77.880	76.050	75.90	
		09:30:00	84.190	81.970	81.990	82.72	
		09:45:00	90.990	89.040	91.930	90.65	
		10:00:00	990.330	97.430	95.550	97.44	
		10:15:00	100.080	99.450	95.550	98.36	
		10:30:00	100.080	99.450	95.550	98.36	
		10:45:00	100.080	99.450	95.550	98.36	
		11:00:00	100.080	99.450	102.890	100.81	

Time Slots →

No. of Solar RTVP are increases ↓

Already connected	Scenario 1 Time 8-11 AM	Scenario 2 Time 11- 1 PM	Scenario 3 Time 1- 4 PM	Scenario 4 Time 4- 7 PM
11% of DT capacity	70 kWp	70 kWp	70 kWp	70 kWp
20% of DT capacity	120 kWp	120 kWp	120 kWp	120 kWp
40% of DT capacity	240 kWp	240 kWp	240 kWp	240 kWp
60% of DT capacity	360 kWp	360 kWp	360 kWp	360 kWp
80% of DT capacity	480 kWp	480 kWp	480 kWp	480 kWp
90% of DT capacity	540 kWp	540 kWp	540 kWp	540 kWp
100% of DT capacity	600 kWp	600 kWp	600 kWp	600 kWp

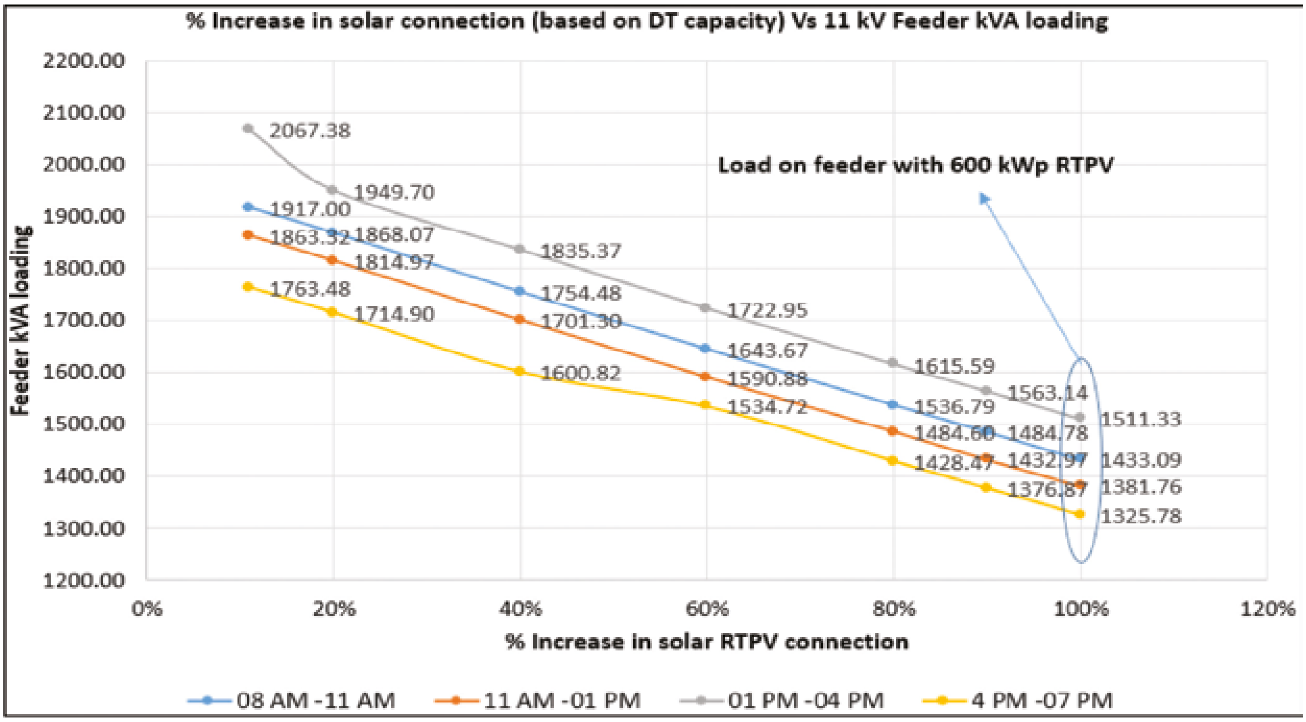
Observations:

Effect on 11 kV feeder:

- The load on feeder continuously decreased in every scenario as solar rooftop connection is increased from 11% to 100% of DT capacity

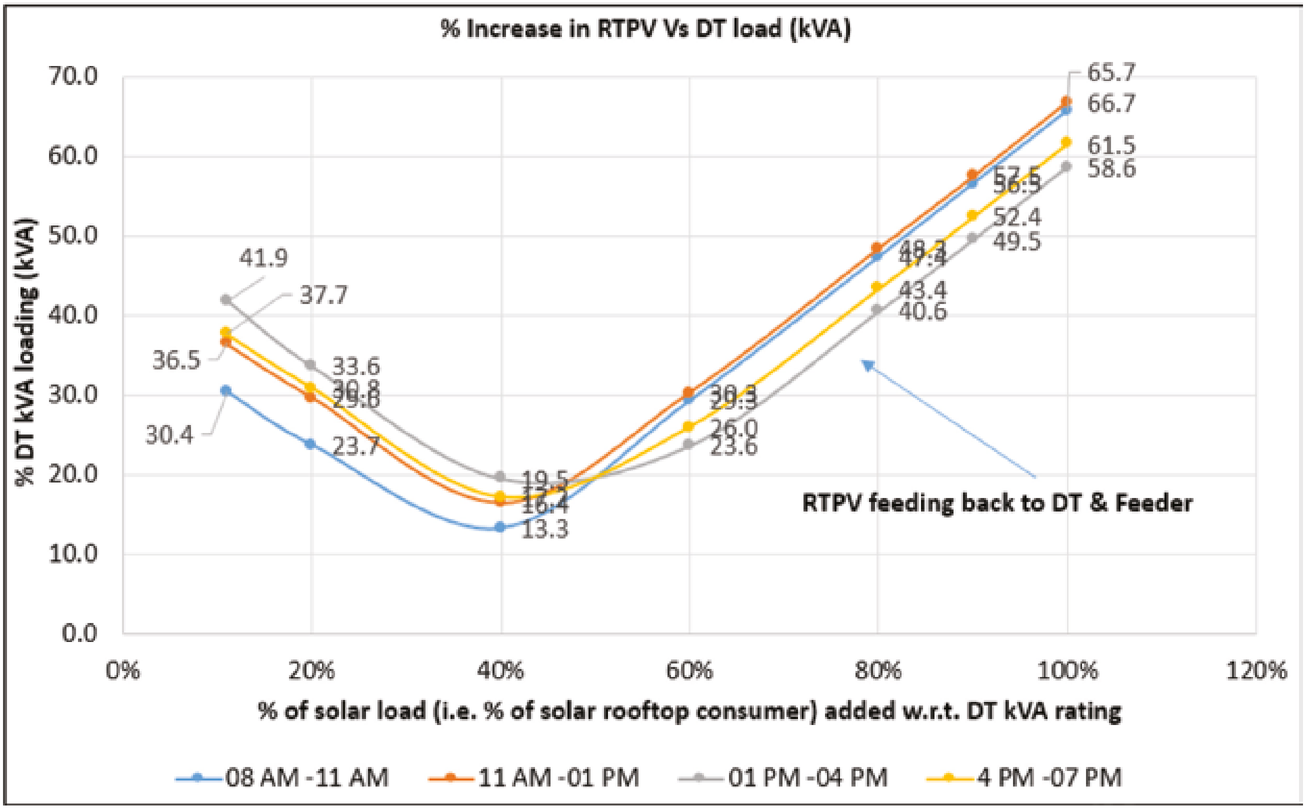
Observations on 11 kV Feeder:

- No thermal issues
- No PQ issues
- Voltage & PF are within permissible limits



Effect on DT:

- Loading on DT first decreased when generation in consumed at DT end
- The loading on DT again increased when there is excess power available and reverse power flow starts back to DT and Feeder
- It is observed with more initial loading on DT graph shifts towards right for reverse power flow



Effect on LT Side:

- No Thermal issues
- **Power Quality Issues:** Per unit voltage of each LT circuit is within permissible limit (i.e. +/- 6 % voltage variation) i.e. 0.94pu <V<1.06. But at RTPV, voltage increases as more solar connection are increased

Scenario 2:

- Time slot selected for study i.e. 11 AM to 01 PM on 03 May 2017 data and time 11.15 AM
- In each scenario first DT connected load is increased (i.e. 50%, 750%, 100% and 120% kW)
- Then RTPV connections are increased in steps in every load flow study from 11 % existing to 100% (i.e. 11%, 20%, 40%, 60%, 80%, 90% & 100%)

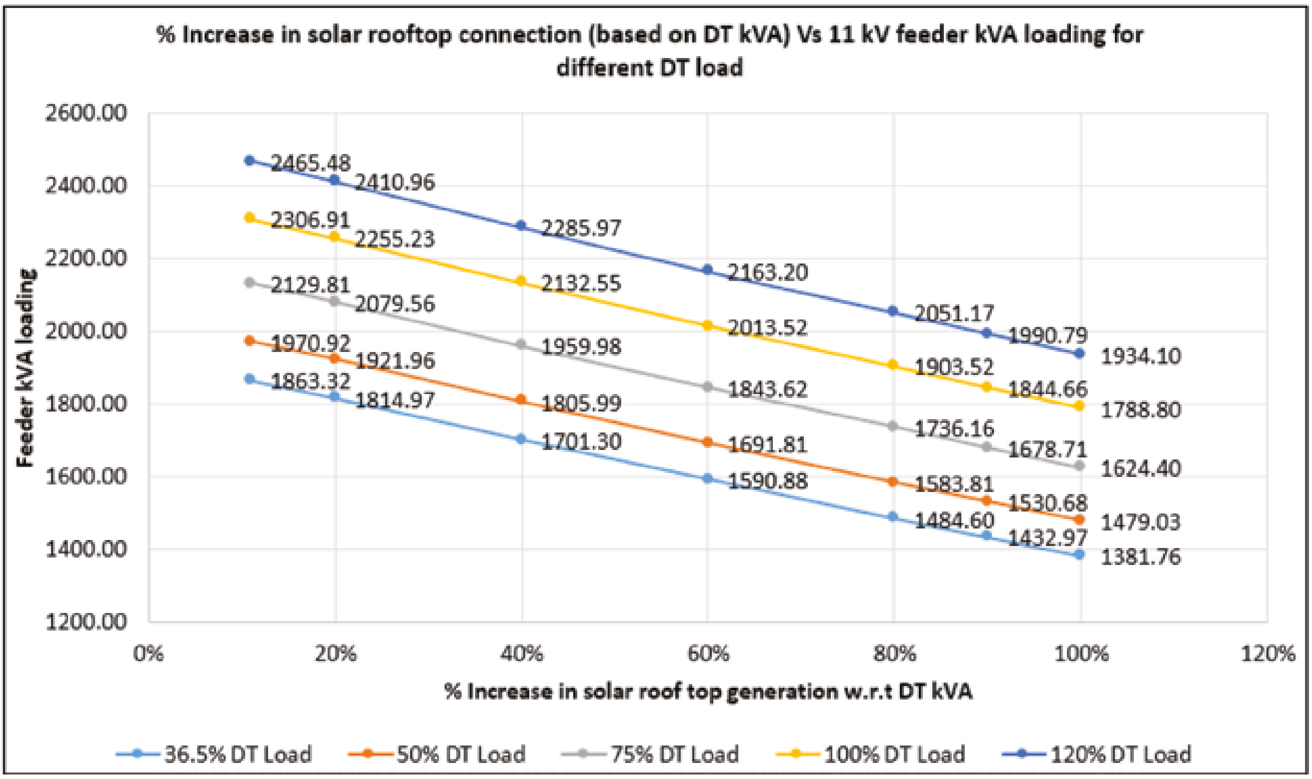
Time Slots →

No. of solar RTVP are increases ↓

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	Initial DT load: 36.5%	DT loading: 50 %	DT loading: 75%	DT loading: 100%	DT Loading: 120%
11% of DT capacity (Already connected)	70 kWp	70 kWp	70 kWp	70 kWp	70 kWp
20% of DT capacity	120 kWp	120 kWp	120 kWp	120 kWp	120 kWp
40% of DT capacity	240 kWp	240 kWp	240 kWp	240 kWp	240 kWp
60% of DT capacity	360 kWp	360 kWp	360 kWp	360 kWp	360 kWp
80% of DT capacity	480 kWp	480 kWp	480 kWp	480 kWp	480 kWp
90% of DT capacity	540 kWp	540 kWp	540 kWp	540 kWp	540 kWp
100% of DT capacity	600 kWp	600 kWp	600 kWp	600 kWp	600 kWp

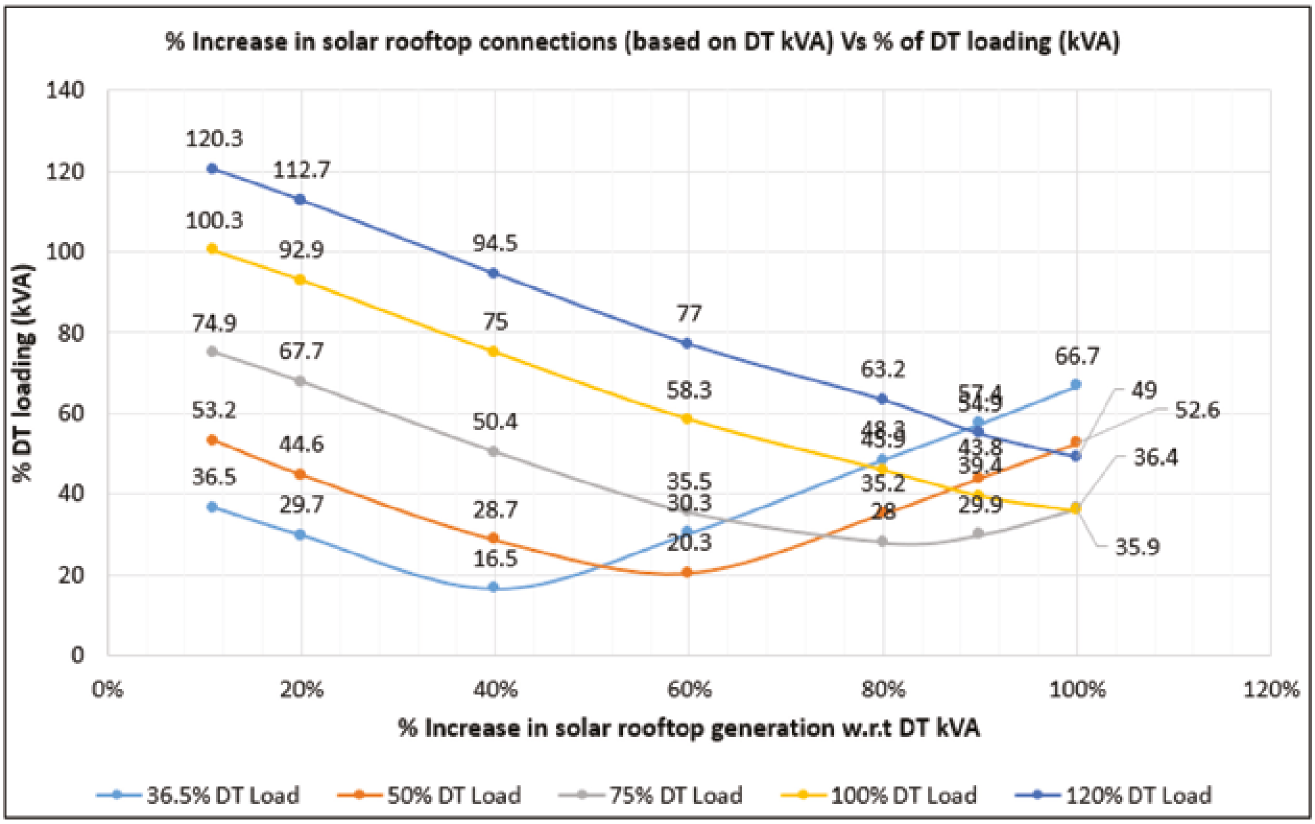
Effect on 11 kV Feeder:

- The load on feeder continuously decreased in every scenario as solar rooftop connection is increased from 11% to 100% for different scenarios of DT Loading
- No thermal and PQ (Power Quality) issues are observed



Effect on DT (630 kVA, 11 kV/433 V):

- Loading on DT first relieved when solar generation in consumed at DT end
- Then loading on DT again increased when there is excess power available and reverse power flow starts back to DT and Feeder
- Reverse power flow comes if DT is more heavily loaded i.e. graph shifts towards right



Effect on LT Network:

Thermal effect:

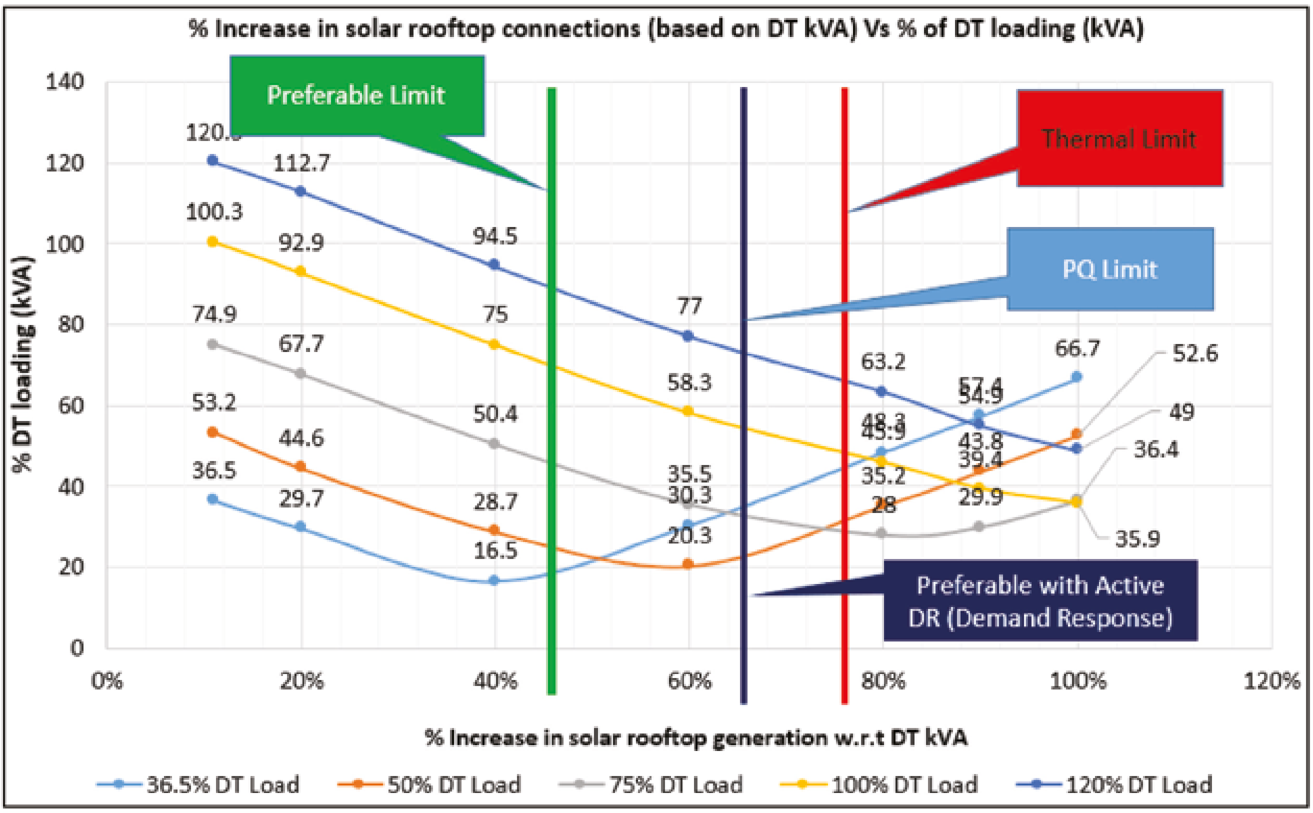
- When DT is heavily loaded i.e. beyond 80%, very high current at DT side observed but as RTPV connections are increased DT load and current are reduced and system becomes healthy. But in case at 80% of solar RTPV connection, due to sudden cloudy weather RTPV solar injection becomes very low, then in that case it will burden DT

Observation:

- Hight RTPV injection (i.e. more than 80 %) when DT connected load is low can cause high reverse current in some LT section. So solar injection more than 80 % at light DT load should be avoided

Summary of Power Quality (PQ) Issues:

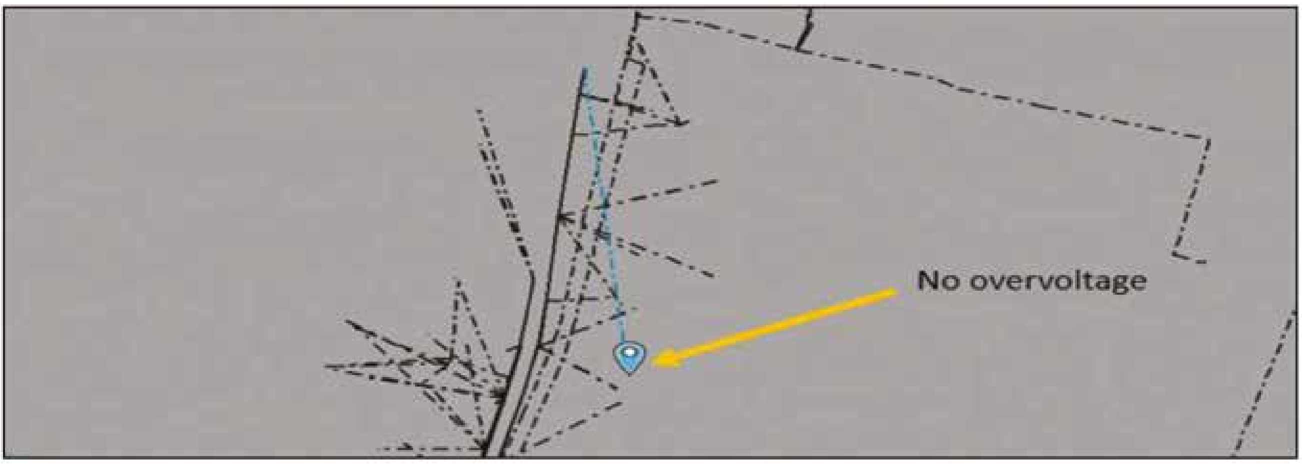
DT loading scenarios	Over voltage (V > = 1.06 PU)	Under voltage (V <= 0.94 PU)	Observations
10% DT loading	540 kWp (90% RTPV)	None	
20% DT loading	540 kWp	None	When DT is lightly loaded, RTPV insertion beyond 80% can cause overvoltage at RTPV end. Which may cause undesirable tripping of Inverts at RTPV
50% DT loading	None	70 kWp & 120 kWp (20% RTPV)	Up to 75% of DT loading undervoltage is removed by 50% of RTPV connections. So, system becomes healthy
75% DT loading	None	70 kWp, 120 kWp & 240 kWp (40% RTPV)	
100% DT loading	None	70 kWp, 120 kWp, 240 kWp, 360 kWp, 480 kWp, 540 kWp, 600 kWp & 620 kWp (special case)	100%, 120% DT loading cases are not practically viable. Moreover, with 100% & 120% RTPV connection undervoltage still present
120% DT loading	None	70 kWp, 120 kWp, 240 kWp, 360 kWp, 480 kWp, 540 kWp, 600 kWp & 755 kWp (special case)	



Power Quality Issues:

- High voltage at RTPV source end: (V> 1.06 PU)
- In some rooftop connection over voltage is observed when RTPV connection are increased more than 480 kWp (i.e. 80% of DT capacity)

RTPV connection: 80% (i.e. 480 kWp)

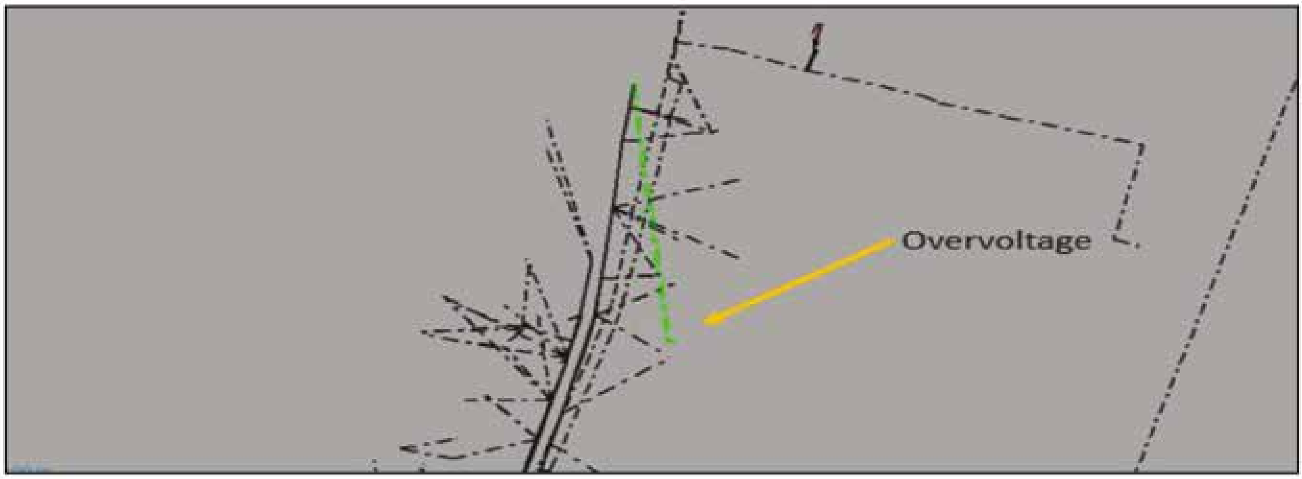


Case -1: 20% of DT loading, RTPV connection 80 % (480 kWp)

P.U voltage less than 1.06

Network Id	Section Id	Equipment Id	KVLL (KVLL)	VA (KVLL)	Per Unit VA	VB (KVLL)	Per Unit VB	VC (KVLL)	Per Unit VC	V (KVLL)	Per Unit V	IA (A)	IB (A)	IC (A)	Pf avg (%)	Total Thru Power (kW)	Total Thru Power (kVA)	Total Thru Power (kvar)	Length (m)	Loading (%)
01-25_FLAG STAFF ROAD S/S NO-1	10943446-13	440V_1.1KV_ABC_3X150	0.433	0.446	1.030	0.446	1.030	0.445	1.028	0.446	1.029	61.877	62.031	60.621	-99.98	-47.363	47.362	0.897	54.4	20.7
01-25_FLAG STAFF ROAD S/S NO-1	10943446-14	440V_1.1KV_ABC_3X150	0.433	0.446	1.030	0.446	1.030	0.445	1.028	0.446	1.029	0.228	0.215	0.336	94.51	0.189	0.200	0.065	27.1	0.1
01-25_FLAG STAFF ROAD S/S NO-1	10943446-15	440V_1.1KV_ABC_3X150	0.433	0.446	[illegible]	[illegible]	[illegible]	0.445	1.028	0.446	1.029	0.228	0.215	0.336	94.51	0.189	0.200	0.065	17.9	0.1
01-25_FLAG STAFF ROAD S/S NO-1	**11579217-0**	**2X10SQ.MM**	0.433	0.446	1.030	0.446	1.029	0.445	1.027	0.445	1.029	0.228	0.215	0.336	94.51	0.189	0.200	0.065	208.9	0.5
01-25_FLAG STAFF ROAD S/S NO-1	70908684-0	440V_95_SQ_MM_ALUMINIUM_XLPE	0.433	0.446	1.030	0.446	1.030	0.445	1.028	0.446	1.029	0.000	0.000	0.000	0.00	0.000	0.000	0.000	6.4	0.0
01-25_FLAG STAFF ROAD S/S NO-1	70908647-0	440V_95_SQ_MM_ALUMINIUM_XLPE	0.433	0.446	1.030	[illegible]	1.030	0.445	1.028	0.446	1.029	0.000	0.000	0.000	0.00	0.000	0.000	0.000	43.3	0.0

RTPV connection: 90% (i.e. 540 kWp)



Over voltage observed i.e. more than 1.06 PU

Network Id	Section Id	Equipment Id	KVLL (KVLL)	VA (KVLL)	Per Unit VA	VB (KVLL)	Per Unit VB	VC (KVLL)	Per Unit VC	V (KVLL)	Per Unit V	IA (A)	IB (A)	IC (A)	Pf avg (%)	Total Thru Power (kW)	Total Thru Power (kVA)	Total Thru Power (kvar)	Length (m)	Loading (%)
01-25_FLAG STAFF ROAD S/S NO-1	10943446-13	440V_1.1KV_ABC_3X150	0.433	0.450	1.039	0.450	1.039	0.449	1.038	0.450	1.039	73.787	73.940	72.546	-99.99	-57.017	57.025	0.922	54.4	24.6
01-25_FLAG STAFF ROAD S/S NO-1	10943446-14	440V_1.1KV_ABC_3X150	0.433	0.450	1.040	0.450	1.040	0.449	1.038	0.450	1.039	12.250	12.263	12.162	-100.00	-9.622	9.622	0.073	27.1	4.1
01-25_FLAG STAFF ROAD S/S NO-1	10943446-15	440V_1.1KV_ABC_3X150	0.433	0.450	1.040	[illegible]	[illegible]	[illegible]	[illegible]	0.450	1.039	12.250	12.263	12.162	-100.00	-9.524	9.524	0.071	17.9	4.1
01-25_FLAG STAFF ROAD S/S NO-1	11579217-0	2X10SQ.MM	0.433	0.464	1.071	0.464	1.071	0.463	1.069	0.464	1.071	[illegible]	12.263	12.162	-100.00	-9.526	9.526	0.071	208.9	18.3
01-25_FLAG STAFF ROAD S/S NO-1	**233 (10KW)**	**TATA POWER(TS250)_250WATTS**	0.433	0.464	1.071	0.464	1.071	0.463	1.069	0.464	1.071	12.457	12.457	12.457	100.00	10.003	10.003	0.002	0.0	79.9
01-25_FLAG STAFF ROAD S/S NO-1	70908684-0	440V_95_SQ_MM_ALUMINIUM_XLPE	0.433	0.450	1.040	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.039	0.000	0.000	0.000	0.00	0.000	0.000	0.000	6.4	0.0
01-25_FLAG STAFF ROAD S/S NO-1	70908647-0	440V_95_SQ_MM_ALUMINIUM_XLPE	0.433	0.450	1.040	0.450	1.040	0.449	1.038	0.450	1.039	0.000	0.000	0.000	0.00	0.000	0.000	0.000	43.3	0.0

Power Quality Issues:

- Undervoltage at High DT Loading: (V< 0.94 PU)
- AT 50% of DT loading: Undervoltage was observed in some portions but when RTPV connection is increased beyond 120 kWp (20% RTPV) and 240 kWp (50% RTPV), this undervoltage is removed and system becomes healthy

AT RTPV connection: 11% (i.e. 70 kWp)

AT RTPV connection: 20% (i.e. 120 kWp)

AT RTPV connection: 50% (i.e. 240 kWp)

Power Quality Issues:

- Under voltage at High DT loading: (V< 0.94 PU)
- Similarly, at 75% of DT loading: Undervoltage observed up to 240 kWp (i.e. 50% of RTPV) and completely removed at 360 kWp (i.e. 60% RTPV)
- Similarly, at 100% of DT loading: undervoltage observed in all the cases when RTPV connections are increased from up to 100% RTPV (i.e. 620 kWp)

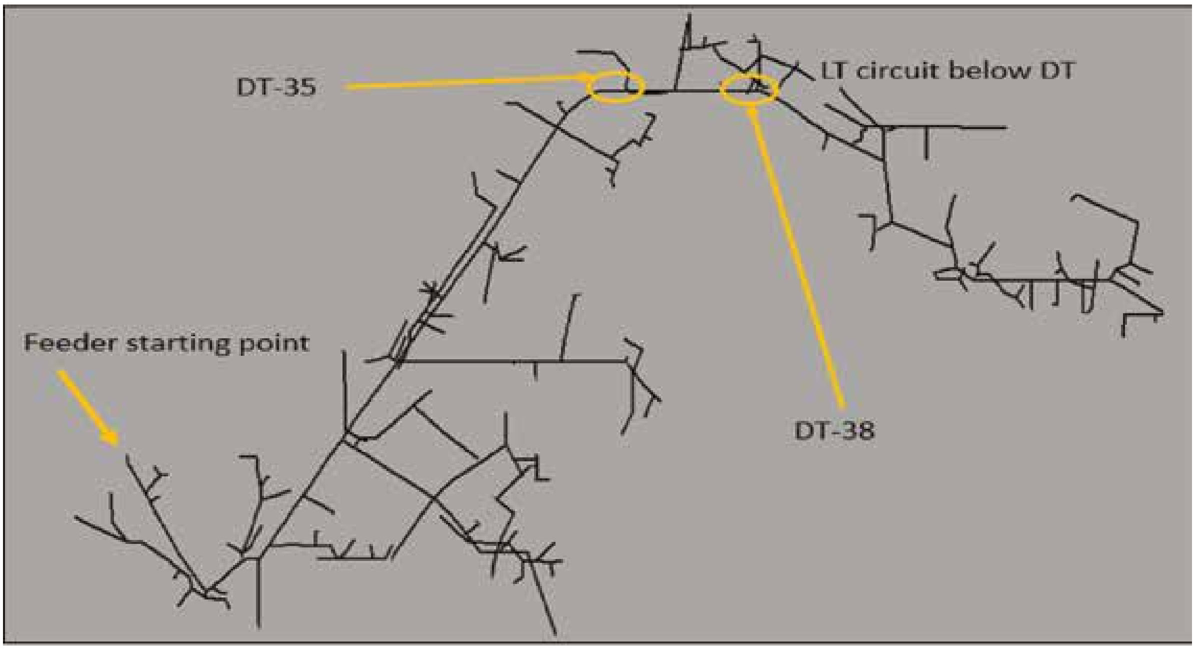
75 % DT loading: RTPV connections: 50% (i.e. 240 kWp)

75% DT loading: RTPV connection: 60% (i.e. 360 kWp)

Annexure 2.2: Load Flow Analysis of UHBVN Feeder

Feeder details:

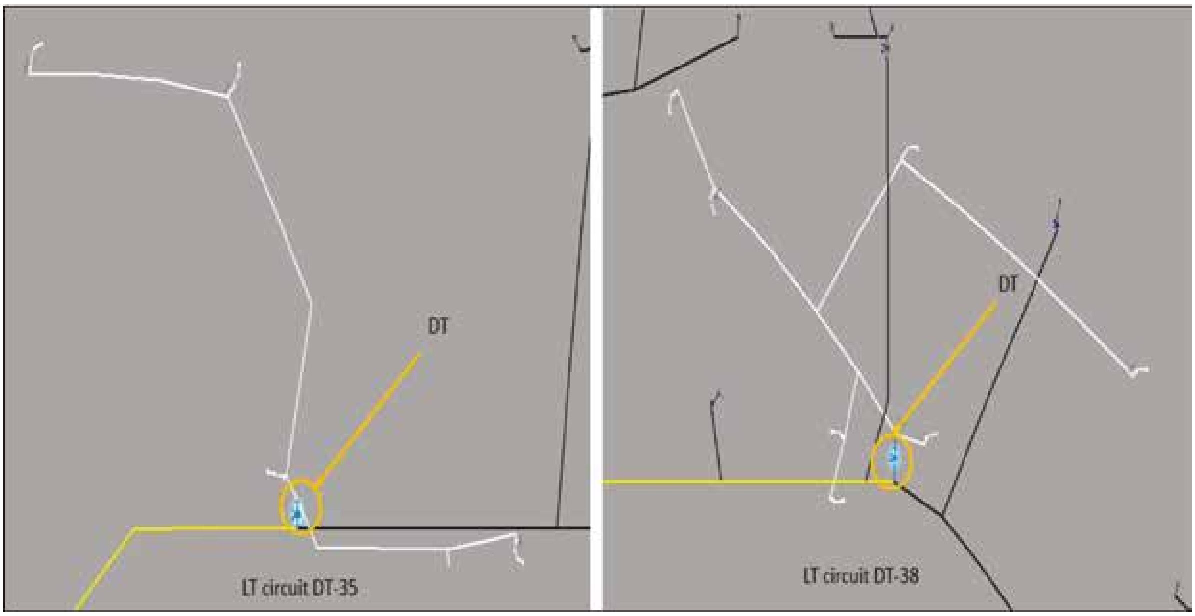
- **Substation:** 66/11 kV
- **Distribution Transformers:** DT-38 (100 kVA, 11KV/433V) & DT-35 (63 kVA, 11 kV/433 V)
- **Length of feeder:** 42.954 km
- **Number of consumers:** DT-38 are 8 (112.5 HP) DT- 35 are 5 (75 HP)
- **Length of LT circuit:** 2.645 km
- **Number of solar RTPV:** There is no RTPV connected to consumers

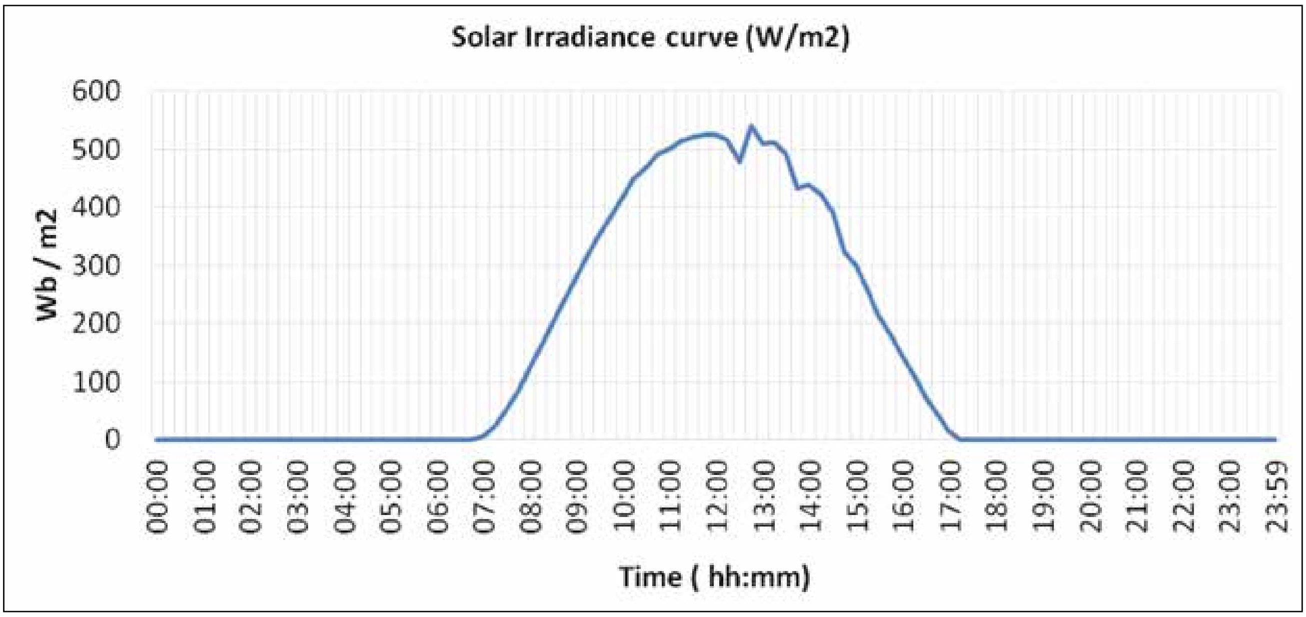


LT Circuits of DTs:

Solar Irradiance Curve:

The solar insolation (W/m²) with respect to time is collected from National Institute of Wind Energy for minute and hourly basis for 21 November 2018.





Load Flow Scenario:
In every scenario solar rooftop connection are increased to observe the behaviour on 11 kV Feeder and LT network at both DT's. For DT 11KV/433 V, 63 kVA) following scenario:

Objective of Study:
- To analyze the effect on 11 kV Feeder and LT network by increasing RTPV injection

Software Tool: CYME (CYMDIST)

Time slots and % increase in DT capacity:

S. No	Time slot	Load flow run at time when DT is max loaded
1	8:00 AM - 11:00 AM	11:00 AM
2	11:00 AM-01:00 PM	11:30 PM
3	01:00 PM -04:00 PM	04:00 PM
4	04:00 PM -07:00 PM	5:00 PM

DT-35 (63 kVA, 11 kV/433 V):

RTPV Scenarios for DT (63 kVA)

No. of Solar RTVP are increases

Time slots	Scenario 1 Time 8-11 AM	Scenario 2 Time 11- 1 PM	Scenario 3 Time 1- 4 PM	Scenario 4 Time 4- 7 PM
Without Solar	-	-	-	-
20% of DT capacity	13 kWp	13 kWp	13 kWp	13 kWp
40% of DT capacity	26 kWp	26 kWp	26 kWp	26 kWp
60% of DT capacity	40 kWp	40 kWp	40 kWp	40 kWp
80% of DT capacity	52 kWp	52 kWp	52 kWp	52 kWp
100% of DT capacity	63 kWp	63 kWp	63 kWp	63 kWp

DT-38 (11 kV/433 V, 100 kVA):

Already connected

No. of Solar RTVP are increase

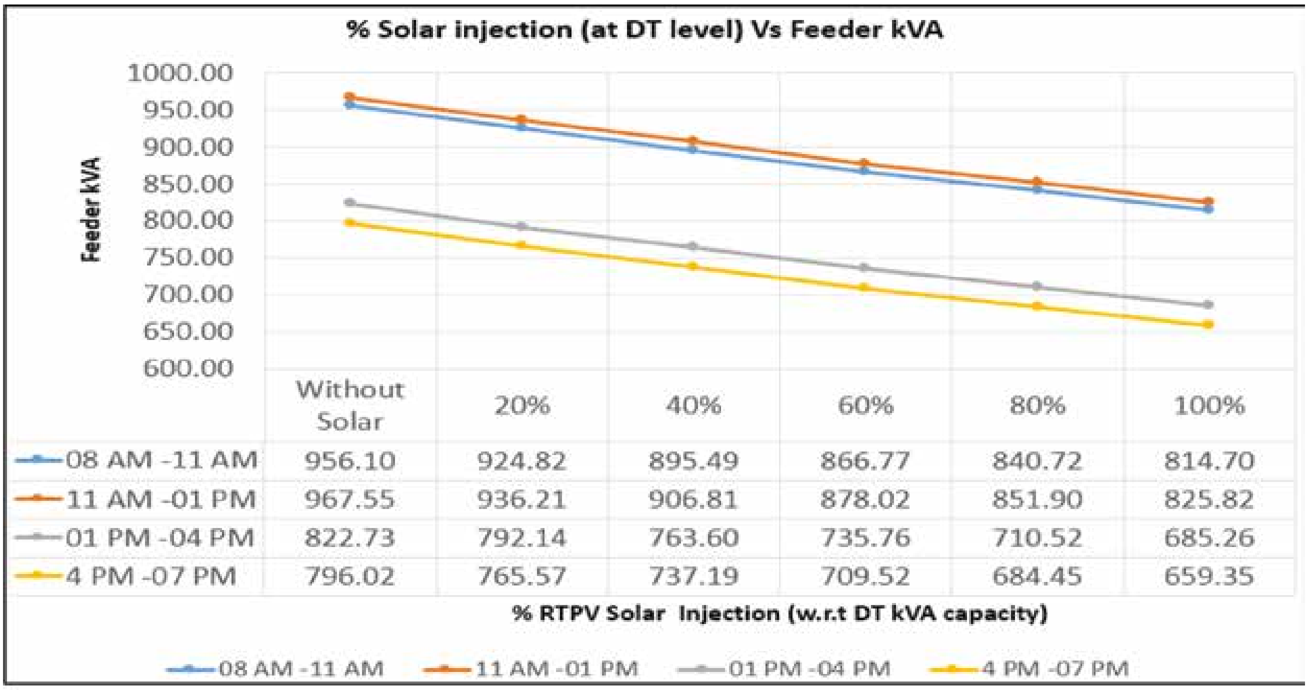
Time slots	Scenario 1 Time 8-11 AM	Scenario 2 Time 11- 1 PM	Scenario 3 Time 1- 4 PM	Scenario 4 Time 4- 7 PM
Without Solar	-	-	-	-
20% of DT capacity	20 kWp	20 kWp	20 kWp	20 kWp
40% of DT capacity	40 kWp	40 kWp	40 kWp	40 kWp
60% of DT capacity	60 kWp	60 kWp	60 kWp	60 kWp
80% of DT capacity	80 kWp	80 kWp	80 kWp	80 kWp
100% of DT capacity	100 kWp	100 kWp	100 kWp	100 kWp

Effect on 11 kV Feeder:

- There is no reverse power flow observed at feeder level even RTPV at 100% of DT capacity in both LT circuits
- Loading on feeders decreased as more RTPV are connected

Observation:

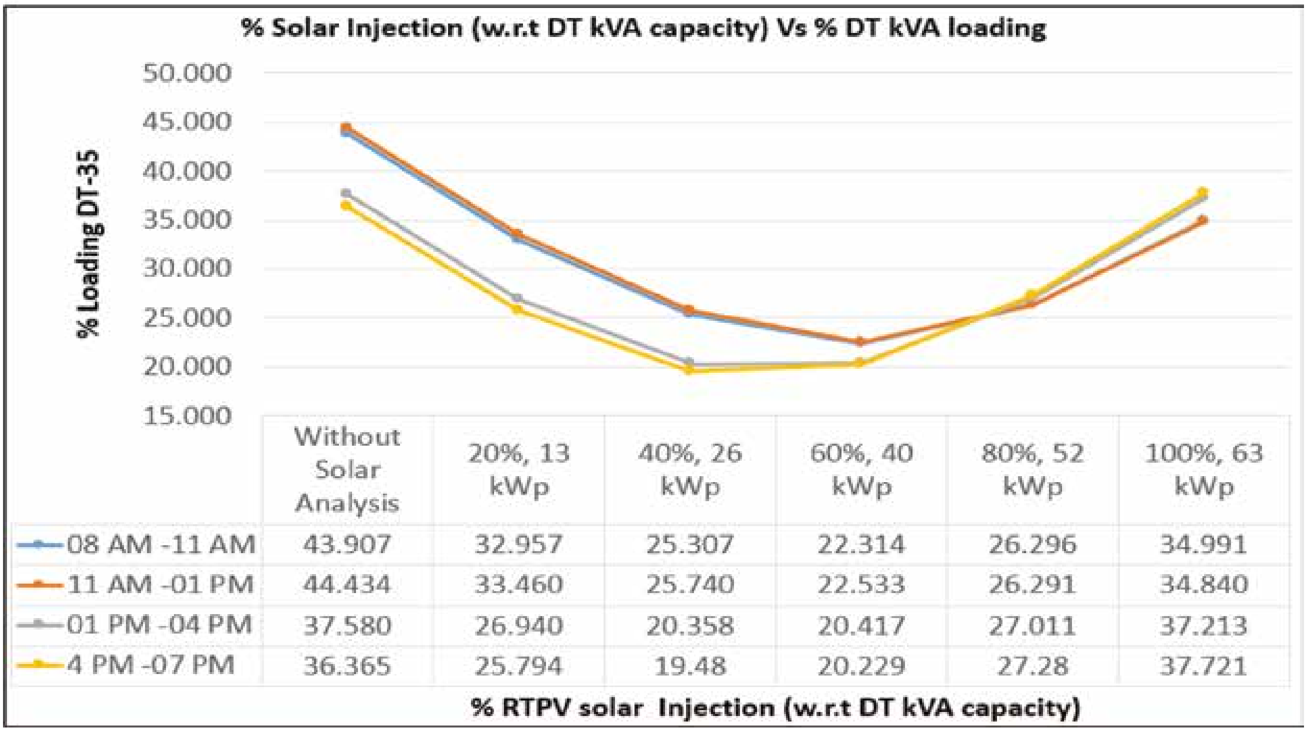
- No abnormality observed at feeder level even at 100% RTPV



	Without Solar	20%	40%	60%	80%	100%
08 AM -11 AM	956.10	924.82	895.49	866.77	840.72	814.70
11 AM -01 PM	967.55	936.21	906.81	878.02	851.90	825.82
01 PM -04 PM	822.73	792.14	763.60	735.76	710.52	685.26
4 PM -07 PM	796.02	765.57	737.19	709.52	684.45	659.35

Effect on DT -35 (11 kV/433 V, 63 kVA):

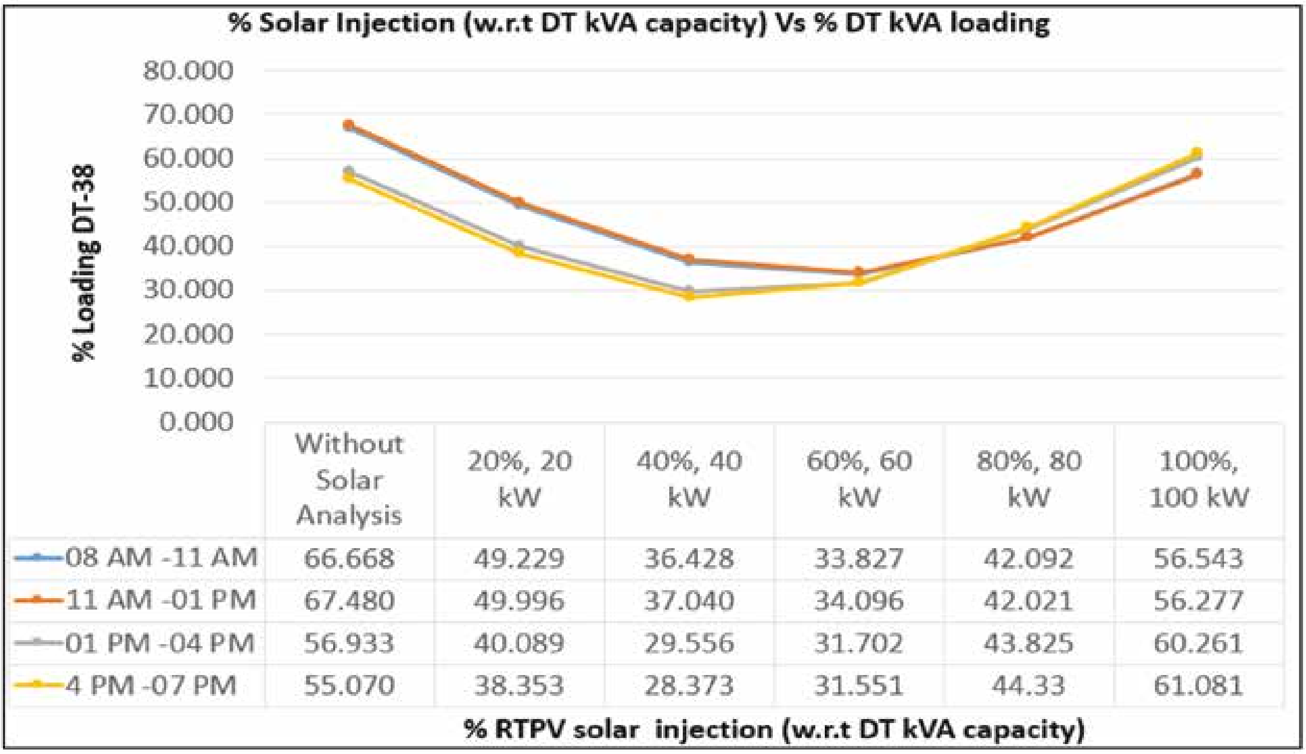
- Loading on DT first decreased with increase in RTPV
- Then loading on DT again increased when there is excess power available and reverse power flow starts back to DT
- It is observed with more initial loading on DT graph shifts towards right for reverse power flow
- Undervoltage observed on some LT circuit at 20% and 40% in all the scenarios but when RTPV increased beyond 40%, system becomes healthy



	Without Solar Analysis	20%, 13 kWp	40%, 26 kWp	60%, 40 kWp	80%, 52 kWp	100%, 63 kWp
08 AM -11 AM	43.907	32.957	25.307	22.314	26.296	34.991
11 AM -01 PM	44.434	33.460	25.740	22.533	26.291	34.840
01 PM -04 PM	37.580	26.940	20.358	20.417	27.011	37.213
4 PM -07 PM	36.365	25.794	19.48	20.229	27.28	37.721

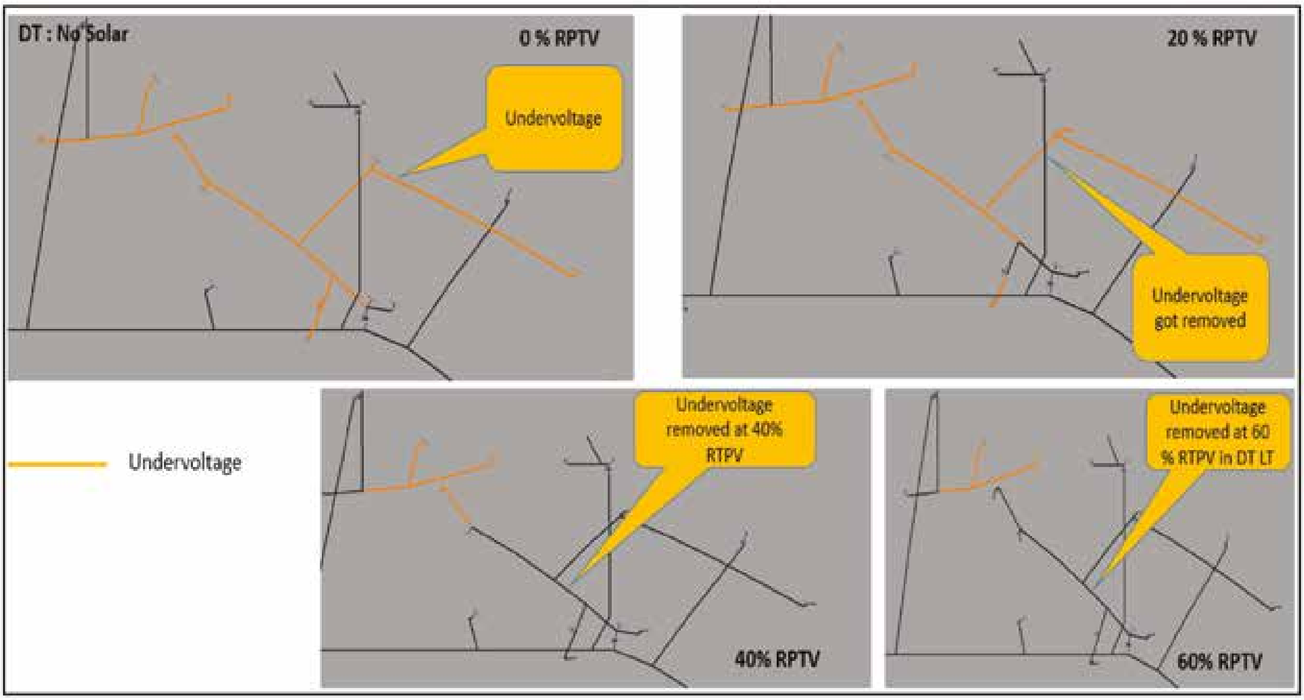
Effect on DT-38 (11 kV/433V, 100 kVA):

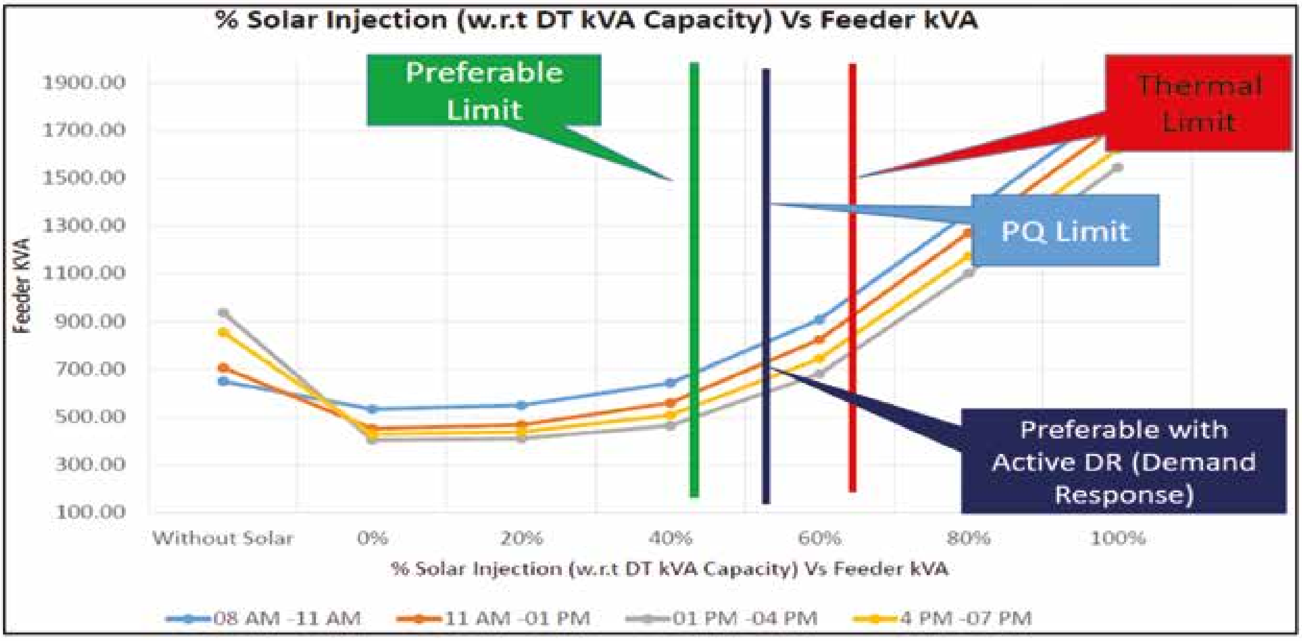
- In AS-IS RTPV connected was 200 kWp which is approximately 57% of DT capacity, so during load flow the RTPV connected kept constant at 200 kWp at 20% and 40%
- Reverse power flow observed even at As-Is and further increase in RTPV
- At 60% of DT capacity RTPV connected is 210 kWp, so there is slight increase in HT DT loading observed
- With further increase in RTPV, loading on HT consumer DT increased



Summary of Power Quality (PQ) Issues:

Time Slots	Over voltage (V > = 1.06 PU)	Under Voltage (V <= 0.94 PU)	Observations
08AM - 11AM	NONE	0 %, 20%, 40%	Undervoltage observed: For DT at 0%, 20 %, 40 % and for DT at 0 %, 20 %, 40 % of solar generation. After that as RTPV increased undervoltage disappear
11AM - 01PM	NONE	0 %, 20 %, 40 %	Undervoltage observed: For DT at 0%, 20 % and for DT at 0 %, 20 %, 40 % of solar generation. After that as RTPV increased undervoltage disappear
01PM - 04PM	NONE	0 %, 20 %, 40 %	Undervoltage observed: for Mahender Singh DT at 0%, 20 % and for SHEO RAM at 0 %, 20 %, 40 % of Solar Generation. After that as RTPV increased undervoltage disappear
04PM - 07PM	NONE	0 %, 20 %, 40 %	Undervoltage observed: for Mahender Singh DT at 0%, 20 % and for SHEO RAM at 0 %, 20 %, 40 % of Solar Generation. After that as RTPV increased undervoltage disappear. These have 8 hours supply only in day time that's why there is no use of RTPV

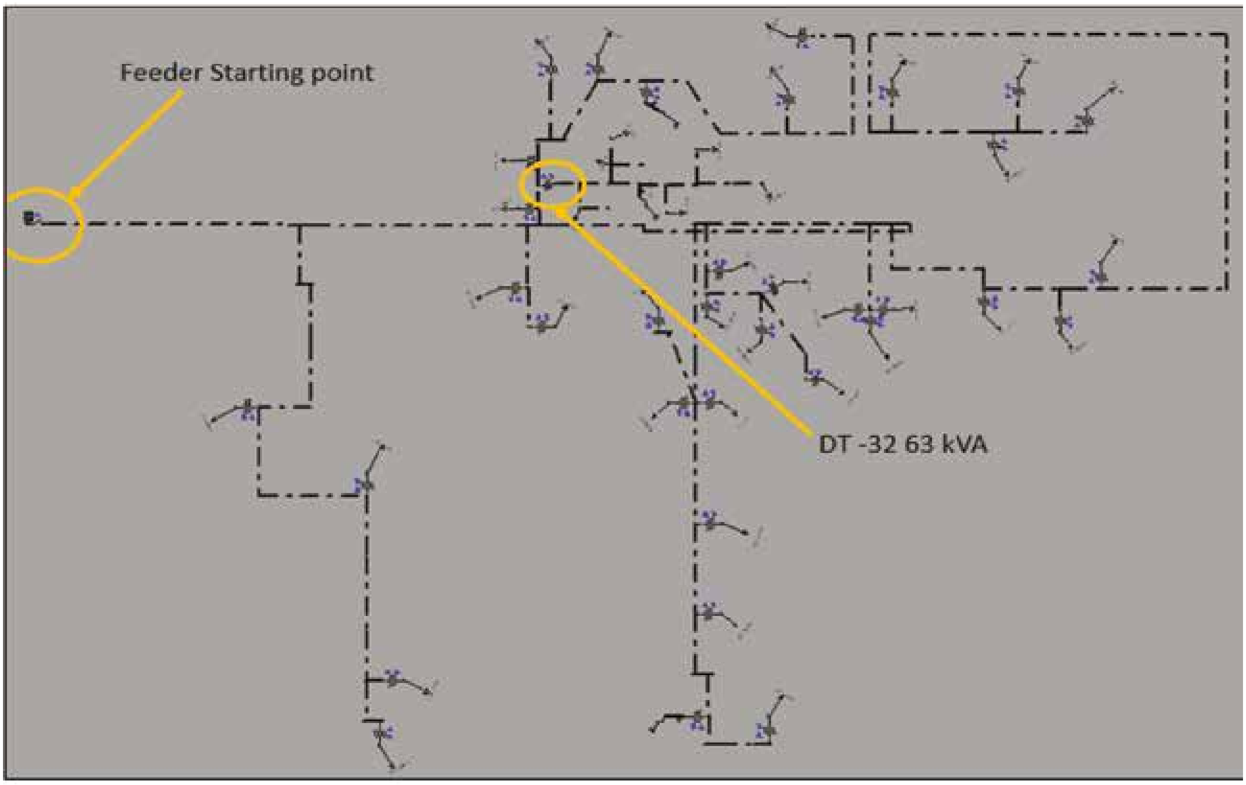

DT : No Solar
0 % RPTV
Undervoltage
20 % RPTV
Undervoltage got removed
Undervoltage
Undervoltage removed at 40% RTPV
40% RPTV
Undervoltage removed at 60 % RTPV in DT LT
60% RPTV


% Solar Injection (w.r.t DT kVA Capacity) Vs Feeder kVA
Preferable Limit
Thermal Limit
PQ Limit
Preferable with Active DR (Demand Response)
Feeder KVA
1900.00
1700.00
1500.00
1300.00
1100.00
900.00
700.00
500.00
300.00
100.00
Without Solar
0%
20%
40%
60%
80%
100%
% Solar Injection (w.r.t DT kVA Capacity) Vs Feeder kVA
08 AM -11 AM
11 AM -01 PM
01 PM -04 PM
4 PM -07 PM

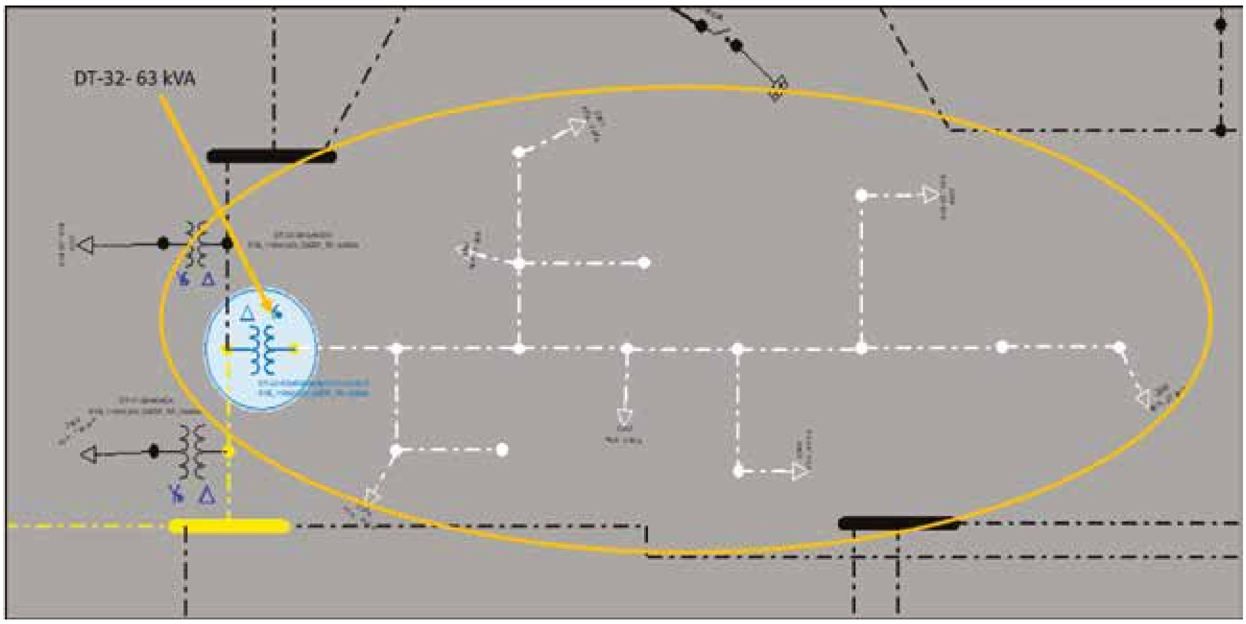
Annexure 2.3: Load Flow Analysis of BESCOM Feeder

Feeder details:

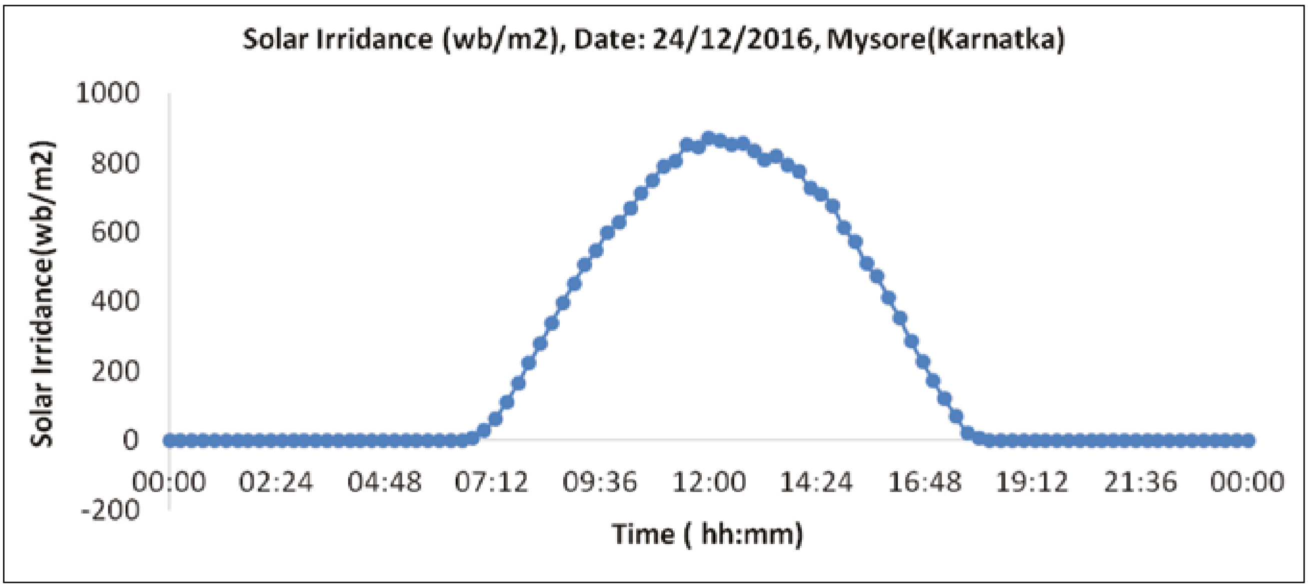
- Substation: 66/11 kV
- Total number of DTs on feeders: 36
- The study is done on: DT-32
- Length of feeder: 2.65 km
- Length of LT circuit: 600 m
- Number of solar RTPV at present: 2 connections (30 kWp and 7.2 kWp)
- Only one HT consumer with RTPV connected: 30 kWp



LT Circuit:



Solar Irradiance Curve: The solar insolation (W/m^2) with respect to time is collected from National Institute of Wind Energy for Minute & Hourly basis for 24 December 2016.



Load Flow Scenario:

In every scenario solar rooftop connection are increased to observe the behaviour on 11 kV feeder and LT network at both DT's. For DT-32 (11 kV/440 V, 63 kVA) following scenarios are run:

Objective of Study:

- To analyze the effect on 11 kV feeder & LT network by increasing RTPV injection

Software Tool: CYME (CYMDIST)

S. No	Time slot	Load flow run at time when DT is max loaded
1	8:00- 11 AM	10 AM
2	11:00 -01:00 PM	11 :00 AM
3	01:00-04:00 PM	04:00 PM
4	04:00-07:00 PM	5:00 PM

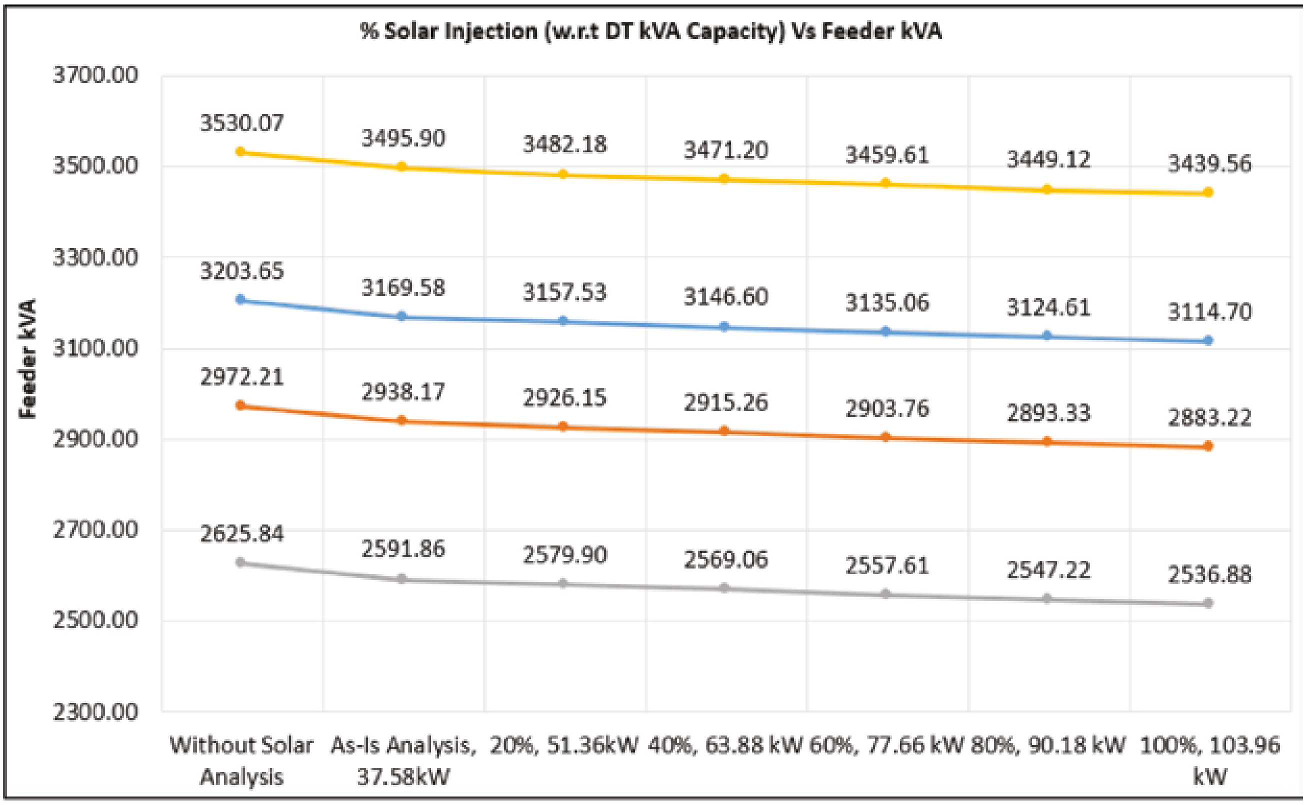
RTPV Scenarios for DT - 32(63 kVA) / Time Slots / No. of solar RTVP are increases	Scenario 1 Time 8-11 AM	Scenario 2 Time 11- 1 PM	Scenario 3 Time 1- 4 PM	Scenario 4 Time 4- 7 PM
Without Solar	-	-	-	-
As-Is (37.58kW)	0 kW	0 kW	0 kW	0 kW
20 % of DT Capacity	13 kW	13 kW	13 kW	13 kW
40 % of DT Capacity	25 kW	25 kW	25 kW	25 kW
60 % of DT Capacity	38 kW	38 kW	38 kW	38 kW
80 % of DT Capacity	50 kW	50 kW	50 kW	50 kW
100 % of DT Capacity	63 kW	63 kW	63 kW	63 kW

Effect on 11 kV feeder:

- There is no reverse power flow observed at feeder level even RTPV at 100% of DT capacity in both LT circuits. Loading on feeders decreased as more RTPV are connected

Observation:

- No abnormality observed at feeder level even at 100% RTPV

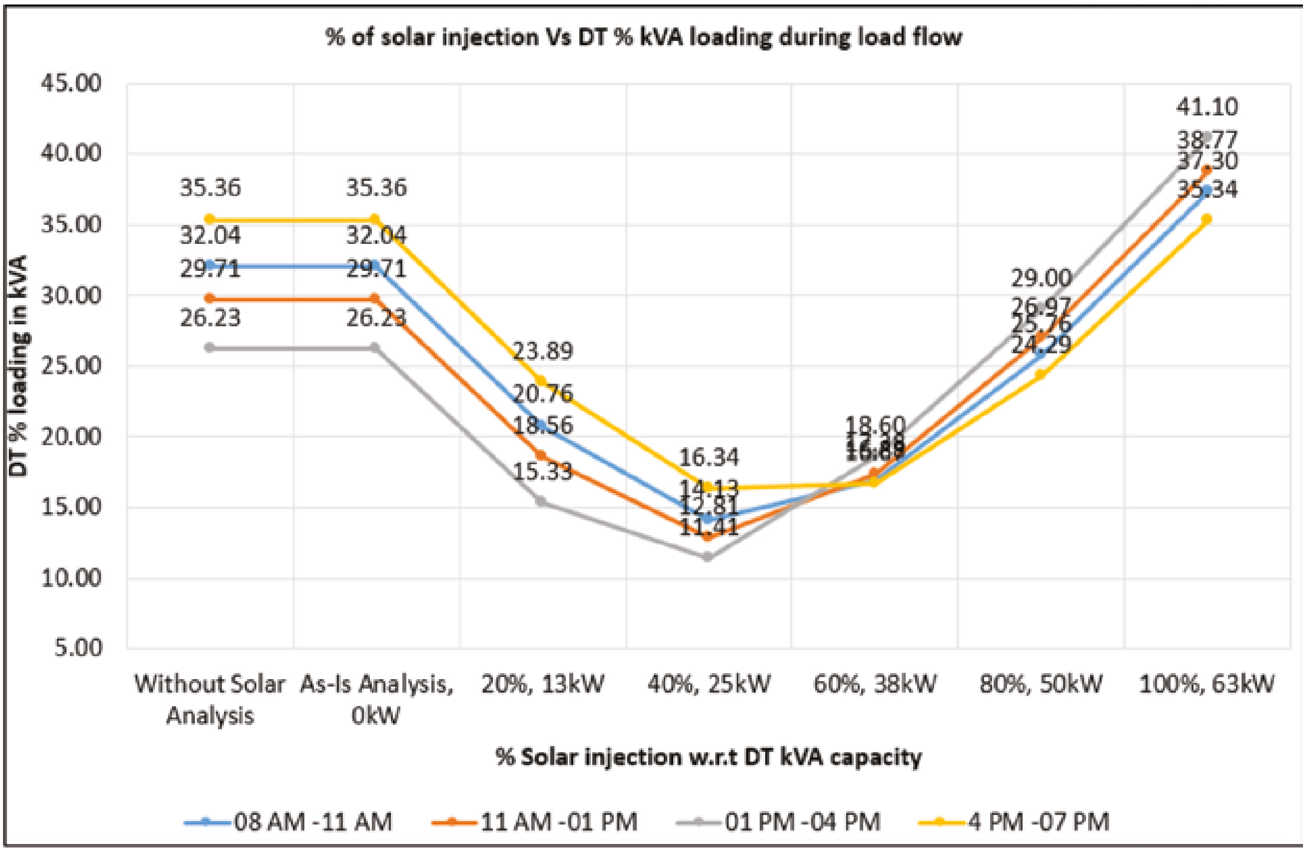


Effect on DT-32 (11 kV/440 V, 63 kVA):

- Loading on DT first decreased with increase in RTPV
- Then loading on DT again increased when there is excess power available and reverse power flow starts back to DT

Power Quality (PQ) Issues:

- Power factor found low on some LT sections during 40% - 80% solar injection, when reverse power flow occurs
- No thermal issue is found
- Voltage near solar end increases but within permissible limit



Effect on LT side of DT:

- Loading on DT first decreased with increase in RTPV
- Then loading on DT again increased when there is excess power available and reverse power flow starts back to DT
- It is observed with more initial loading on DT graph shifts towards right for reverse power flow

Power Quality (PQ) Issues:

- Power factor found low during 40% -80% solar injection on some of LT sections, when reverse power flow occurs at DT side. These LT sections are near to Solar generating loads. E.g. at 2354 XLPE cable, pf found low between 40% and 80% solar injection during 1 to 4 pm
- Similarly, lower power factor is observed in some LT section near solar generation RTPV in between 40 % to 80% RTPV increase during time interval 8 to 11 am, 11:00 to 01 :00 pm and 4 :00 to 07 :00 pm
- It is observed that during all time interval reverse power flow occurs between 40 to 60% RTPV solar generation and this reverse power flow occurs first if loading is less and later if loading is more at DT end. But during reverse power flow active power becomes less and power factor becomes low beyond limit, so reactive power compensation is needed. This is section where smart inverter and power factor capacitor bank is needed

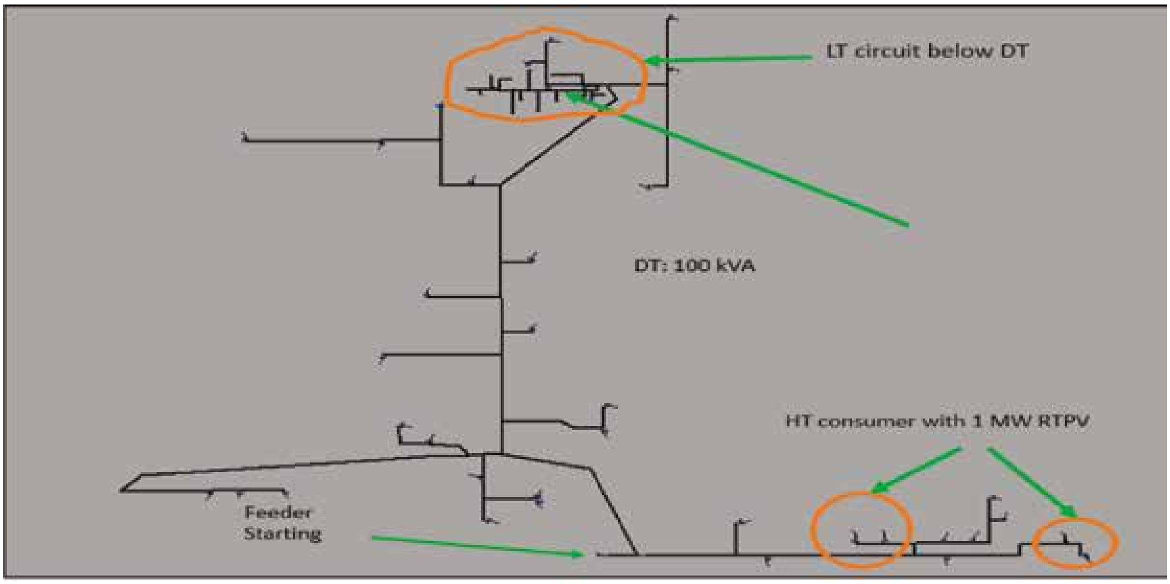
Summary of Power Quality (PQ) Issues:

Time Slots	Over Voltage (V > = 1.06 pu)	Under Voltage (V <= 0.94 pu)	Power factor (0.85 to 0.99)	Observations
08 AM – 11 AM	NONE	NONE	Section 2354, 2345 and also on DT	Undervoltage observed: No undervoltage is observed beyond permissible limit, but it improves as RTPV is increased. Overvoltage: No overvoltage is observed on any section as oversize conductor of 90 mm2 were used in LT side. **Power factor:** • Lower power is observed on DT when loading on DT decreased due to increased RTPV in each scenario i.e. at 20%, to 60%. After 60% power factor improves on DT due to more reverse power flow as loading on DT increased • In sections near to RTPV generation e.g. 2354, 2345 XLPE cables, lower power factor is observed between 40 to 80% increase in RTPV
11 AM – 01 PM	NONE	NONE		
01 PM – 04 PM	NONE	NONE		
04 PM – 07 PM	NONE	NONE		

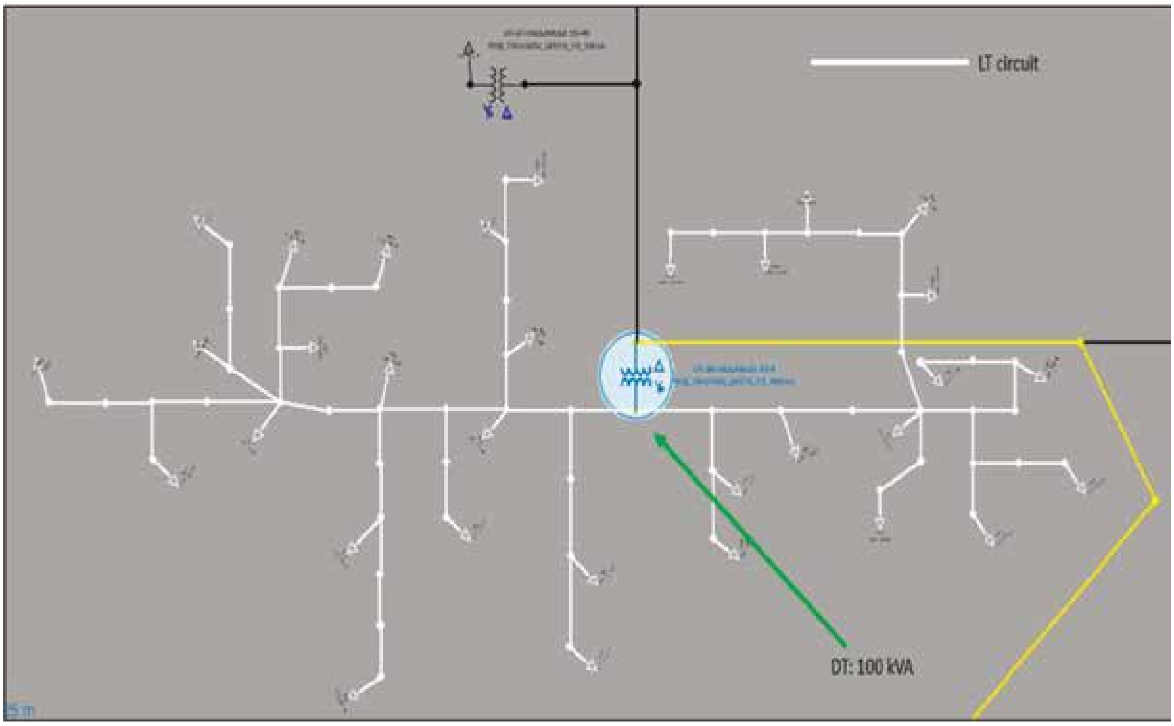
Annexure 2.4: Load Flow Analysis of APSPDCL Feeder

Feeder details:

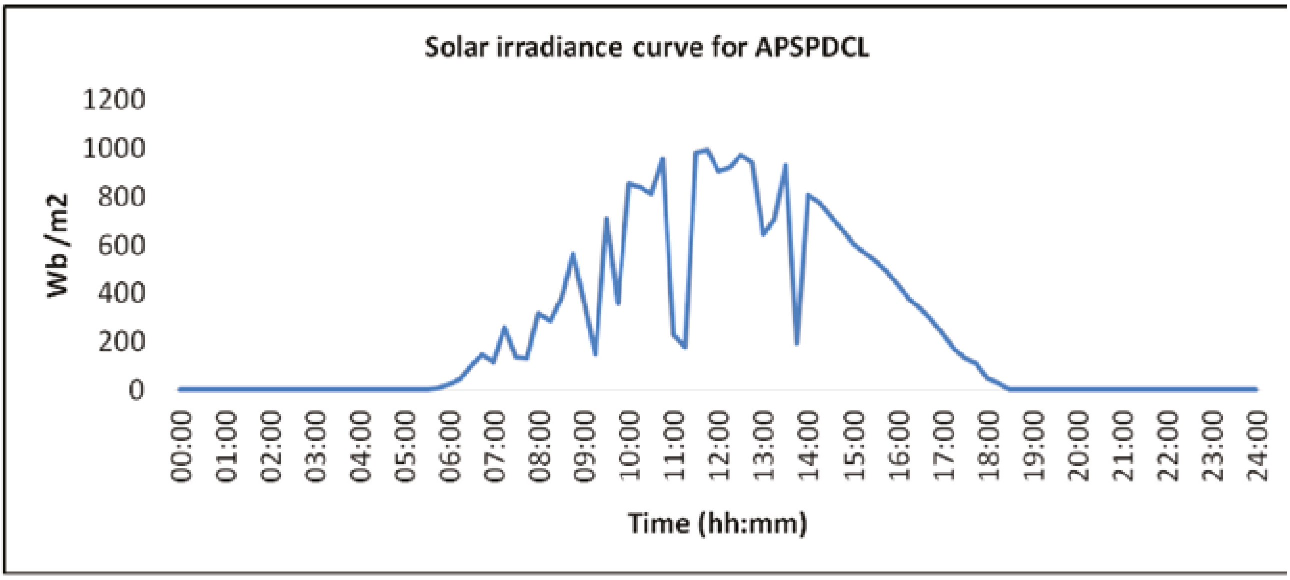
- Substation: 33/11 kV
- Total number of DTs on feeder: 36
- Distribution Transformer (DT): 100 KVA
- Voltage Level: 11 kV/415 V
- Length of feeder: 15.64 km
- Number of consumers connected to DT: 379
- Length of LT circuit: 2.645 km
- Number of solar RTPV at present: Number of solar RTPV at DT level but 4 HT consumers (out of 5 HT consumers) have total RTPV connected 1 MW



LT circuit:



Solar Irradiance Curve: The solar insolation (W/m²) with respect to time is collected from National Institute of Wind Energy for Minute & Hourly basis for 21 June 2018.



Load Flow Scenario:

In every scenario solar rooftop connection are increased to observe the behaviour on 11 kV feeder and LT network at DT (100 kVA) & HT consumer level.

Objective of Study:

- To analyze the effect on 11 kV Feeder & LT network by increasing RTPV injection

Software Tool: CYME (CYMDIST)

Time Slots:

S. No	Time Slot	Load Flow run at Time when DT is max Loaded
1	8:00 AM - 11:00 AM	11:00 AM
2	11:00 AM - 01:00 PM	12:30 PM
3	01:00 PM - 04:00 PM	04:00 PM
4	04:00 PM - 07:00 PM	04:30 PM

Already connected

No. of solar RTVP are increases

Time Slots	Scenario 1 Time 8-11 AM	Scenario 2 Time 11- 1 PM	Scenario 3 Time 1- 4 PM	Scenario 4 Time 4- 7 PM
Without solar	-	-	-	-
As-Is	0 kWp	0 kWp	0 kWp	0 kWp
20% of DT capacity	20 kWp	20 kWp	20 kWp	20 kWp
40% of DT capacity	40 kWp	40 kWp	40 kWp	40 kWp
60% of DT capacity	60 kWp	60 kWp	60 kWp	60 kWp
80% of DT capacity	80 kWp	80 kWp	80 kWp	80 kWp
100% of DT capacity	100 kWp	100 kWp	100 kWp	100 kWp

Scenarios run for HT consumer:

- HT consumer 1: DT-33
- HT DT rating: 350 kVA

Already connected

No. of solar RTVP are increases

Time Slots	Scenario 1 Time 8-11 AM	Scenario 2 Time 11- 1 PM	Scenario 3 Time 1- 4 PM	Scenario 4 Time 4- 7 PM
Without Solar	-	-	-	-
As-Is	200 kWp	200 kWp	200 kWp	200 kWp
20% of DT capacity	200 kWp	200 kWp	200 kWp	200 kWp
40% of DT capacity	200 kWp	200 kWp	200 kWp	200 kWp
60% of DT capacity	210 kWp	210 kWp	210 kWp	210 kWp
80% of DT capacity	280 kWp	280 kWp	280 kWp	280 kWp
100% of DT capacity	350 kWp	350 kWp	350 kWp	350 kWp

- HT consumer 2: DT-32
- DT rating: 630 kVA

Already connected

No. of solar RTVP are increases

Time Slots	Scenario 1 Time 8-11 AM	Scenario 2 Time 11- 1 PM	Scenario 3 Time 1- 4 PM	Scenario 4 Time 4- 7 PM
Without Solar	-	-	-	-
As-Is	200 kWp	200 kWp	200 kWp	200 kWp
20% of DT capacity	200 kWp	200 kWp	200 kWp	200 kWp
40% of DT capacity	252 kWp	252 kWp	252 kWp	252 kWp
60% of DT capacity	378 kWp	378 kWp	378 kWp	378 kWp
80% of DT capacity	504 kWp	504 kWp	504 kWp	504 kWp
100% of DT capacity	630 kWp	630 kWp	630 kWp	630 kWp

- HT consumer 3: DT-35
- DT rating: 350 kVA

Already connected

No. of solar RTVP are increases

Time Slots	Scenario 1 Time 8-11 AM	Scenario 2 Time 11- 1 PM	Scenario 3 Time 1- 4 PM	Scenario 4 Time 4- 7 PM
Without Solar	-	-	-	-
As-Is	100 kWp	100 kWp	100 kWp	100 kWp
20% of DT capacity	100 kWp	100 kWp	100 kWp	100 kWp
40% of DT capacity	140 kWp	140 kWp	140 kWp	140 kWp
60% of DT capacity	210 kWp	210 kWp	210 kWp	210 kWp
80% of DT capacity	280 kWp	280 kWp	280 kWp	280 kWp
100% of DT capacity	350 kWp	350 kWp	350 kWp	350 kWp

- HT consumer 4: DT-34
- DT rating: 950 kVA

Time Slots	Scenario 1 Time 8-11 AM	Scenario 2 Time 11- 1 PM	Scenario 3 Time 1- 4 PM	Scenario 4 Time 4- 7 PM
Without Solar	-	-	-	-
As-Is (Already connected)	500 kWp	500 kWp	500 kWp	500 kWp
20% of DT capacity	500 kWp	500 kWp	500 kWp	500 kWp
40% of DT capacity	500 kWp	500 kWp	500 kWp	500 kWp
60% of DT capacity	570 kWp	570 kWp	570 kWp	570 kWp
80% of DT capacity	760 kWp	760 kWp	760 kWp	760 kWp
100% of DT capacity	950 kWp	950 kWp	950 kWp	950 kWp

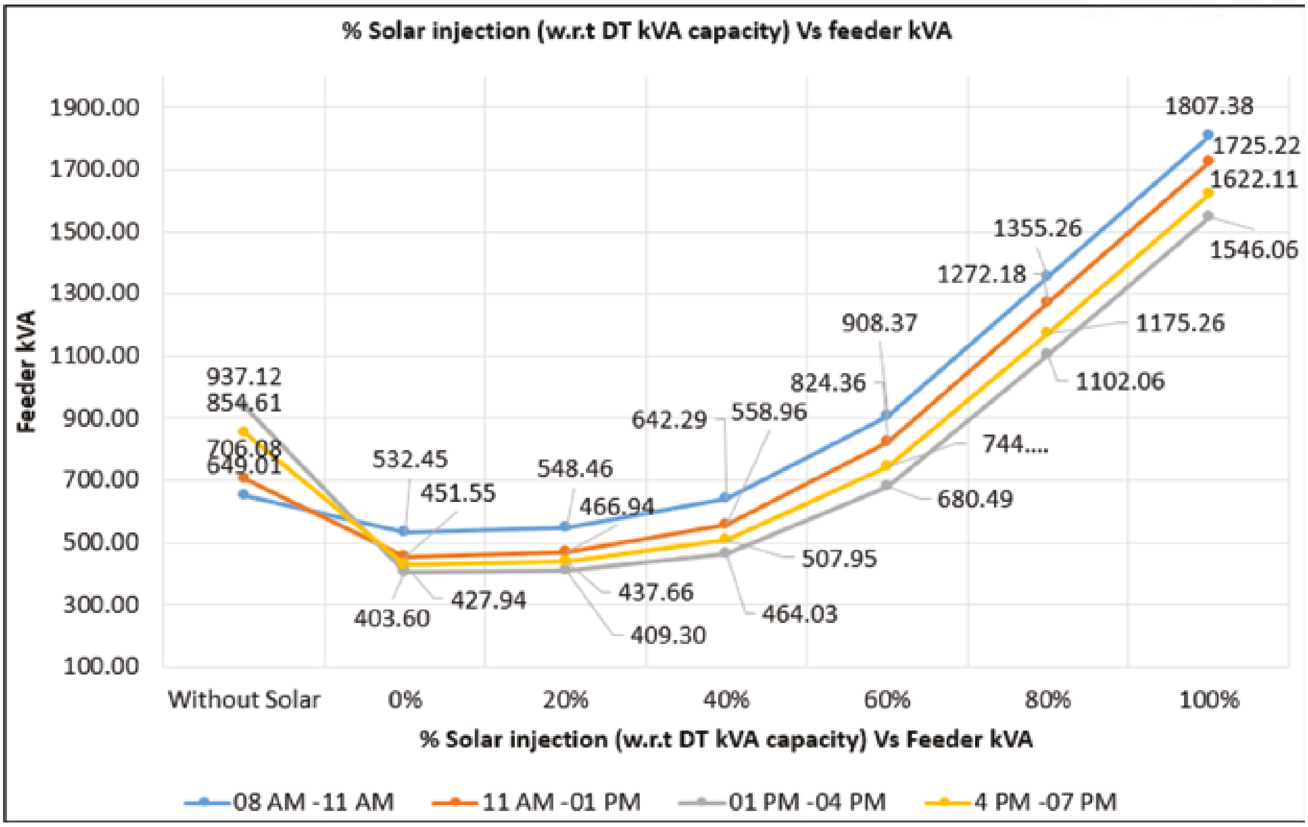
No. of solar RTVP are increases

Effect on 11 kV feeder:

- Reverse power flow is observed at feeder level even in As-Is scenarios because HT consumer
- Loading on feeders increased as more RTPV are connected

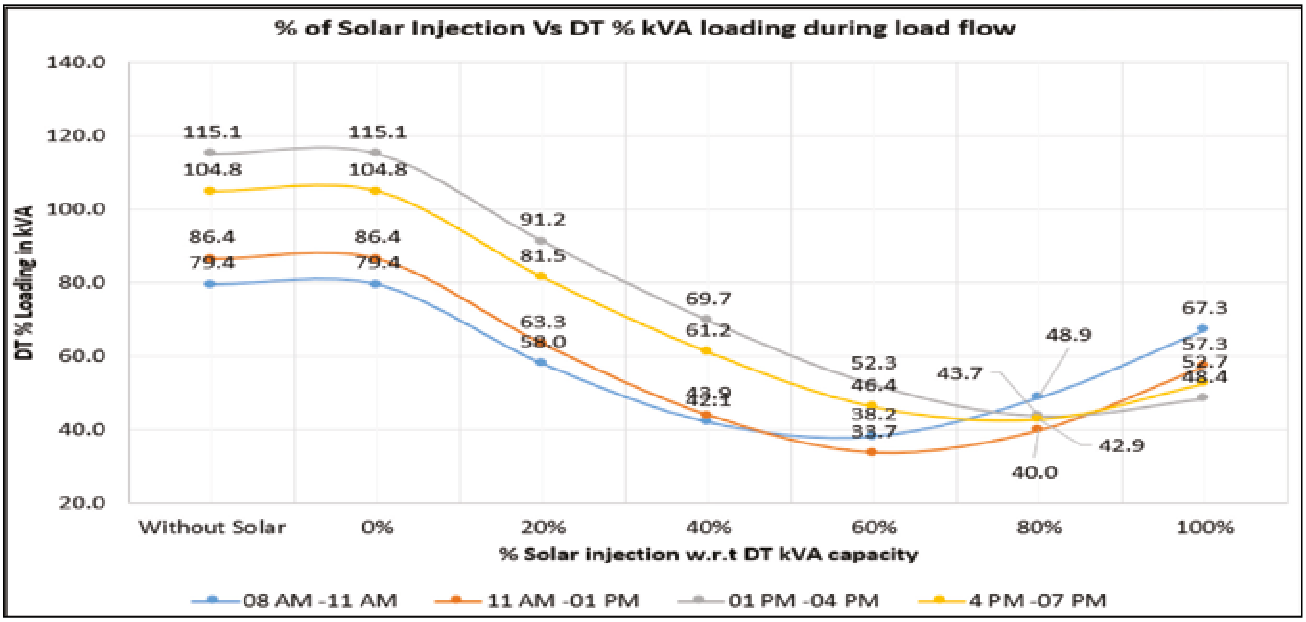
Observation:

- Overloading observed on HT consumer DT when RTPV increased beyond 60%
- Voltage rise on 11 KV feeder is also found on some section but within 2% limit
- No overloading observed in any section of feeder even at 100% loading



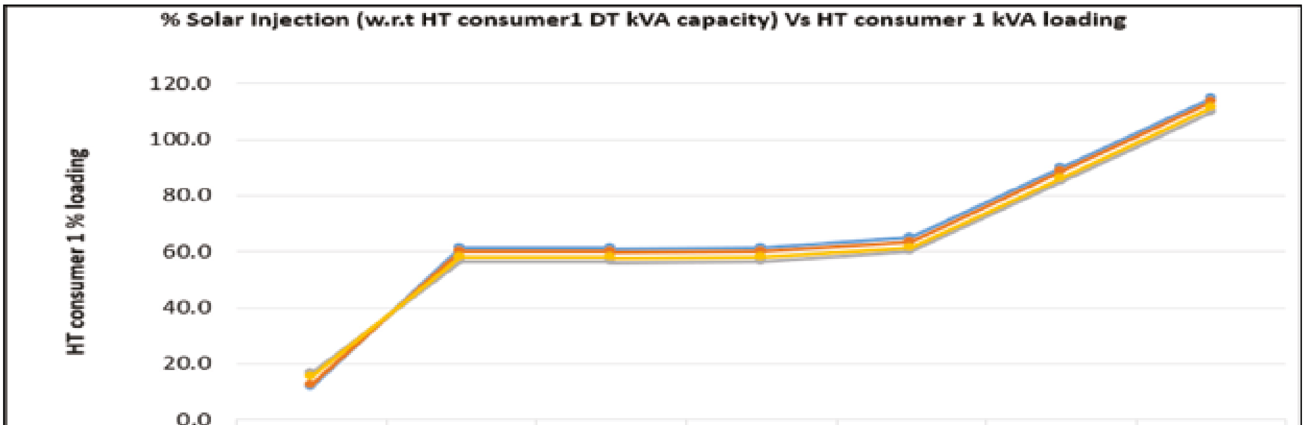
Effect on DT (11 kV/415 V, 100 kVA):

- Loading on DT first decreased when generation in consumed at DT end
- The loading on DT again increased when there is excess power available and reverse power flow starts back to DT and Feeder
- It is observed with more initial loading on DT graph shifts towards right for reverse power flow



Effect on HT consumer 1, DT Name: HT consumer 1, DT name: DT-33-HT, 11 KV/415V, 350 kVA

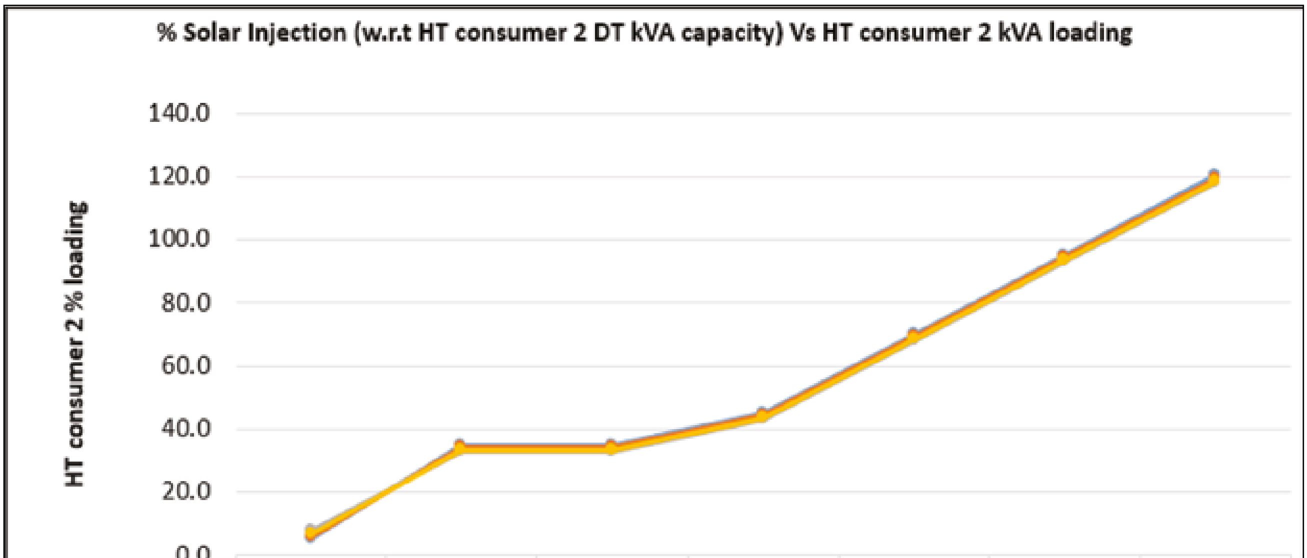
- In As-Is RTPV connected was 200 kWp which is approximately 57% of DT capacity, so during load flow the RTPV connected kept constant at 200 kWp at 20% and 40%.
- Reverse power flow observed even at As-is and further increase in RTPV
- At 60% of DT capacity RTPV connected is 210 kWp so there is slight increase in HT DT loading observed
- With further increase in RTPV, loading on HT consumer DT increased



	Without Solar Analysis	As-Is, 200KW	20%, 200 kW	40%, 200 kW	60%, 210 kW	80%, 280 KW	100%, 350 kW
08 AM -11 AM	11.6	61.5	61.5	61.5	65.1	90.0	115.0
11 AM -01 PM	12.6	60.0	60.0	60.0	63.6	88.6	113.5
01 PM -04 PM	16.7	56.4	56.4	56.4	60.0	84.9	109.8
4 PM -07 PM	15.2	57.9	57.9	57.9	61.5	86.4	111.3

Effect on HT consumer 2, DT name: DT-32-HT, 11 kV/415 V, 630 kVA:

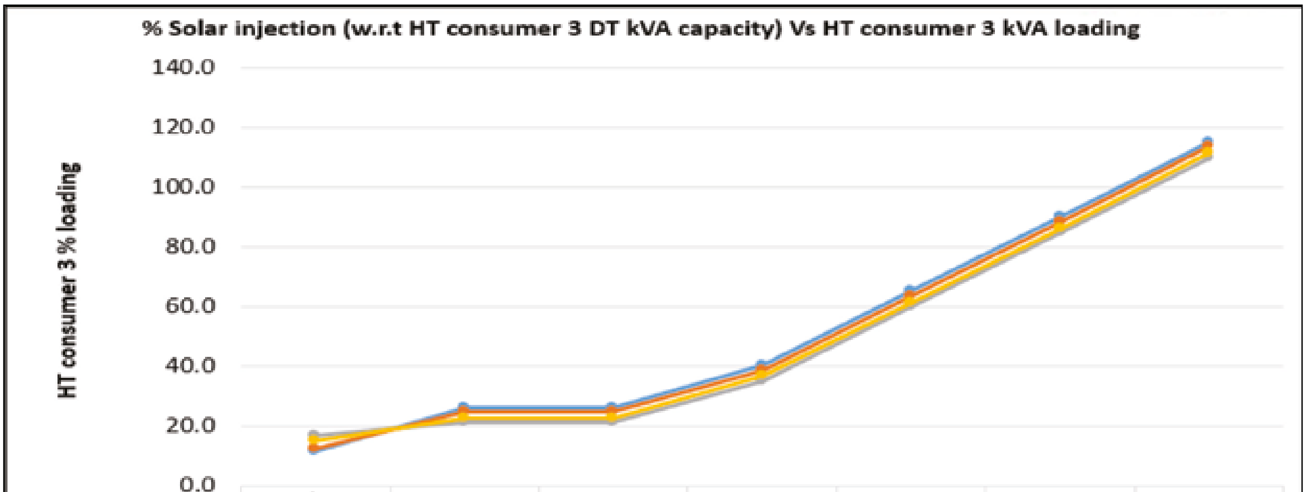
- In As-Is RTPV connected was 200 kWp which was approximately more than 31% of DT capacity, so during load flow the RTPV connected kept constant at 200 kWp at 20%.
- Reverse power flow observed even at As-is and further increase in RTPV
- At 40% RTPV connected was 252 kWp so there is slight increase in HT DT loading observed
- With further increase in RTPV, loading on HT consumer DT increased



	Without Solar Analysis	As-Is, 200 kW	20%, 200 kW	40%, 252 kW	60%, 378 kW	80%, 504 KW	100%, 630 kW
08 AM -11 AM	5.4	35.0	35.0	45.3	70.3	95.3	120.3
11 AM -01 PM	5.9	34.4	34.4	44.7	69.6	94.6	119.6
01 PM -04 PM	7.8	32.6	32.6	42.9	67.9	92.9	117.9
4 PM -07 PM	7.1	33.3	33.3	43.6	68.6	93.6	118.6

Effect on HT consumer 3, DT name: DT-35 HT, 11 kV/415 V, 350 kVA:

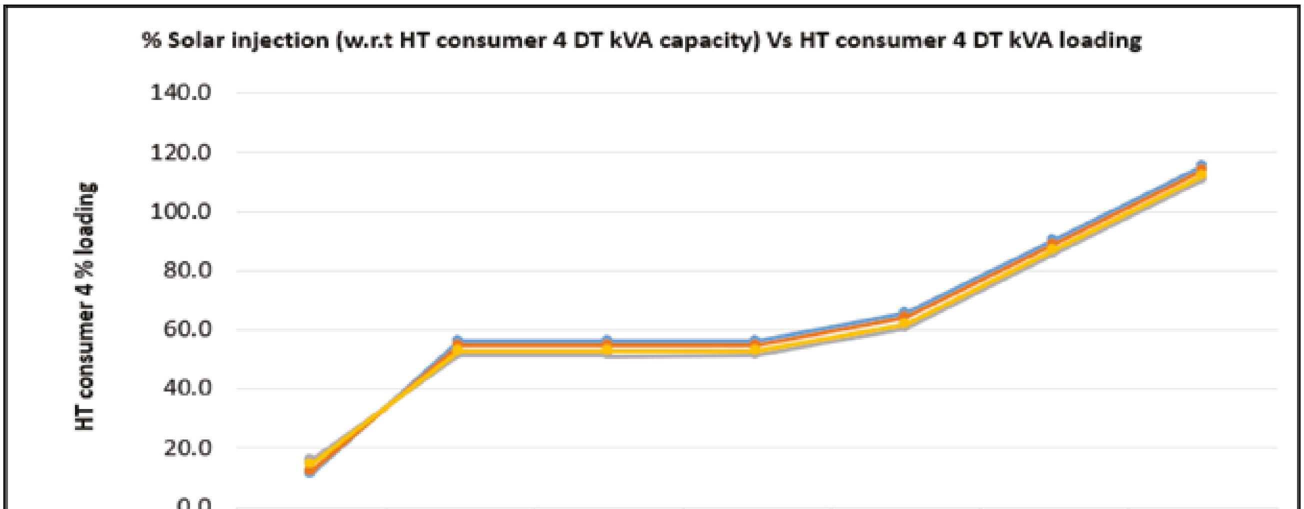
- In AS-IS RTPV connected was 100 kWp which was approximately more than 28% of DT capacity, so during load flow the RTPV connected kept constant at 200 kWp up to 20%
- Reverse power flow observed even at As-Is and further increase in RTPV
- At 40% RTPV connected was 140 kWp so there is slight increase in HT DT loading observed
- With further increase in RTPV, loading on HT consumer DT increased



	Without Solar Analysis	As-Is, 100 kW	20%,100 kW	40%, 140 kW	60%, 210 kW	80%, 280 Kw	100%, 350 kW
08 AM -11 AM	11.6	26.1	26.1	40.2	65.1	90.0	115.0
11 AM -01 PM	12.6	24.6	24.6	38.7	63.6	88.6	113.5
01 PM -04 PM	16.7	21.3	21.3	35.2	60.0	84.9	109.8
4 PM -07 PM	15.2	22.7	22.7	36.7	61.5	86.4	111.3

Effect on HT consumer 4, DT name: DT-34-HT, 11 kV/415 V, 950 kVA:

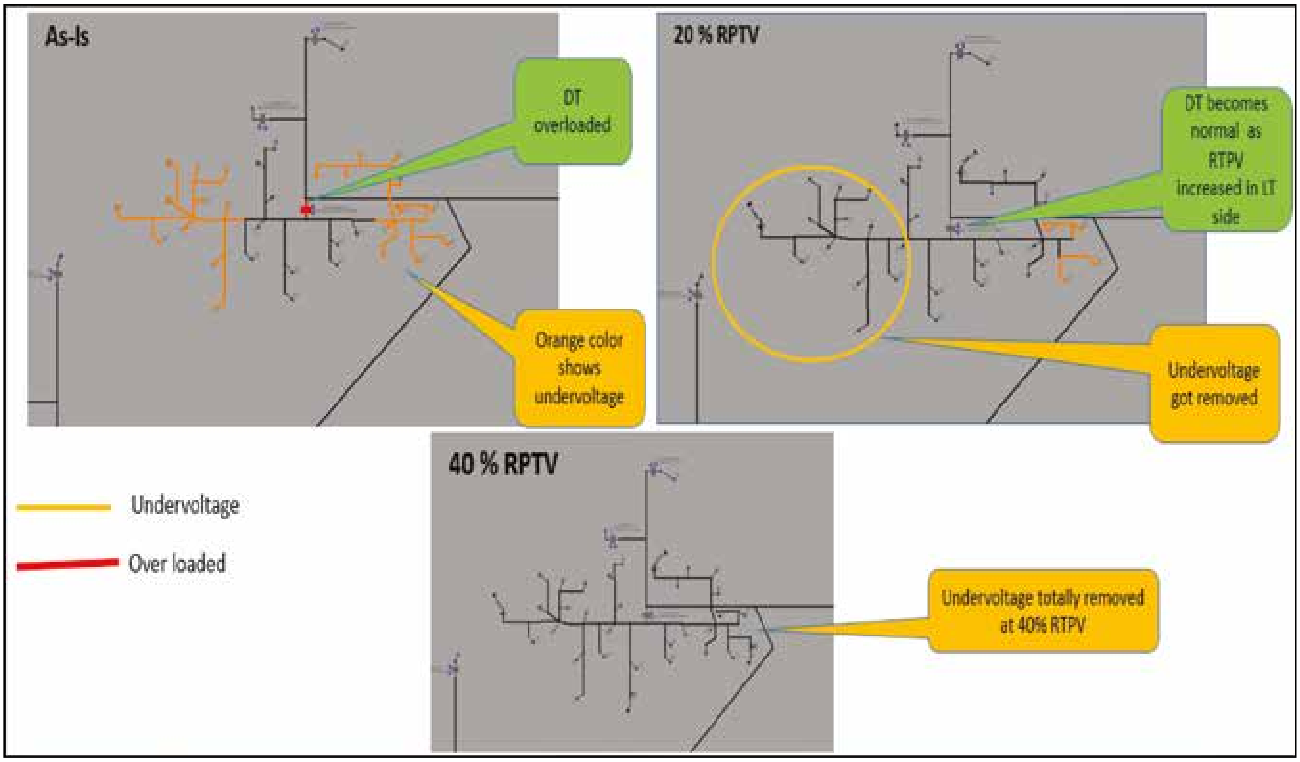
- In AS-IS RTPV connected was 500 kWp which was approximately more than 52 % of DT capacity, so during load flow the RTPV connected kept constant at 200 kWp up to 20% & 40%
- Reverse power flow observed even at As-Is and further increase in RTPV
- At 60% RTPV connected was 570 kWp so there is slight increase in HT DT loading observed
- With further increase in RTPV, loading on HT consumer DT increased

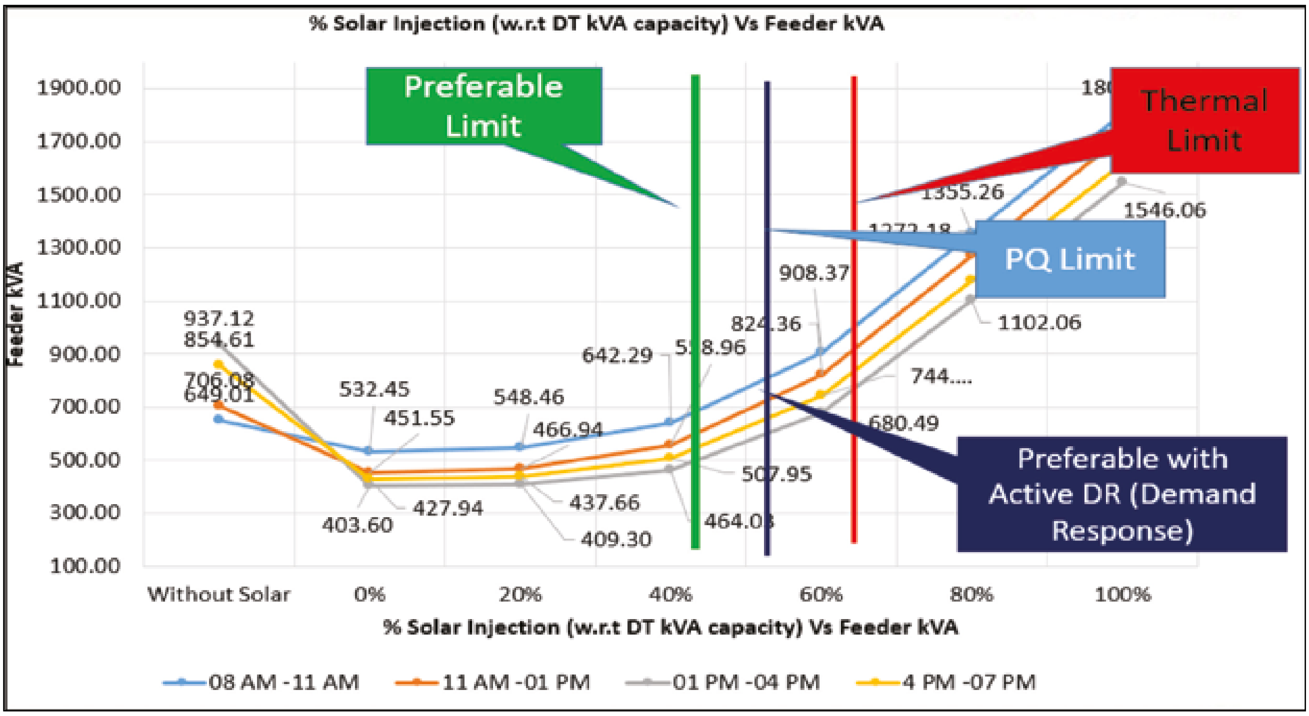


	Without Solar Analysis	As-Is, 500 kW	20%, 500 kW	40%, 500 kW	60%, 570 kW	80%, 760 Kw	100%, 950 kW
08 AM -11 AM	11.1	56.3	56.3	56.3	65.5	90.4	115.4
11 AM -01 PM	12.1	54.9	54.9	54.9	64.1	89.0	114.0
01 PM -04 PM	16.0	51.4	51.4	51.4	60.6	85.5	110.5
4 PM -07 PM	14.6	52.9	52.9	52.9	62.0	86.9	111.9

Summary of Power Quality (PQ) Issues:

Time Slots	Over Voltage (V > = 1.06 PU)	Under Voltage (V <= 0.94 PU)	Observations
08:00 AM – 11:00 AM	NONE	NONE	At 100% RTPV, overloading observed at all the HT consumers
11:00 AM – 01:00 PM	NONE	NONE	At 100% RTPV, overloading observed at all the HT consumers. Power factor decreased at higher RTPV. There should be power.
01:00 PM – 04:00 PM	NONE	0% Solar, 1002 kWp (AS-IS), 1022 kWp (20% RTPV)	Under voltage observed on some LT section of DT and after 20% RTPV under voltage removed due to more injection of RTPV. At 100 % RTPV, overloading observed at all the HT consumers DT.
04:00 PM – 07:00 PM	NONE	0% Solar, 1002 kWp (AS-IS)	Under voltage observed on some LT section of DT and after 20% RTPV under voltage removed due to more injection of RTPV. At 100% RTPV, overloading observed at all the HT consumers DT.

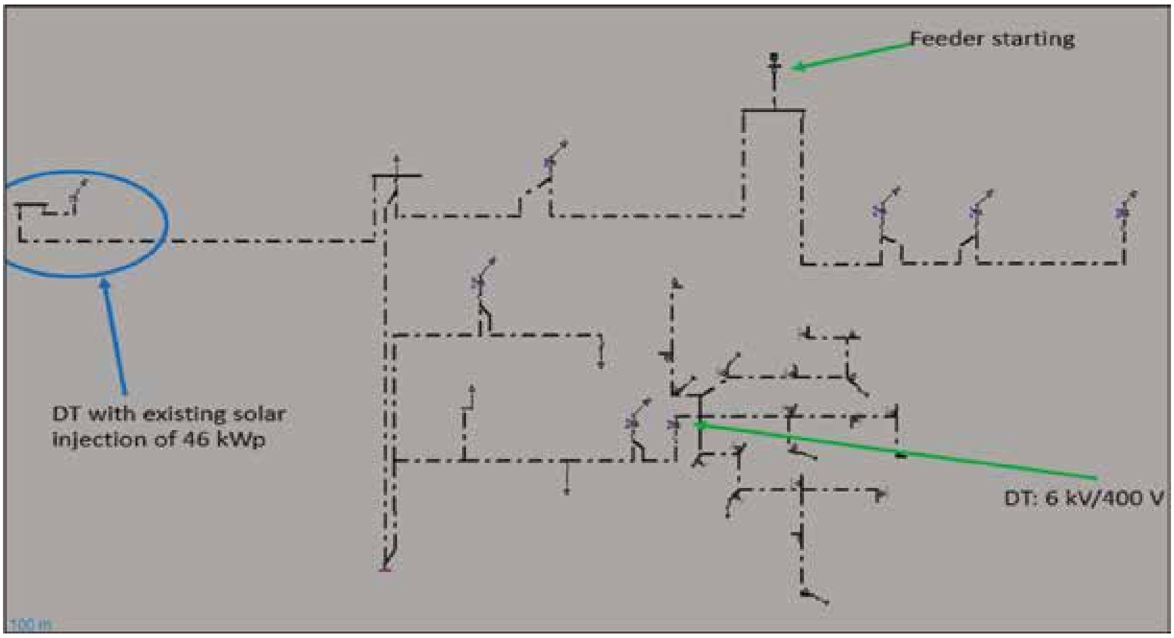




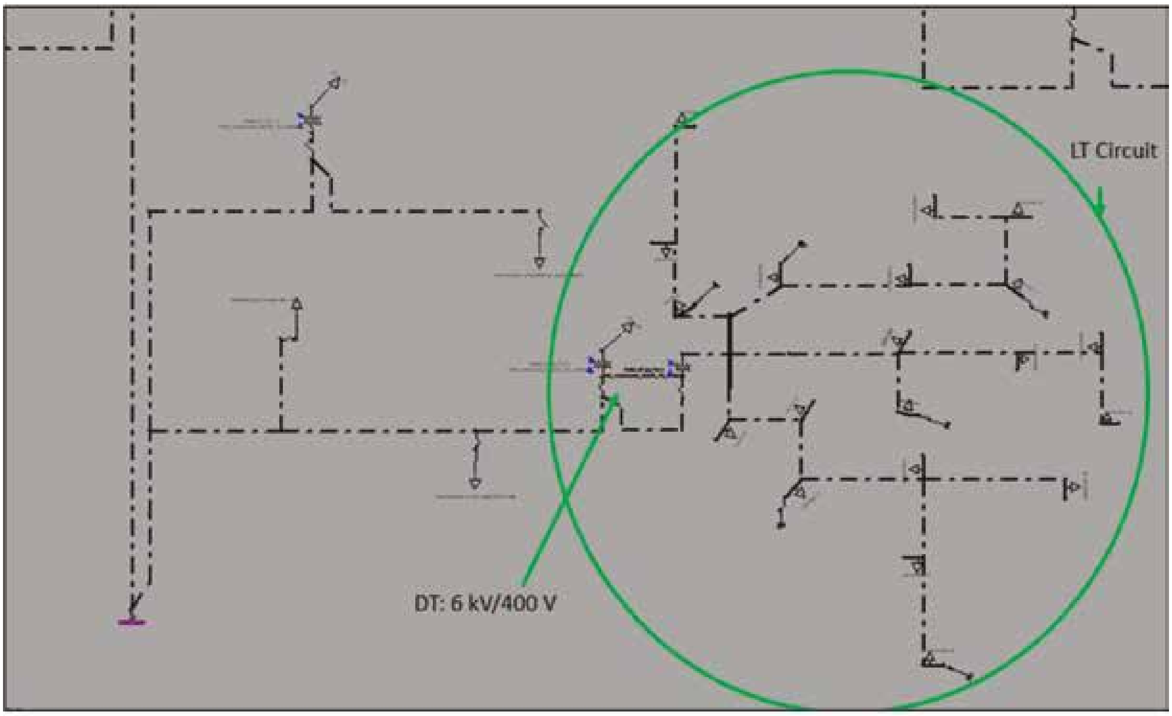
% Solar Injection (w.r.t DT kVA capacity) Vs Feeder kVA
Preferable Limit
Thermal Limit
PQ Limit
Preferable with Active DR (Demand Response)
Feeder kVA
1900.00
1700.00
1500.00
1300.00
1100.00
900.00
700.00
500.00
300.00
100.00
Without Solar
0%
20%
40%
60%
80%
100%
937.12
854.61
706.08
649.01
532.45
451.55
548.46
466.94
642.29
824.36
908.37
1355.26
1546.06
1102.06
744....
680.49
507.95
464.03
427.94
403.60
437.66
409.30
% Solar Injection (w.r.t DT kVA capacity) Vs Feeder kVA
08 AM -11 AM
11 AM -01 PM
01 PM -04 PM
4 PM -07 PM

Annexure 2.5: Load Flow Analysis of CESC Feeder

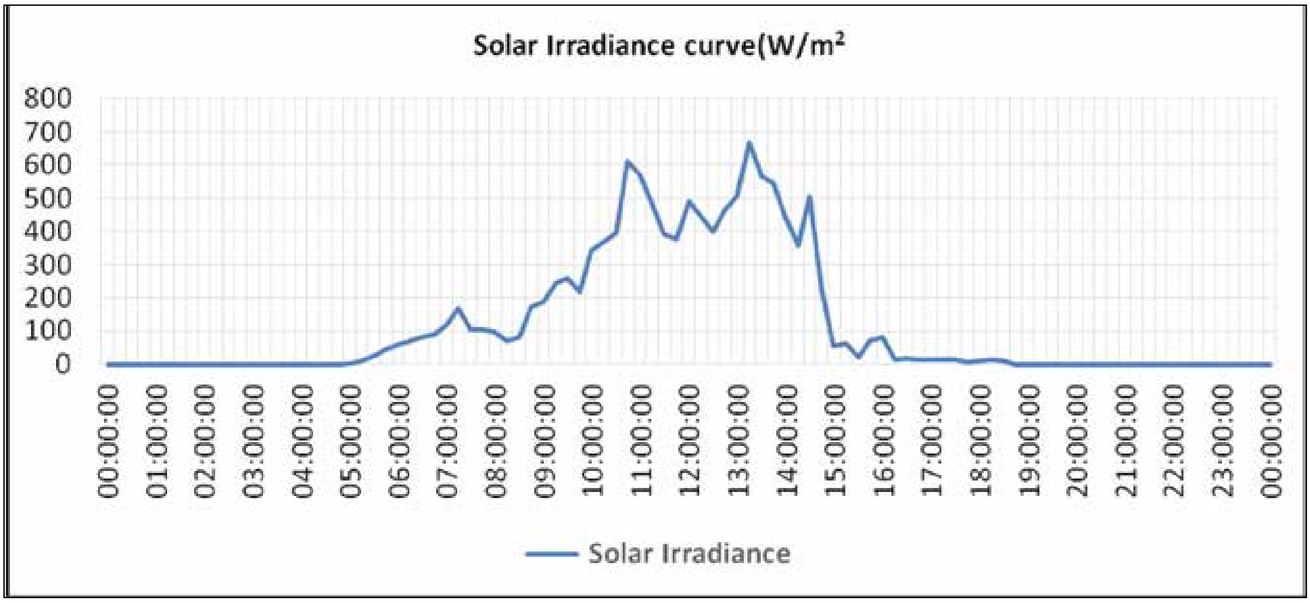
- Distribution Transformer (DT): 315 kVA
- Voltage level: 6 kV/400 V
- Length of feeder: 7.593 km
- Number of consumers: 198
- Length of LT circuit: 4.146 km
- Number of solar RTPV at present: No solar RTPV was present at DT
- In As-Is scenarios: DT (315 kVA) with 46 kWp solar injection



LT circuit:



Solar irradiance Curve: The solar insolation (W/m^2) with respect to time is collected from National Institute of Wind Energy for Minute & Hourly basis for 31 May 2018.



Load Flow Scenario:

In every scenario solar rooftop connection are increased to observe the behaviour on 6 kV Feeder and LT network.

Objective of Study:

- To analyze the effect on 6 kV Feeder & LT network by increasing RTPV injection

Software Tool: CYME (CYMDIST)

Time Slots:

S. No	Time Slot	Load flow run at time when DT is maximum loaded
1	8:00 AM - 11:00 AM	11:00 AM
2	11:00 AM - 01:00 PM	12:30 PM
3	01:00 PM - 04:00 PM	01:30 PM
4	04:00 PM - 07:00 PM	4:30 PM

Already connected

No. of solar RTVP are increases

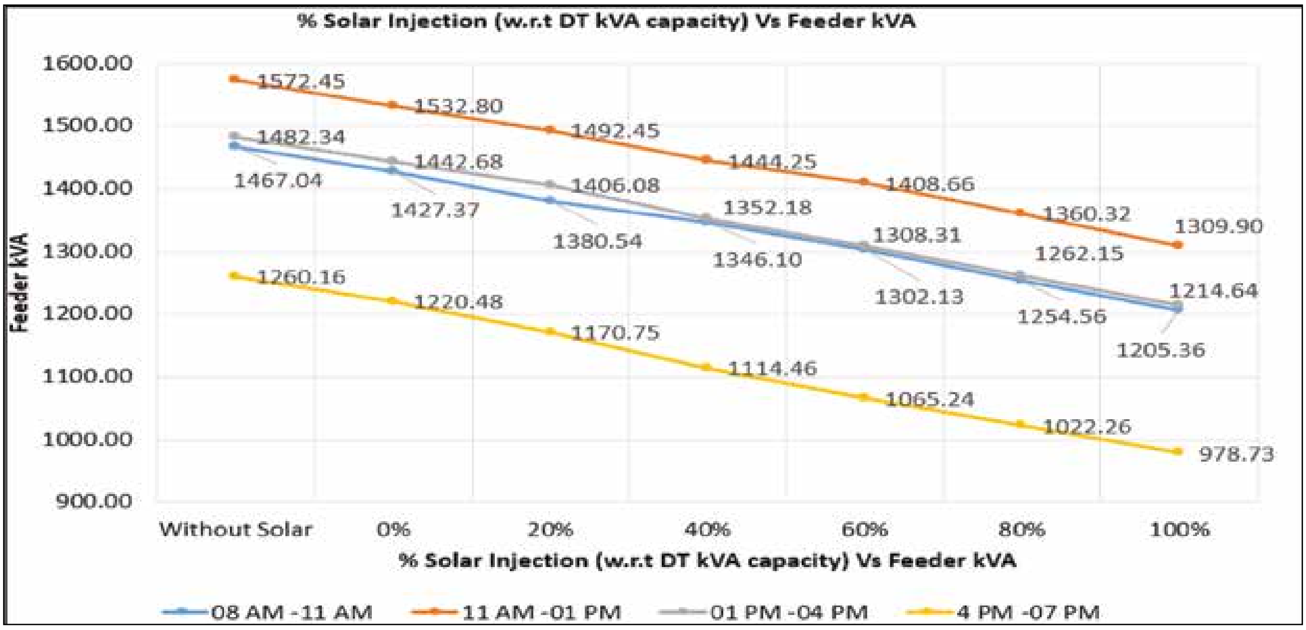
Time Slots	Scenario 1 Time 8-11 AM	Scenario 2 Time 11- 1 PM	Scenario 3 Time 1- 4 PM	Scenario 4 Time 4- 7 PM
Without solar	-	-	-	-
As-Is	46 kWp	46 kWp	46 kWp	46 kWp
20% of DT capacity	106 kWp	106 kWp	106 kWp	106 kWp
40% of DT capacity	166 kWp	166 kWp	166 kWp	166 kWp
60% of DT capacity	226 kWp	226 kWp	226 kWp	226 kWp
80% of DT capacity	286 kWp	286 kWp	286 kWp	286 kWp
100% of DT capacity	346 kWp	346 kWp	346 kWp	346 kWp

Effect on 6 kV feeder:

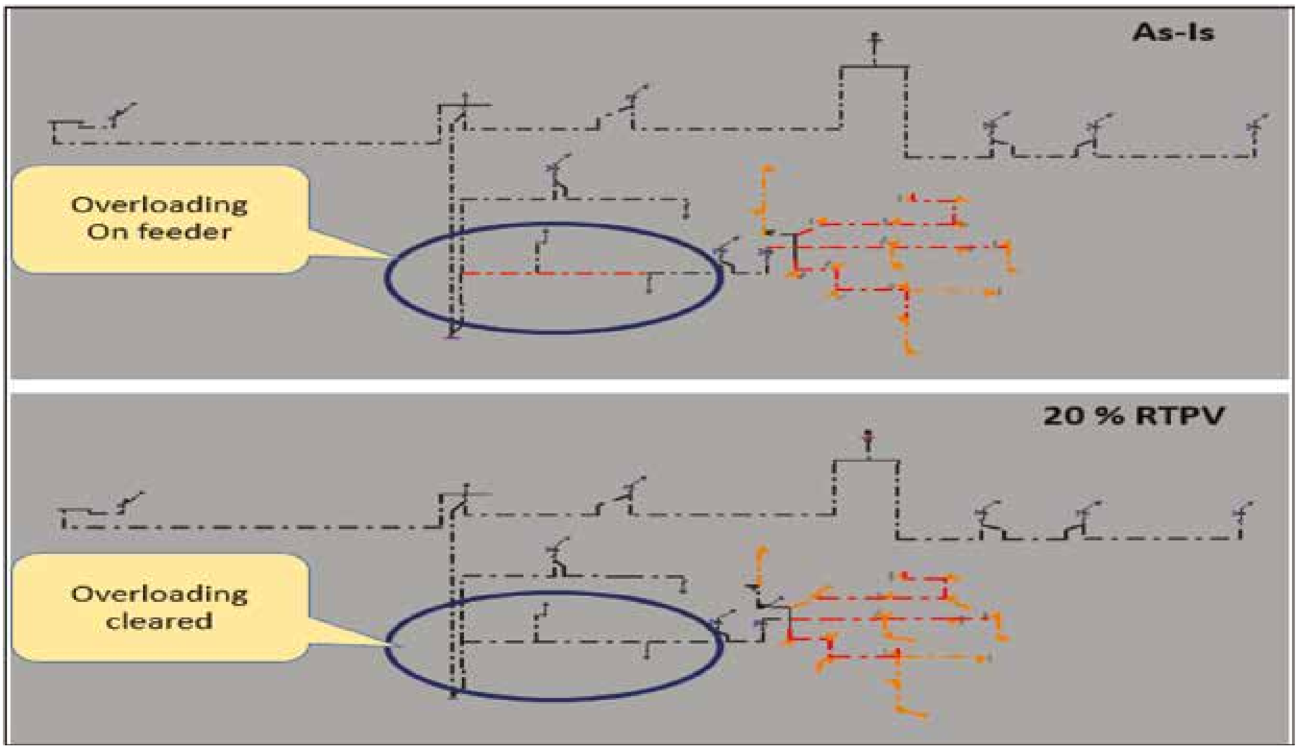
- The load on feeder continuously decreased in every scenario as solar roof top connection are increased from 0% to 100% of DT capacity

Observations on 6 kV feeder side:

- In 0% solar and As-Is scenarios (46 kWp) two sections on 6 kV feeder are overloaded, this got cleared with 20% of solar injection (106 kWp)

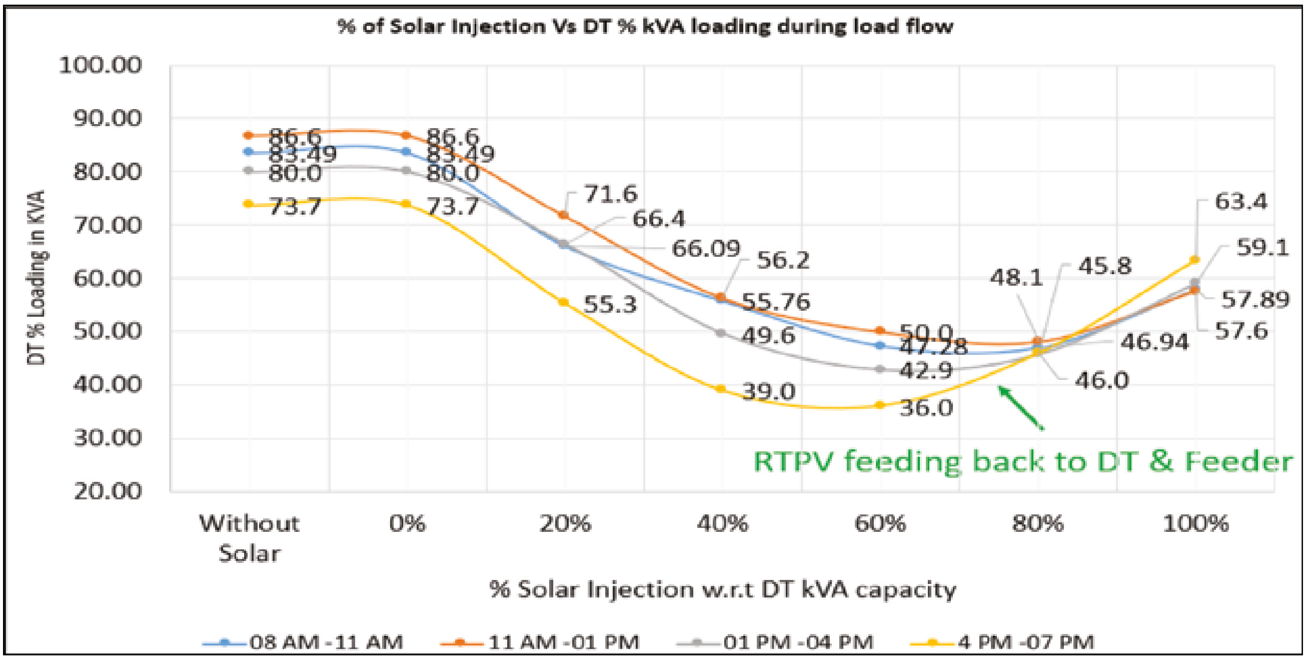


Time Slot	Overloading observed at Solar injection	Overloading cleared with solar injection
8:00 AM - 11:00 AM	As-Is (46 kWp)	20% (106 kWp)
11:00 PM - 01:00 PM	As-Is (46 kWp)	20% (106 kWp)
01:00 PM -04:00 PM	As-Is (46 kWp)	20% (106 kWp)
04:00 PM -07:00 PM	No overloading	

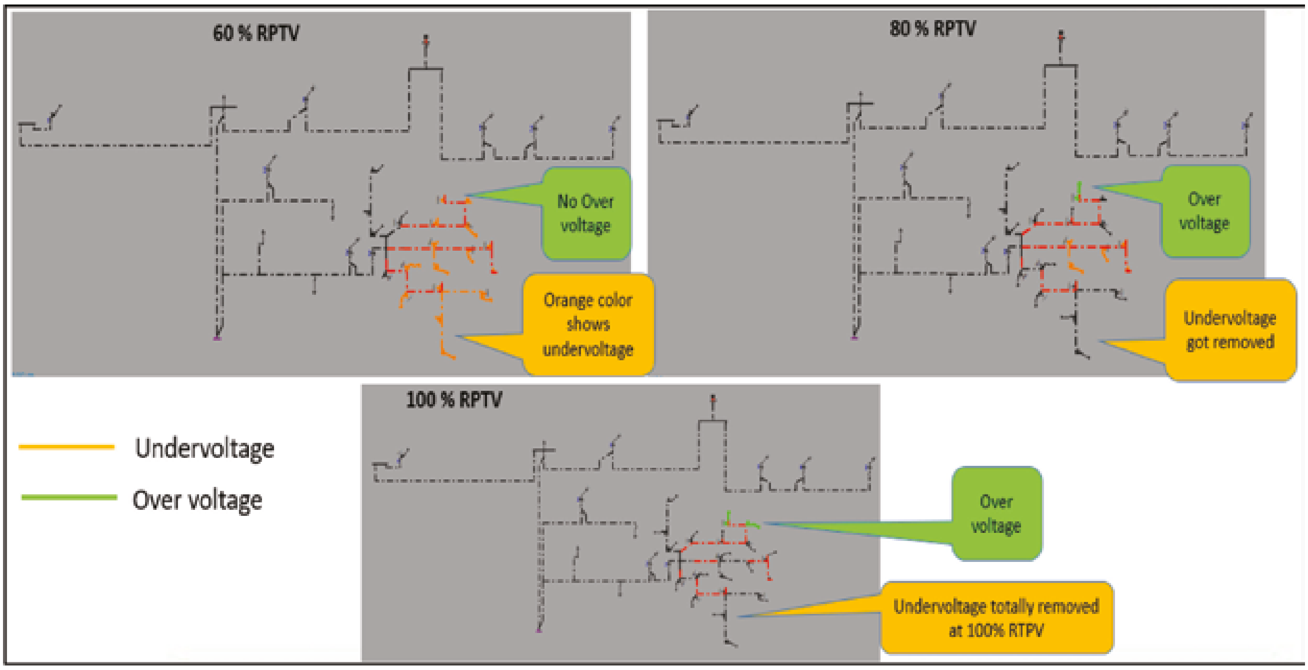


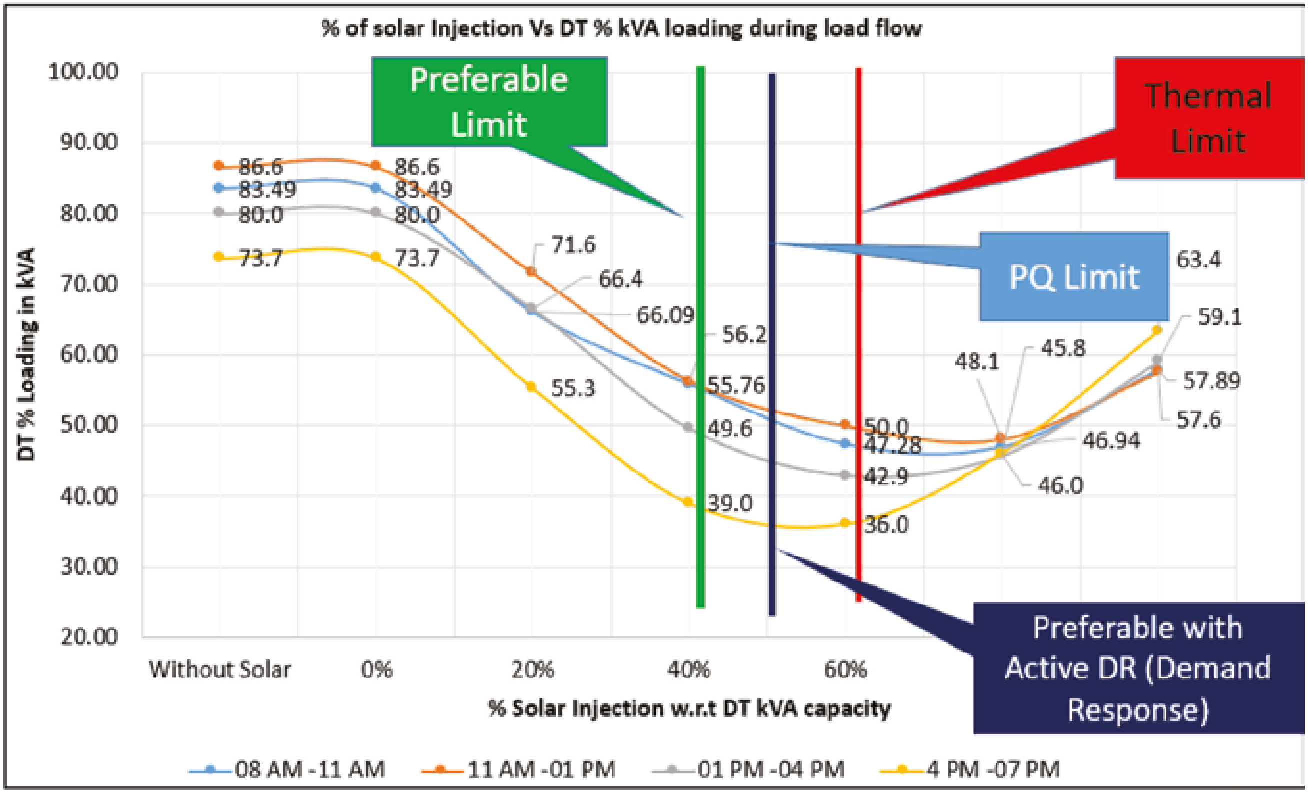
Effect on DT:

- Loading on DT first decreased when generation in consumed at DT end
- The loading on DT again increased when there is excess power available and reverse power flow starts back to DT and feeder
- It is observed with more initial loading on DT graph shifts towards right for reverse power flow



Time Slots	Overvoltage (V > = 1.06 PU)	Undervoltage (V <= 0.94 PU)	Observations
08:00 AM – 11:00 AM	286kWp (80% RTPV) & 346 kWp (100% RTPV)	0% Solar, 46 kWp (As-Is), 106 kWp (20% RTPV), 166 kWp (40% RTPV), 226 kWp (60% RTPV), 286 kWp (80% RTPV)	Overvoltage - Observed on some RTPV connection after increasing RTPV more than or equal to 80 %. Undervoltage – Undervoltage on many sections of LT feeder observed up to 80% RTPV. But it gets cleared after 80 % RTPV. This is due to more loading at LT end.
11:00 AM – 01:00 PM	286 kWp (80 % RTPV) & 346 kWp (100% RTPV)	0% Solar, 46 kWp (As-Is), 106 kWp (20% RTPV), 166 kWp (40% RTPV), 226 kWp (60% RTPV), 286 kWp (80% RTPV)	
01:00 PM – 04:00 PM	226 kWp (60% RTPV), 286 kWp (80% RTPV) & 346 kWp (100% RTPV)	0% Solar, 46 kWp (As-Is), 106 kWp (20% RTPV), 166 kWp (40% RTPV), 226 kWp (60% RTPV), 286 kWp (80% RTPV)	Overvoltage - Observed on some RTPV connection after increasing RTPV more than or equal to 60%. Undervoltage - On many sections of LT feeder observed when RTPV increased from As-Is to 80 % RTPV. But it gets cleared after 80% RTPV. This is due to more loading at LT end.
04:00 PM – 07:00 PM	226 kWp (60% RTPV), 286 kWp (80% RTPV) & 346 kWp (100% RTPV)	0% Solar, 46 kWp (As-Is), 106 kWp (20% RTPV), 166 kWp (40% RTPV), 226 kWp (60% RTPV), 286 kWp (80% RTPV)	

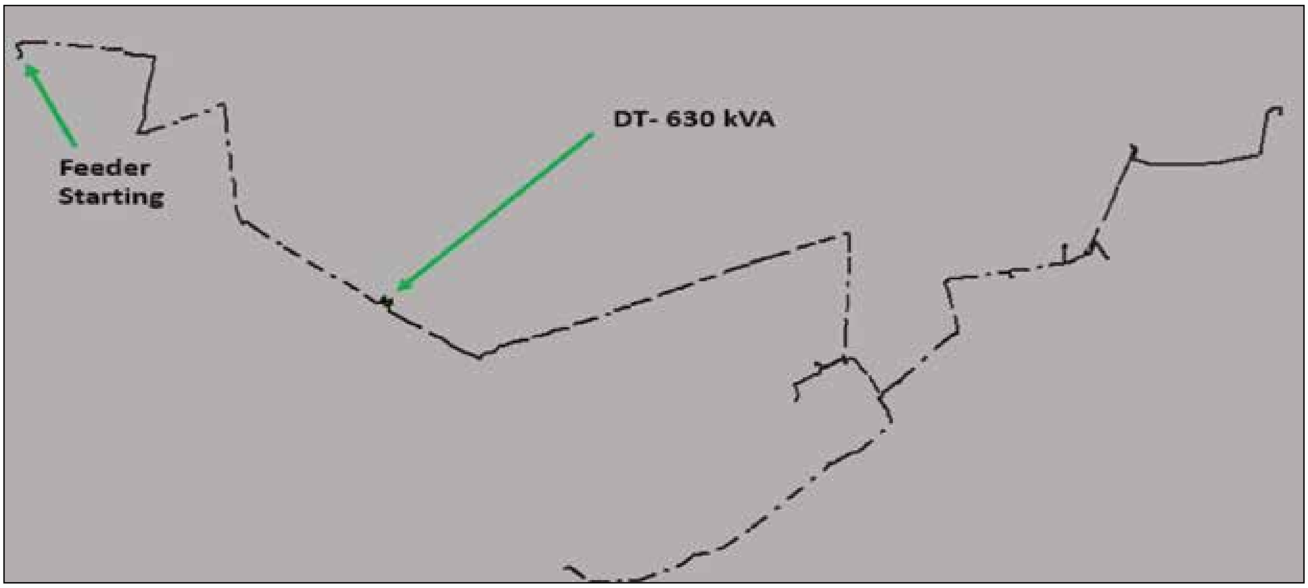

60 % RPTV
No Over voltage
Orange color shows undervoltage
80 % RPTV
Over voltage
Undervoltage got removed
100 % RPTV
Undervoltage
Over voltage
Over voltage
Undervoltage totally removed at 100% RTPV


% of solar Injection Vs DT % kVA loading during load flow
DT % Loading in kVA
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
Without Solar
0%
20%
40%
60%
% Solar Injection w.r.t DT kVA capacity
Preferable Limit
Thermal Limit
PQ Limit
Preferable with Active DR (Demand Response)
86.6
83.49
80.0
73.7
71.6
66.4
66.09
56.2
55.3
55.76
49.6
39.0
50.0
47.28
42.9
36.0
48.1
45.8
46.94
46.0
63.4
59.1
57.89
57.6
08 AM -11 AM
11 AM -01 PM
01 PM -04 PM
4 PM -07 PM

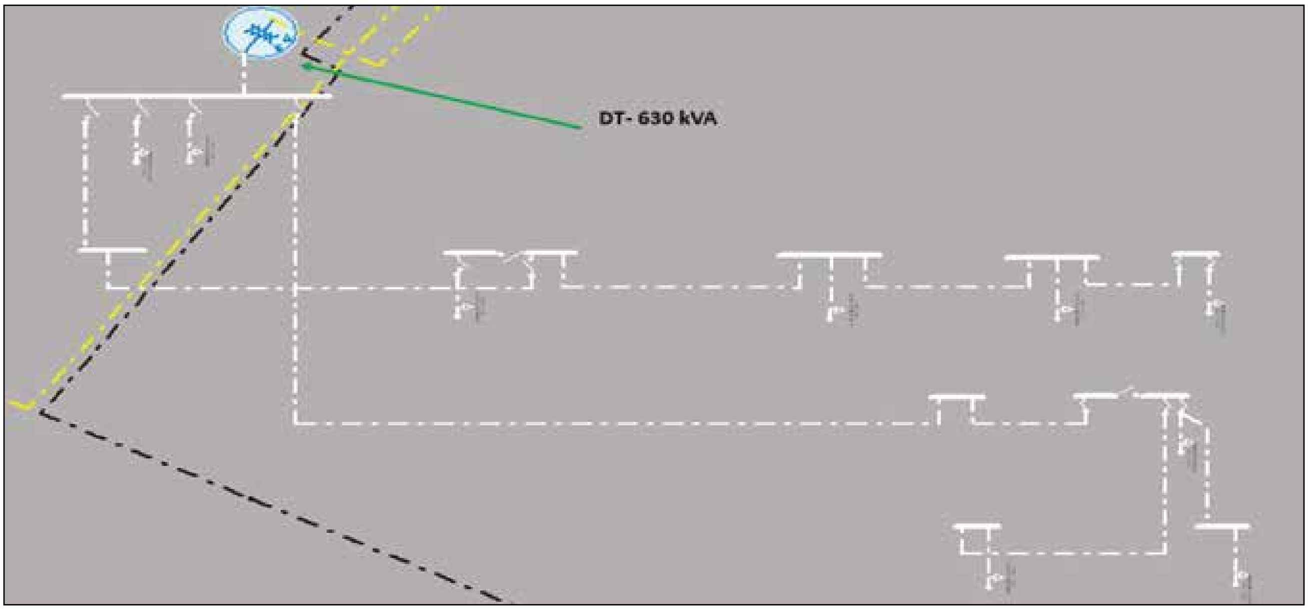
Annexure 2.6: Load Flow Analysis of AEML Feeder

Feeder details:

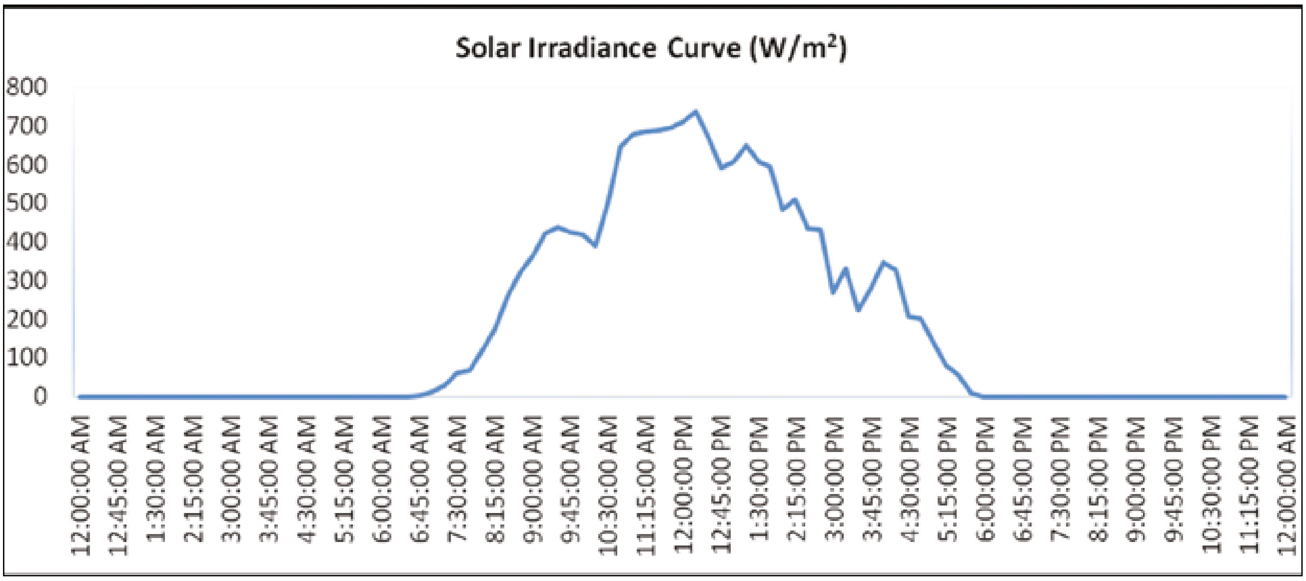
- **Substation:** 33/11kV
- **Total number of DTs on feeder:** 8 DTs and 1 HT consumer
- **Distribution Transformer (DT):** DT-30 kVA
- **Voltage level:** 11 kV/433 V
- **Length of feeder:** 5.871 km
- **Number of consumers on DT:** 492 (approx.)
- **Length of LT circuit:** 1.6 km
- **Solar RTPV at present:** Total 100 kWp RTPV
- **In AS-IS scenarios:** DT (630 kVA) with 100kWp solar injection



LT circuit:



Solar Irradiance Curve: The Solar Insolation (W/m^2) with respect to time is collected from National Institute of Wind Energy for Minute & Hourly basis for 19th November 2016.



Load Flow Scenarios:

In every scenario, Solar Roof Top Connections are increased to observe the behaviour on 11kV Feeder and LT network.

Objective of Study:

- To analyze the effect on 11 kV feeder & LT network by increasing RTPV injection

Software Tool: CYME (CYMDIST)

S. No	Time slot	Load flow run at time when DT is maximum loaded
1	8:00 AM – 11:00 AM	10:30 AM
2	11:00 AM -01:00 PM	11:00 AM
3	01:00 PM - 04:00 PM	02:30 PM
4	04:00 PM - 07:00 PM	04:15 PM

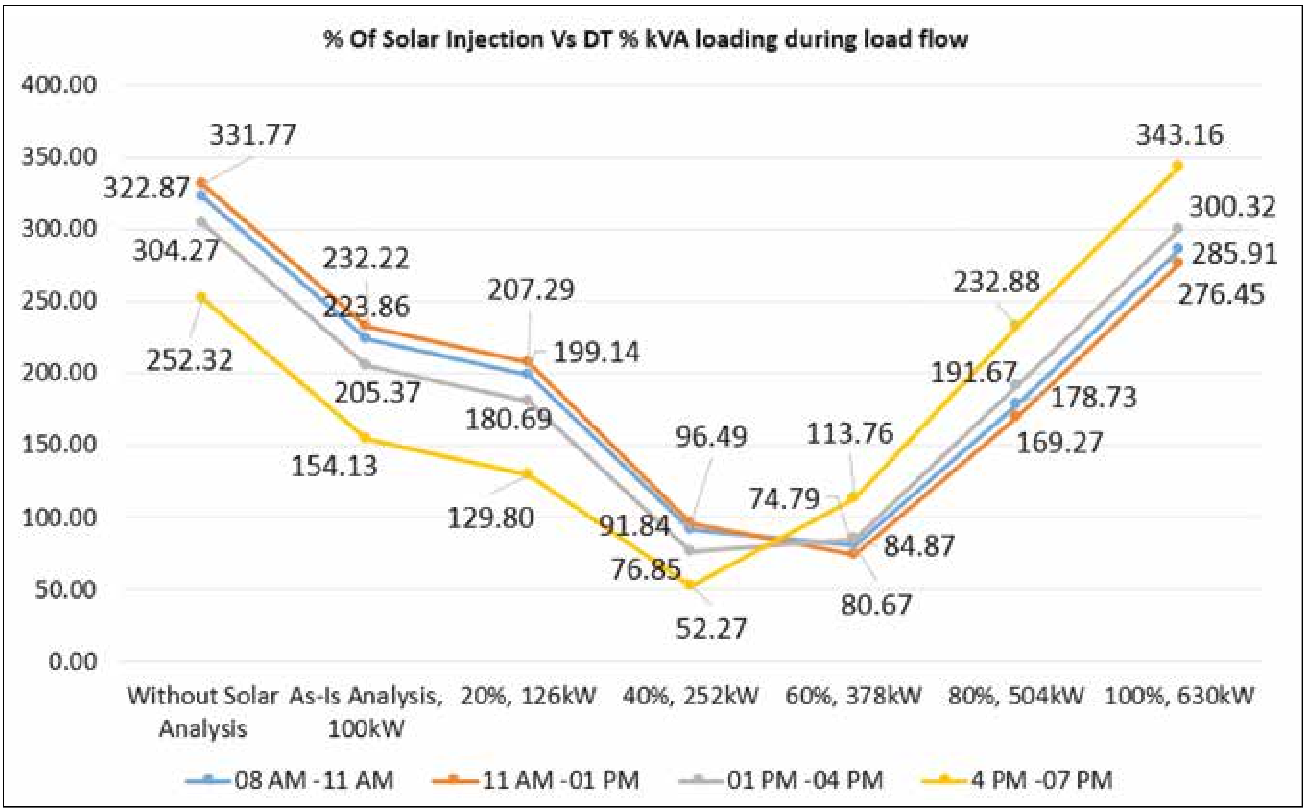
Already connected

No. of Solar RTVP are increases

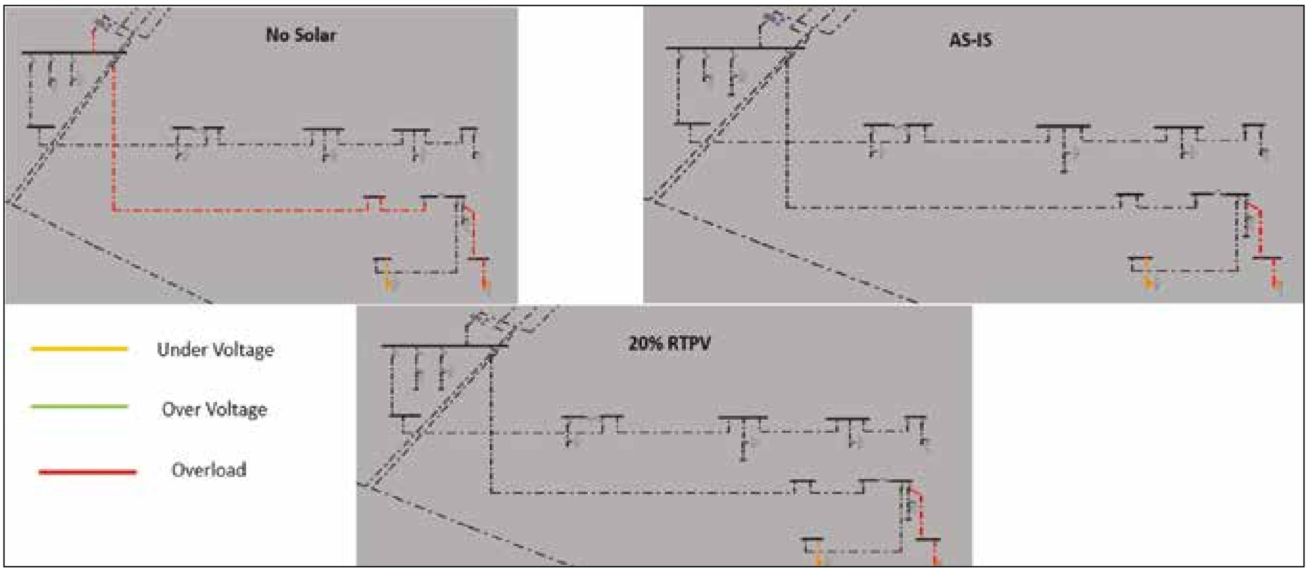
Time Slots	Scenario 1 Time 8-11 AM	Scenario 2 Time 11- 1 PM	Scenario 3 Time 1- 4 PM	Scenario 4 Time 4- 7 PM
Without Solar	-	-	-	-
As-Is	100 kWp	100 kWp	100 kWp	100 kWp
20% of DT capacity	126 kWp	126 kWp	126 kWp	126 kWp
40% of DT capacity	252 kWp	252 kWp	252 kWp	252 kWp
60% of DT capacity	380 kWp	380 kWp	380 kWp	380kWp
80% of DT capacity	504 kWp	504 kWp	504 kWp	504 kWp
100% of DT capacity	630 kWp	630 kWp	630 kWp	630 kWp

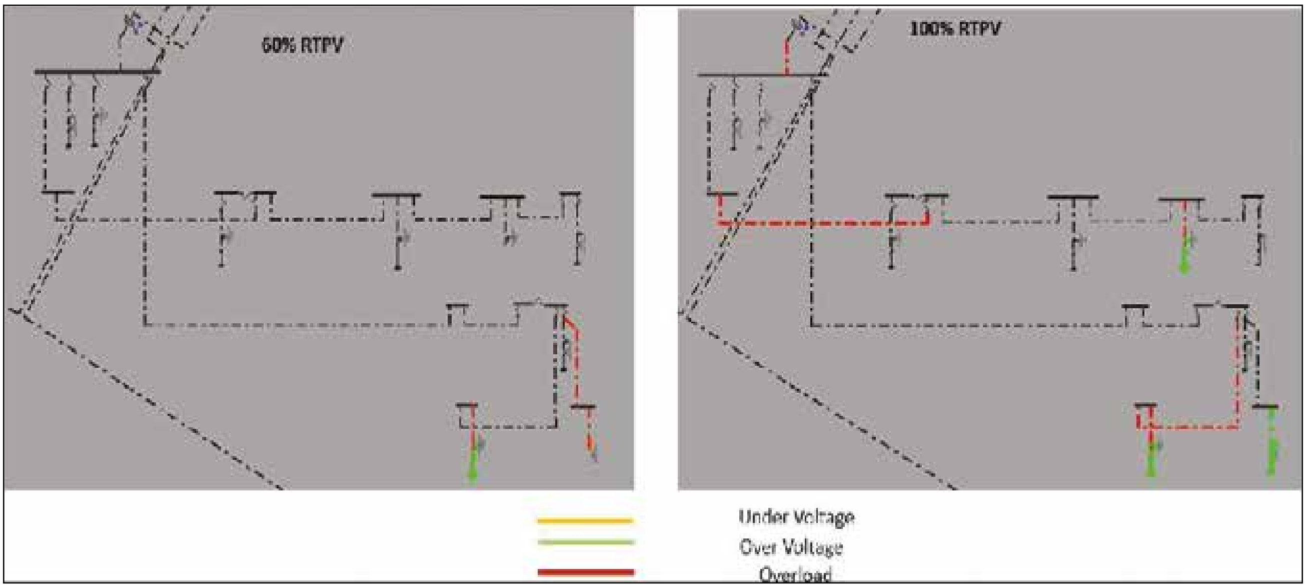
Effect on DT- 630 kVA:

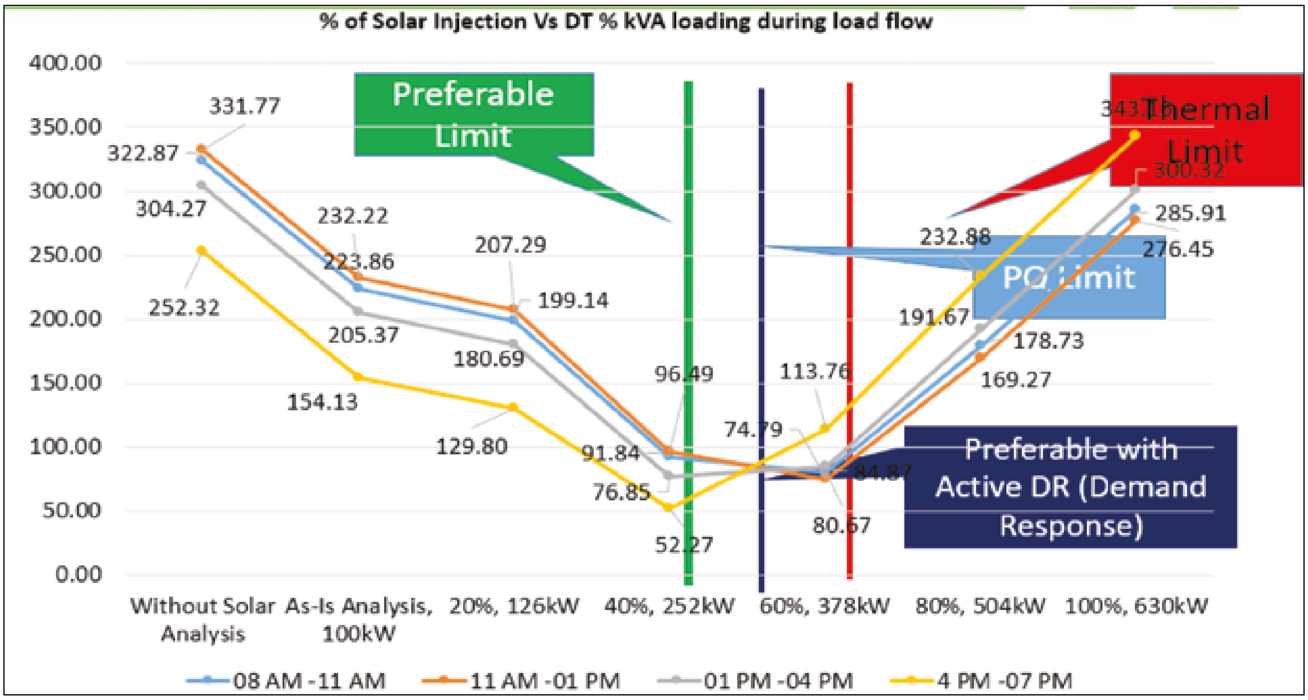
- Loading on DT first decreased when generation in consumed at DT end
- The loading on DT again increased when there is excess power available and reverse power flow starts back to DT and feeder
- It is observed with more initial loading on DT graph shifts towards right for reverse power flow
- Under voltage and overvoltage observed on some sections of LT during increased solar penetration



Time slots	Overvoltage (V > = 1.06 PU)	Undervoltage (V <= 0.94 PU)	Observations
08:00 AM – 11:00 AM	60% PV, 80% PV, 100% PV	No Solar, As-Is, 20% PV, 40% PV, 60% PV	Overvoltage - Observed on some RTPV connection after increasing RTPV more than or equal to 60%. Undervoltage – Undervoltage on many sections of LT feeder observed up to 60% RTPV. But it gets cleared after 80% RTPV. This is due to more loading at LT end. Overloading – Up to 40% RTPV, overloading has decreased significantly. However, after 60% RTPV injection, it increased again.
11:00 AM – 01:00 PM	60% PV, 80% PV, 100% PV	No Solar, As-Is, 20% PV, 40% PV, 60% PV	
01:00 PM – 04:00 PM	60% PV, 80% PV, 100% PV	No Solar, As-Is, 20% PV, 40% PV, 60% PV	
04:00 PM – 07:00 PM	60% PV, 80% PV, 100% PV	No Solar, As-Is, 20% PV, 40% PV, 60% PV	


No Solar
AS-IS
20% RTPV
Under Voltage
Over Voltage
Overload


60% RTPV
100% RTPV
Under Voltage
Over Voltage
Overload


% of Solar Injection Vs DT % kVA loading during load flow
Preferable Limit
Thermal Limit
PQ Limit
Preferable with Active DR (Demand Response)
Without Solar Analysis
As-Is Analysis, 100kW
20%, 126kW
40%, 252kW
60%, 378kW
80%, 504kW
100%, 630kW
08 AM -11 AM
11 AM -01 PM
01 PM -04 PM
4 PM -07 PM

Annexure 3: State Wise ESS Estimations 2019-2032

Southern Region

State - Karnataka	2019	2022	2027	2032
Generation (MW)				
Thermal	9961	15121		
Hydro	3586			
Nuclear	698			
Solar	5329	8500	13497	22297
Ground Mounted Solar	5175	6200	8097	12597
RTPV	154	2300	5400	9700
Connected to EHV	3105	3720	4858	7558
Connected to MV	2070	2480	3239	5039
Connected to LV	154	2300	5400	9700
Wind	4683	6200		
Small Hydro	1231	1500		
Biomass & Biopower	1800	1420		
Peak Load (MW)	10857	18403	25396	34720
Energy (MUs)				
Annual Energy	67869	108012	147941	200736
Storage Recommended (MWh)				
Battery (LV)	23	345	810	1455
Battery (MV)	207	248	324	504

State – Andhra Pradesh	2019	2022	2027	2032
Generation (MW)				
Thermal	14644	16525	18525	NA
Hydro	1674	1764	NA	NA
Nuclear	128	NA	NA	NA
Solar	2890	9834	21503	28503
Ground Mounted Solar	2841	7834	15703	18703
RTPV	49	2000	5800	9800
Connected to EHV	1704	4700	9422	10862
Connected to MV	1137	3134	6281	7841
Connected to LV	49	2000	5800	9800
Wind	4076	8100		
Small Hydro	162	-	-	409
Biomass & Biopower	500	543	NA	NA
Peak Load (MW)	8983	33194	51601	74818
Energy (MUs)				
Annual Energy	58384	191912	284776	412903
Storage Recommended (MWh)				
Battery (LV)	7	300	870	1470
Battery (MV)	114	313	628	784

State – Tamil Nadu	2019	2022	2027	2032
Generation (MW)				
Thermal	14786	20647	NA	NA
Hydro	2178	2733	NA	NA
Nuclear	1448	1500		
Solar	2233	8884	19884	26000
Ground Mounted Solar	2098	5384	11284	14100
RTPV	135	3500	8600	11900
Connected to EHV	1259	3230	6770	8460
Connected to MV	839	2154	4515	5640
Connected to LV	135	3500	8600	11900
Wind	8764	11900	NA	NA
Small Hydro	123	75	NA	604
Biomass & Biopower	1004	649	NA	NA
Peak Load (MW)	14975	29975	43044	59827
Energy (MUs)				
Annual Energy	106006	171718	244703	337491
Storage Recommended (MWh)				
Battery (LV)	20	525	1290	1785
Battery (MV)	84	215	451	564

State – Kerala	2019	2022	2027	2032
Generation (MW)				
Thermal	2452	NA	NA	NA
Hydro	1882	2556	NA	NA
Nuclear	362		NA	NA
Solar	139	1870	5582	10082
Ground Mounted Solar	100	1070	2982	5082
RTPV	39	800	2600	5000
Connected to EHV	60	642	1789	3049
Connected to MV	40	428	1193	2033
Connected to LV	39	800	2600	5000
Wind	53	-		
Small Hydro	222	100		647
Biomass & Biopower	0.72	-	-	NA
Peak Load (MW)	3870	6093	8150	10903
Energy (MUs)				
Annual Energy	25004	34691	46049	61125
Storage Recommended (MWh)				
Battery (LV)	6	120	390	750
Battery (MV)	4	43	119	203

UT – Puducherry	2019	2022	2027	2032
Generation (MW)				
Thermal	281	NA	NA	NA
Hydro	0	NA	NA	NA
Nuclear	86	NA	NA	NA
Solar	19	246	646	1200
Ground Mounted Solar	5	146	446	790
RTPV	14	100	200	410
Connected to EHV	-	-	-	-
Connected to MV	14	146	446	790
Connected to LV	5	100	200	410
Wind	-	-		
Small Hydro	-	-	-	-
Biomass & Biopower	-	-	-	-
Peak Load (MW)	387	782	787	940
Energy (MUs)				
Annual Energy	2669	4452	4444	5271
Storage Recommended (MWh)				
Battery (LV)	1	15	30	61
Battery (MV)	1.5	15	45	79

State – Telangana	2019	2022	2027	2032
Generation (MW)				
Thermal	8829	14909	NA	NA
Hydro	2450	NA	NA	NA
Nuclear	149	236	NA	NA
Solar	3583	6990	11990	17990
Ground Mounted Solar	3519	4990	5190	9990
RTPV	64	2000	6800	8000
Connected to EHV	2111	2994	3114	5994
Connected to MV	1408	1996	2076	3996
Connected to LV	64	2000	6800	8000
Wind	128	2000	NA	NA
Small Hydro	91	-	-	102
Biomass & Biopower	178	-	-	-
Peak Load (MW)	10284	-	-	-
Energy (MUs)				
Annual Energy	60318	NA	NA	NA
Storage Recommended (MWh)				
Battery (LV)	0.96	300	1020	1200
Battery (MV)	141	200	208	400

Western Region

State – Goa	2019	2022	2027	2032
Generation (MW)				
Thermal	523	NA	NA	NA
Hydro	0	NA	NA	NA
Nuclear	26	NA	NA	NA
Solar	2	358	1000	1500
Ground Mounted Solar	1	208	710	1060
RTPV	1	150	290	440
Connected to EHV	-	-	-	-
Connected to MV	1	208	710	1060
Connected to LV	1	150	290	440
Wind	-	-		
Small Hydro	0.05	-	-	4.7
Biomass & Biopower	-	-	-	-
Peak Load (MW)	558	1192	1658	2216
Energy (MUs)				
Annual Energy	4117	6837	9442	12617
Storage Recommended (MWh)				
Battery (LV)	0.15	22.5	43.5	66
Battery (MV)	0.1	21	71	106

UT – Daman & Diu	2019	2022	2027	2032
Generation (MW)				
Thermal	170	NA	NA	NA
Hydro	0	NA	NA	NA
Nuclear	7	NA	NA	NA
Solar	14.4	199	500	850
Ground Mounted Solar	10	99	300	540
RTPV	4.4	100	200	310
Connected to EHV	-	-	-	-
Connected to MV	10	99	300	540
Connected to LV	4.4	100	200	310
Wind	-	-	-	-
Small Hydro	-	-	-	-
Biomass & Biopower	-	-	-	-
Peak Load (MW)	362	605	818	1082
Energy (MUs)				
Annual Energy	2533	3706	4980	6536
Storage Recommended (MWh)				
Battery (LV)	0.645	15	30	46
Battery (MV)	1	10	30	54

State – Gujarat	2019	2022	2027	2032
Generation (MW)				
Thermal	22168	22968	NA	NA
Hydro	772	NA	NA	NA
Nuclear	559	1400	NA	NA
Solar	2003	8020	23500	35500
Ground Mounted Solar	1836	4820	14400	22300
RTPV	167	3200	9100	13200
Connected to EHV	1012	2892	8640	13380
Connected to MV	734	1928	5760	8920
Connected to LV	257	3200	9100	13200
Wind	5967	8800	NA	NA
Small Hydro	46	25	NA	NA
Biomass & Biopower	77	288		NA
Peak Load (MW)	16590	26973	38691	53301
Energy (MUs)				
Annual Energy	109985	153582	218610	301160
Storage Recommended (MWh)				
Battery (LV)	39	480	1365	1980
Battery (MV)	73	193	576	892

State – Madhya Pradesh	2019	2022	2027	2032
Generation (MW)				
Thermal	12806	15826	NA	NA
Hydro	3224	NA	NA	NA
Nuclear	273	NA	NA	NA
Solar	1650	5675	17000	22500
Ground Mounted Solar	1619	3475	9900	11300
RTPV	31	2200	7100	11200
Connected to EHV	971	2085	5940	6780
Connected to MV	648	1390	3960	4520
Connected to LV	31	2200	7100	11200
Wind	2520	6200	NA	NA
Small Hydro	96	25	NA	NA
Biomass & Biopower	121	118	NA	820
Peak Load (MW)	12301	18802	27519	38088
Energy (MUs)				
Annual Energy	69925	107060	155489	213539
Storage Recommended (MWh)				
Battery (LV)	4.65	330	1065	1680
Battery (MV)	65	140	396	452

State – Chhattisgarh	2019	2022	2027	2032
Generation (MW)				
Thermal	12724	26864	NA	NA
Hydro	120	NA	NA	NA
Nuclear	48	NA	NA	NA
Solar	232	1783	5000	8000
Ground Mounted Solar	216	1083	3600	4000
RTPV	16	700	2400	4000
Connected to EHV	-	-	-	-
Connected to MV	216	1083	3600	4000
Connected to LV	16	700	2400	4000
Wind	-	-	-	-
Small Hydro	76	25		
Biomass & Biopower	231	-	-	1098
Peak Load (MW)	3887	6599	9090	12116
Energy (MUs)				
Annual Energy	25915	34106	46979	62620
Storage Recommended (MWh)				
Battery (LV)	2.4	105	360	600
Battery (MV)	22	108	360	400
Battery (MV)	58	289	600	764

State – Maharashtra	2019	2022	2027	2032
Generation (MW)				
Thermal	30474	34434	NA	NA
Hydro	3332	NA	NA	NA
Nuclear	690	2430	NA	NA
Solar	1619	11924	25000	35000
Ground Mounted Solar	1447	7224	15000	19100
RTPV	172	4700	10000	15900
Connected to EHV	868	4334	9000	11460
Connected to MV	579	2890	6000	7640
Connected to LV	172	4700	10000	15900
Wind	4795	7600	NA	NA
Small Hydro	376	50	NA	786
Biomass & Biopower	2529	2469	NA	NA
Peak Load (MW)	22494	39622	54982	74528
Energy (MUs)				
Annual Energy	149759	225606	310654	417826
Storage Recommended (MWh)				
Battery (LV)	25.8	705	1500	2385
Battery (MV)	58	289	600	764

UT – Dadra & Nagar Naveli	2019	2022	2027	2032
Generation (MW)				
Thermal	241	NA	NA	NA
Hydro	0	NA	NA	NA
Nuclear	9	NA	NA	NA
Solar	6	449	1000	1500
Ground Mounted Solar	3	249	620	930
RTPV	3	200	380	570
Connected to EHV	-	-	-	-
Connected to MV	3	249	620	930
Connected to LV	3	200	380	570
Wind	-	-	NA	NA
Small Hydro	-	-	-	-
Biomass & Biopower	-	-	-	-
Peak Load (MW)	790	1297	1733	2294
Energy (MUs)				
Annual Energy	6166	8413	11164	14676
Storage Recommended (MWh)				
Battery (LV)	0.45	30	57	85.5
Battery (MV)	0.3	25	62	93

Northern Region

State – Delhi	2019	2022	2027	2032
Generation (MW)				
Thermal	6938	NA	NA	NA
Hydro	723	NA	NA	NA
Nuclear	103	NA	NA	NA
Solar	124	500	1000	2050
Ground Mounted Solar	9	20	30	50
RTPV	115	480	970	2000
Connected to EHV	-	-	-	-
Connected to MV	9	20	30	50
Connected to LV	115	480	970	2000
Wind	-	-	-	-
Small Hydro	-	-	-	-
Biomass & Biopower	52	-	-	-
Peak Load (MW)	6526	9024	12681	17246
Energy (MUs)				
Annual Energy	31825	52930	73827	99649
Storage Recommended (MWh)				
Battery (LV)	17.25	72	146	300
Battery (MV)	1	2	3	5

State – Haryana	2019	2022	2027	2032
Generation (MW)				
Thermal	8781	NA	NA	NA
Hydro	663	NA	NA	NA
Nuclear	101	1501	NA	NA
Solar	220	4142	8000	12500
Ground Mounted Solar	131	2542	3900	7500
RTPV	89	1600	4100	5000
Connected to EHV	79	1525	2260	4500
Connected to MV	52	1017	1640	3000
Connected to LV	89	1600	4100	5000
Wind	-	-	-	-
Small Hydro	74	25	-	107
Biomass & Biopower	206	209	NA	NA
Peak Load (MW)	9539	14244	20103	27202
Energy (MUs)				
Annual Energy	50775	78586	110915	150083
Storage Recommended (MWh)				
Battery (LV)	13.35	240	615	750
Battery (MV)	5	102	164	300

State – Himachal Pradesh	2019	2022	2027	2032
Generation (MW)				
Thermal	245	NA	NA	NA
Hydro	2910	5386	NA	NA
Nuclear	29	NA	NA	NA
Solar	22.7	776	1500	1800
Ground Mounted Solar	17	456	800	840
RTPV	5.7	320	700	960
Connected to EHV	-	-	-	-
Connected to MV	9	456	800	840
Connected to LV	6	320	700	960
Wind	-	-	-	-
Small Hydro	861	1500		3460
Biomass & Biopower	7	-	-	-
Peak Load (MW)	1594	2589	3424	4476
Energy (MUs)				
Annual Energy	9399	14514	19198	25096
Storage Recommended (MWh)				
Battery (LV)	1	48	105	144
Battery (MV)	2	46	80	84

State – Jammu & Kashmir	2019	2022	2027	2032
Generation (MW)				
Thermal	810	NA	NA	NA
Hydro	2369	3744	NA	NA
Nuclear	68	NA	NA	NA
Solar	15	1155	11000	15000
Ground Mounted Solar	9	705	9140	12750
RTPV	6	450	1860	2250
Connected to EHV	-	-	-	-
Connected to MV	9	705	9140	12750
Connected to LV	6	450	1860	2250
Wind	-	-	-	-
Small Hydro	180	150		1707
Biomass & Biopower	-	-	-	-
Peak Load (MW)	2319	4217	5996	8302
Energy (MUs)				
Annual Energy	18808	21884	31110	43075
Storage Recommended (MWh)				
Battery (LV)	1	68	279	337
Battery (MV)	1	71	914	1275

State – Punjab	2019	2022	2027	2032
Generation (MW)				
Thermal	9004	10204	NA	NA
Hydro	3781	4061	NA	NA
Nuclear	197	NA	NA	NA
Solar	905	4772	8500	11000
Ground Mounted Solar	828	2772	3500	5000
RTPV	77	2000	5000	6000
Connected to EHV	497	1664	2100	3000
Connected to MV	331	1108	1400	2000
Connected to LV	77	2000	5000	6000
Wind	-	-	-	-
Small Hydro	174	50	NA	578
Biomass & Biopower	326	244	NA	NA
Peak Load (MW)	11705	14552	18352	23144
Energy (MUs)				
Annual Energy	54812	86941	108835	136243
Storage Recommended (MWh)				
Battery (LV)	12	300	750	900
Battery (MV)	33	110	140	200

State – Rajasthan	2019	2022	2027	2032
Generation (MW)				
Thermal	11763	14403	NA	NA
Hydro	1931	NA	NA	NA
Nuclear	556	NA	NA	NA
Solar	3227	5762	13500	22500
Ground Mounted Solar	3072	3462	8500	15800
RTPV	155	2300	5000	6700
Connected to EHV	1854	2077	5100	9480
Connected to MV	1218	1385	3400	6320
Connected to LV	155	2300	5000	6700
Wind	4300	8600	NA	NA
Small Hydro	24	-	-	51
Biomass & Biopower	121	-	-	-
Peak Load (MW)	11564	19692	28828	40284
Energy (MUs)				
Annual Energy	71193	110483	161741	226014
Storage Recommended (MWh)				
Battery (LV)	23	345	750	1005
Battery (MV)	122	139	340	632

State – Uttar Pradesh	2019	2022	2027	2032
Generation (MW)				
Thermal	18623	26163	NA	NA
Hydro	3421	3497	NA	NA
Nuclear	289	NA	NA	NA
Solar	902	10697	20000	27500
Ground Mounted Solar	834	6397	10700	15500
RTPV	68	4300	9300	12000
Connected to EHV	500	3838	6420	9300
Connected to MV	334	2559	4280	6200
Connected to LV	68	4300	9300	12000
Wind	-	-	-	-
Small Hydro	25	25	NA	460
Biomass & Biopower	2118	3499	NA	NA
Peak Load (MW)	18061	36061	53690	73708
Energy (MUs)				
Annual Energy	120051	209046	308887	420829
Storage Recommended (MWh)				
Battery (LV)	10	645	1395	1800
Battery (MV)	33	256	429	620

State – Uttarakhand	2019	2022	2027	2032
Generation (MW)				
Thermal	962	NA	NA	NA
Hydro	1815	4341	NA	NA
Nuclear	31	NA	NA	NA
Solar	305	800	1500	1950
Ground Mounted Solar	240	450	840	950
RTPV	65	350	660	1000
Connected to EHV	-	-	-	-
Connected to MV	240	450	840	950
Connected to LV	65	350	660	1000
Wind	-	-	-	-
Small Hydro	214	700	NA	1664
Biomass & Biopower	131	197	NA	NA
Peak Load (MW)	2149	2901	3911	5222
Energy (MUs)				
Annual Energy	13457	16774	22438	29733
Storage Recommended (MWh)				
Battery (LV)	10	53	99	150
Battery (MV)	24	45	84	95

UT – Chandigarh	2019	2022	2027	2032
Generation (MW)				
Thermal	53	NA	NA	NA
Hydro	102	NA	NA	NA
Nuclear	8	NA	NA	NA
Solar	35	153	650	1000
Ground Mounted Solar	6	53	450	690
RTPV	29	100	200	310
Connected to EHV	-	-	-	-
Connected to MV	6	53	450	690
Connected to LV	29	100	200	310
Wind	-	-	-	-
Small Hydro	-	-	-	-
Biomass & Biopower	-	-	-	-
Peak Load (MW)	363	559	732	948
Energy (Mus)				
Annual Energy	1610	2842	3719	4821
Storage Recommended (MWh)				
Battery (LV)	4	15	30	46.5
Battery (MV)	0.6	5	45	69

Eastern Region

State – Bihar	2019	2022	2027	2032
Generation (MW)				
Thermal	3905	9365	NA	NA
Hydro	110	NA	NA	NA
Nuclear	0	-	-	-
Solar	142.5	2493	6500	8500
Ground Mounted Solar	139	1493	4400	5200
RTPV	3.5	1000	2100	3300
Connected to EHV	-	-	-	-
Connected to MV	139	1493	4400	5200
Connected to LV	3.5	1000	2100	3300
Wind	-	-	-	-
Small Hydro	71	25	-	526
Biomass & Biopower	121	244	NA	NA
Peak Load (MW)	4515	9306	16239	23411
Energy (MUs)				
Annual Energy	27018	52975	91733	131219
Storage Recommended (MWh)				
Battery (LV)	0.5	150	315	495
Battery (MV)	14	150	440	520

State – Jharkhand	2019	2022	2027	2032
Generation (MW)				
Thermal	1543	4723	NA	NA
Hydro	191	NA	NA	NA
Nuclear	0	-	-	-
Solar	32.3	1995	5500	8000
Ground Mounted Solar	19	1195	3900	5500
RTPV	13.3	800	1600	2500
Connected to EHV	-	-	-	-
Connected to MV	19	1995	5500	5500
Connected to LV	13.3	800	1600	2500
Wind	-	-	-	-
Small Hydro	4	10	-	227
Biomass & Biopower	4.3	-	-	-
Peak Load (MW)	1260	6341	8780	11930
Energy (Mus)				
Annual Energy	7906	37482	51512	69475
Storage Recommended (MWh)				
Battery (LV)	2	120	240	375
Battery (MV)	2	200	550	550

State – West Bengal	2019	2022	2027	2032
Generation (MW)				
Thermal	8805	14145	NA	NA
Hydro	1396	3126	NA	NA
Nuclear	-	-	-	-
Solar	70	5336	10500	13000
Ground Mounted Solar	50	3236	6600	7300
RTPV	20	2100	3900	5700
Connected to EHV	-	-	-	-
Connected to MV	50	3236	6600	7300
Connected to LV	20	2100	3900	5700
Wind	-	-	-	-
Small Hydro	99	50	-	392
Biomass & Biopower	320	-	-	-
Peak Load (MW)	8114	17703	26027	36187
Energy (MUs)				
Annual Energy	50760	103283	150704	207948
Storage Recommended (MWh)				
Battery (LV)	3	315	585	855
Battery (MV)	5	324	660	730

State – Odisha	2019	2022	2027	2032
Generation (MW)				
Thermal	4992	14042	NA	NA
Hydro	2150	NA	NA	NA
Nuclear	0	NA	NA	NA
Solar	391	2377	6500	8500
Ground Mounted Solar	384	1377	4500	5300
RTPV	7	1000	2000	3200
Connected to EHV	-	-	-	-
Connected to MV	384	1377	4500	5300
Connected to LV	7	1000	2000	3200
Wind	-	-	-	-
Small Hydro	65	-	-	286
Biomass & Biopower	59	-	-	-
Peak Load (MW)	4402	6749	8712	11280
Energy (MUs)				
Annual Energy	28801	42566	54565	70154
Storage Recommended (MWh)				
Battery (LV)	1.05	150	300	480
Battery (MV)	38	138	450	530

State – Sikkim	2019	2022	2027	2032
Generation (MW)				
Thermal	87	NA	NA	NA
Hydro	823	944	2056	NA
Nuclear	0	-	-	-
Solar	0.01	76	200	250
Ground Mounted Solar	0	26	120	150
RTPV	0.01	50	80	100
Connected to EHV	-	-	-	-
Connected to MV	0	26	120	150
Connected to LV	0.01	50	80	100
Wind	-	-	-	-
Small Hydro	52	-	-	266
Biomass & Biopower	-	-	-	-
Peak Load (MW)	96	176	245	341
Energy (MUs)				
Annual Energy	486	645	898	1250
Storage Recommended (MWh)				
Battery (LV)	0	7.5	12	15
Battery (MV)	0	3	12	15

North-Eastern Region

State – Assam	2019	2022	2027	2032
Generation (MW)				
Thermal	1027	1777	NA	NA
Hydro	431	NA	NA	NA
Nuclear	0	-	-	-
Solar	18	663	1500	1800
Ground Mounted Solar	10	413	1000	1060
RTPV	8	250	500	740
Connected to EHV	-	-	-	-
Connected to MV	10	413	1000	1060
Connected to LV	8	250	500	740
Wind	-	-	-	-
Small Hydro	34	36	-	201
Biomass & Biopower	-	-	-	-
Peak Load (MW)	1745	2534	3613	5033
Energy (MUs)				
Annual Energy	9094	12699	18107	25224
Storage Recommended (MWh)				
Battery (LV)	1.2	37.5	75	111
Battery (MV)	1	41	100	106

State – Arunachal Pradesh	2019	2022	2027	2032
Generation (MW)				
Thermal	72	NA	NA	NA
Hydro	97	4816	NA	NA
Nuclear	0		NA	NA
Solar	5.4	71	120	190
Ground Mounted Solar	1.3	21	30	50
RTPV	4.1	50	90	140
Connected to EHV	-	-	-	-
Connected to MV	1.3	21	30	50
Connected to LV	4.1	50	90	140
Wind	-	-	-	-
Small Hydro	107	500	-	2064
Biomass & Biopower	-	-	-	-
Peak Load (MW)	145	177	266	365
Energy (MUs)				
Annual Energy	798	721	1085	1489
Storage Recommended (MWh)				
Battery (LV)	0.6	7.5	13.5	21
Battery (MV)	0	2	3	5

State – Meghalaya	2019	2022	2027	2032
Generation (MW)				
Thermal	140	300	NA	NA
Hydro	387	NA	NA	NA
Nuclear	0	NA	NA	NA
Solar	0.12	161	450	600
Ground Mounted Solar	0	111	360	440
RTPV	0.12	50	90	160
Connected to EHV	-	-	-	-
Connected to MV	0	111	360	440
Connected to LV	0.12	50	90	160
Wind	-	-	-	-
Small Hydro	31	55	-	230
Biomass & Biopower	14	-	-	-
Peak Load (MW)	368	596	828	1112
Energy (MUs)				
Annual Energy	1555	3029	4206	5651
Storage Recommended (MWh)				
Battery (LV)	0	7.5	13.5	24
Battery (MV)	0	11	36	44

State – Tripura	2019	2022	2027	2032
Generation (MW)				
Thermal	644	NA	NA	NA
Hydro	62	NA	NA	NA
Nuclear	0	NA	NA	NA
Solar	5.1	105	350	550
Ground Mounted Solar	5	55	260	390
RTPV	0.01	50	90	160
Connected to EHV	-	-	-	-
Connected to MV	5	55	260	390
Connected to LV	0.09	50	90	160
Wind	-	-	-	-
Small Hydro	16	-	-	46
Biomass & Biopower	-	-	-	-
Peak Load (MW)	342	472	674	913
Energy (MUs)				
Annual Energy	2599	2026	2892	3921
Storage Recommended (MWh)				
Battery (LV)	0	7.5	13.5	24
Battery (MV)	0.5	5.5	26	39

State – Manipur	2019	2022	2027	2032
Generation (MW)				
Thermal	139	NA	NA	NA
Hydro	89	NA	NA	NA
Nuclear	0	NA	NA	NA
Solar	3.2	105	250	400
Ground Mounted Solar	0	55	160	240
RTPV	3.2	50	90	160
Connected to EHV	-	-	-	-
Connected to MV	0	55	160	240
Connected to LV	3.2	50	90	160
Wind	-	-		
Small Hydro	5.5	-	-	99
Biomass & Biopower	-	-	-	-
Peak Load (MW)	195	497	869	1212
Energy (MUs)				
Annual Energy	871	2219	3881	5416
Storage Recommended (MWh)				
Battery (LV)	0.5	7.5	13.5	24
Battery (MV)	0	5.5	16	24

State – Nagaland	2019	2022	2027	2032
Generation (MW)				
Thermal	70	NA	NA	NA
Hydro	53	239	NA	NA
Nuclear	0	NA	NA	NA
Solar	1	61	200	350
Ground Mounted Solar	0	11	110	190
RTPV	1	50	90	160
Connected to EHV	-	-	-	-
Connected to MV	0	11	110	190
Connected to LV	8	50	90	160
Wind	-	-	-	-
Small Hydro	31	32	-	182
Biomass & Biopower	-	-	-	-
Peak Load (MW)	146	271	403	554
Energy (MUs)				
Annual Energy	794	1163	1728	2373
Storage Recommended (MWh)				
Battery (LV)	0	7.5	13.5	24
Battery (MV)	0	1	11	19

State – Mizoram	2019	2022	2027	2032
Generation (MW)				
Thermal	61	NA	NA	NA
Hydro	94	NA	NA	NA
Nuclear	0	NA	NA	NA
Solar	0.5	72	200	350
Ground Mounted Solar	0.1	22	110	190
RTPV	0.4	50	90	160
Connected to EHV	-	-	-	-
Connected to MV	0.1	22	110	190
Connected to LV	0.4	50	90	160
Wind	-	-	-	-
Small Hydro	37	49	-	168
Biomass & Biopower	-	-	-	-
Peak Load (MW)	96	352	521	723
Energy (MUs)				
Annual Energy	497	1388	2053	2847
Storage Recommended (MWh)				
Battery (LV)	0	7.5	13.5	24
Battery (MV)	0	2.2	11	19

UTs

UT – Andaman & Nicobar	2019	2022	2027	2032
Generation (MW)				
Thermal	40	NA	NA	NA
Hydro	0	NA	NA	NA
Nuclear	0	NA	NA	NA
Solar	7	27	100	150
Ground Mounted Solar	5	15	60	75
RTPV	2	12	40	75
Connected to EHV	-	-	-	-
Connected to MV	5	15	60	75
Connected to LV	2	12	40	75
Wind	-	-	NA	
Small Hydro	5	-	-	-
Biomass & Biopower	-	-	-	-
Peak Load (MW)	54	89	125	172
Energy (MUs)				
Annual Energy	329	505	709	963
Storage Recommended (MWh)				
Battery (LV)	0.3	2	6	11
Battery (MV)	0.5	1.5	6	7.5

UT – Lakshadweep	2019	2022	2027	2032
Generation (MW)				
Thermal	0	NA	NA	NA
Hydro	0	NA	NA	NA
Nuclear	0	NA	NA	NA
Solar	0.75	20	50	100
Ground Mounted Solar	0.75	10	30	68
RTPV	0	10	20	32
Connected to EHV	-	-	-	-
Connected to MV	0.75	10	30	68
Connected to LV	0	10	20	32
Wind	-	-	-	-
Small Hydro	-	-	-	-
Biomass & Biopower	-	-	-	-
Peak Load (MW)	9	18	23	30
Energy (MUs)				
Annual Energy	48	65	84	110
Storage Recommended (MWh)				
Battery (LV)	0	1	3	5
Battery (MV)	0	1	3	7

Source:

http://www.cea.nic.in/reports/annual/lgbr/lgbr-2018.pdf

http://www.cea.nic.in/reports/committee/nep/nep_jan_2018.pdf

http://allaboutrenewables.com/capacity-addition

http://www.cea.nic.in/reports/monthly/executivesummary/2018/exe_summary-03.pdf

NOTE: Assumptions done by considering the following

1. 100 GW Solar Target by 2022, out of which 40 GW is RTPV, 20 GW Medium Size Installations and 40 GW Solar Parks
2. 250 GW Solar Target by 2027, ratio taken in accordance with 2022 targets
3. 360 GW Solar Target by 2032, ratio taken in accordance with 2022 targets
4. All values post 2022 have been forecasted using best estimates methodology devised by ISGF

Annexure 4: CYMDIST Library Files

The issues and impact of RTPV faced by utilities across India varies according to their geographical location, their feeder loads and their MV/LV network topologies. Thus, the RTPV hosting capacity varies for different feeders. This is particularly more sensitive in the lower MV voltages with maximum sensitivity in the 415V and 230V secondary voltages. The most impact is on power quality aspects particularly with respect to “low or high permissible voltages” in select parts of the network. A second aspect is the imbalance of VAR requirements/flows due to the addition of the RTPV which typically operate at unity power factor. It is however not possible to do an in-depth feeder analysis for every RTPV addition. Thus, a qualitative set of limits must be arrived at after performing sample quantitative studies of typical feeders, together with the RTPV connections, feeder loads (both MV and LV), the network line parameters and DT capacities.

In order to analyze the details of the MV/LV network, six distribution utilities were selected to conduct a detailed load flow analysis of distribution feeders. We have carried out detailed load flow analysis of the six feeders mentioned below. DISCOMs falling under any of the (below mentioned) categories can contact ISGF for the detailed study.

Region	Selected State	Feeder Category	DISCOM Name
North	Delhi	Urban Lightly Loaded	Tata Power Delhi Distribution Ltd. (TPDDL)
	Haryana	Agricultural	Uttar Haryana Bijli Vitran Nigam Ltd. (UHBVN)
South	Karnataka	11 kV	Bangalore Electricity Supply Company Ltd. (BESCOM)
	Andhra Pradesh	Semi Urban Heavily Loaded	Andhra Pradesh Southern Power Distribution Company Ltd. (APSPDCL)
West	Maharashtra	Urban Lightly Loaded	Adani Energy Mumbai Ltd. (AEML)
East	West Bengal	Urban Heavily Loaded	Calcutta Electric Supply Corporation (CESC), Kolkata

Note: The CYMDIST Library files of aforementioned DISCOMs are available with ISGF for study on a request basis.

Note:

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