Energy Storage Systems (ESS) Roadmap for India: 2019-2032

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Sponsored by: MacArthur Foundation

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Scope of the Project

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- Assessment of MV/LV stabilization and optimization for 40GW RTPV by 2022 and much larger by 2032
- Study of different ESS Technologies and its effectiveness in India
    - Detailed Techno-commercial Evaluation
    - Guiding Document for Choosing ESS solutions
- Estimation of Grid connected ESS in each state considering planned VRE Penetration
- VRE Hosting Capacity of Feeders (MV/LV)
    - Solutions enabling portfolio for VRE integration
    - Network Model – assess different scenarios for VRE penetration
- Energy Storage India Tool (ESIT)
- Energy Storage System Roadmap for India

Renewable Energy Capacity Region-Wise and Total Target for 2022

State	Solar	Wind	Small Hydro	Biomass and Biopower	Total RE Target 2022 (MW)	RE Installed Capacity September 2020 (MW)
Northern Region	31,119	8,600	2,450	4,149	46,318	17,393
Western Region	28,410	22,600	125	2,875	54,010	26,792
Southern Region	26,531	28,200	1,675	2,612	59,018	43,089
Eastern Region	12,237	0	135	244	12,616	1,552
North Eastern Region	1,206	0	615	0	1,821	369
All India Total	99,534	60,000	5000	10,000	**1,74,534**	**89,229**

40 GW RTPV Allocation

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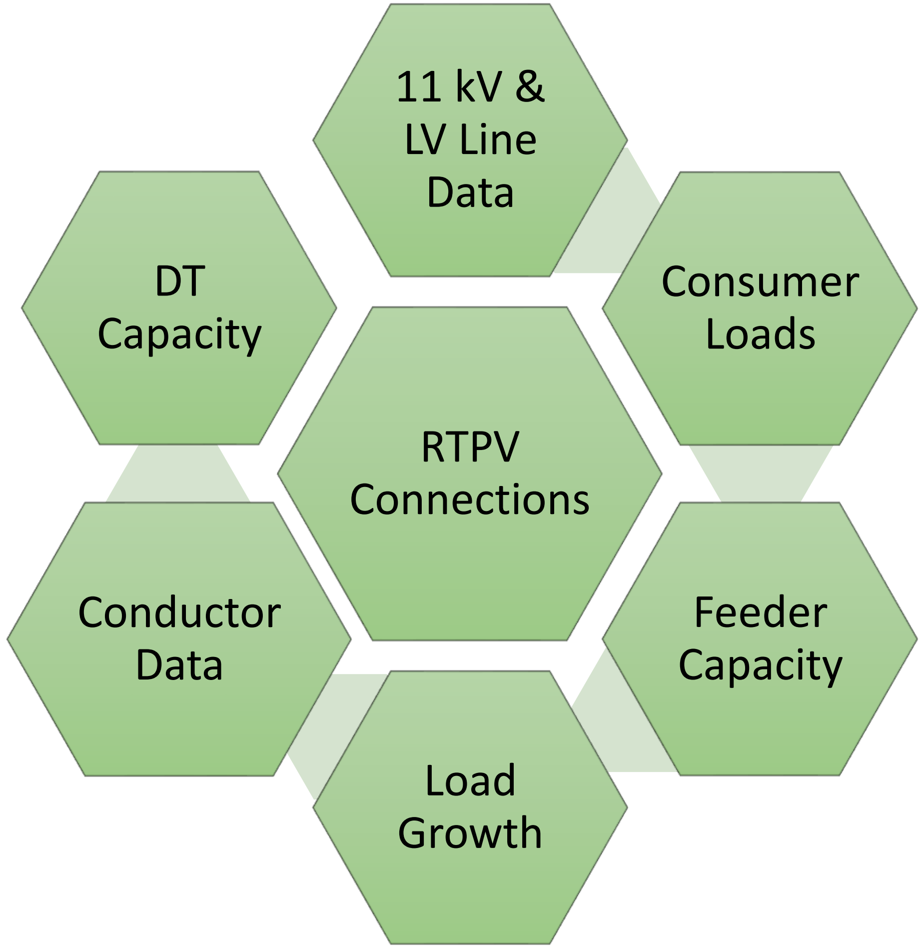
States	Target by 2022 (MW)
Andhra Pradesh	2,000
Bihar	1,000
Chhattisgarh	700
Delhi	1,100
Gujarat	3,200
Haryana	1,600
Himachal Pradesh	320
Jammu & Kashmir	450
Jharkhand	800
Karnataka	2,300
Kerala	800
Madhya Pradesh	2,200
Maharashtra	4,700
Orissa	1,000
Punjab	2,000
Rajasthan	2,300
Tamil Nadu	3,500
Telangana	2,000
Uttarakhand	350
Uttar Pradesh	4,300
West Bengal	2,100
Arunachal Pradesh	50
Assam	250
Manipur	50
Meghalaya	50
Mizoram	50
Nagaland	50
Sikkim	50
Tripura	50
Chandigarh	100
Goa	150
Dadra & Nagra Haveli	200
Daman & Diu	100
Pondicherry	100
Andaman & Nicobar Islands	20
Lakshadweep	10
Total	**40,000**

Feeder Categories and Data Collection

Region	State Selected	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)
	Maharashtra	Urban Lightly Loaded	Adani Energy Mumbai Ltd. (AEML)
East	West Bengal	Urban Heavily Loaded	Calcutta Electric Supply Corporation Ltd. (CESC)



RTPV Load Flow Study Assumptions

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Identify/select time slots for the load flow study (Four time slots i.e. 8:00 AM -11:00 AM, 11:00 AM - 1:00 PM, 1:00PM - 4:00 PM, 4:00PM - 7:00PM)

Select any specific time during each time slot for which feeder is heavily loaded (in this study, ISGF considered heavily loaded time in order to run load flow during severe conditions)

Run the load flow study of feeder during the selected time slot

Perform load flow analysis for increasing solar RTPV connection at consumer side (LT/HT/agriculture/commercial etc.) in steps w.r.t. percentage of transformer rating

Typical Analysis Urban Lightly Loaded Feeder (TPDDL)

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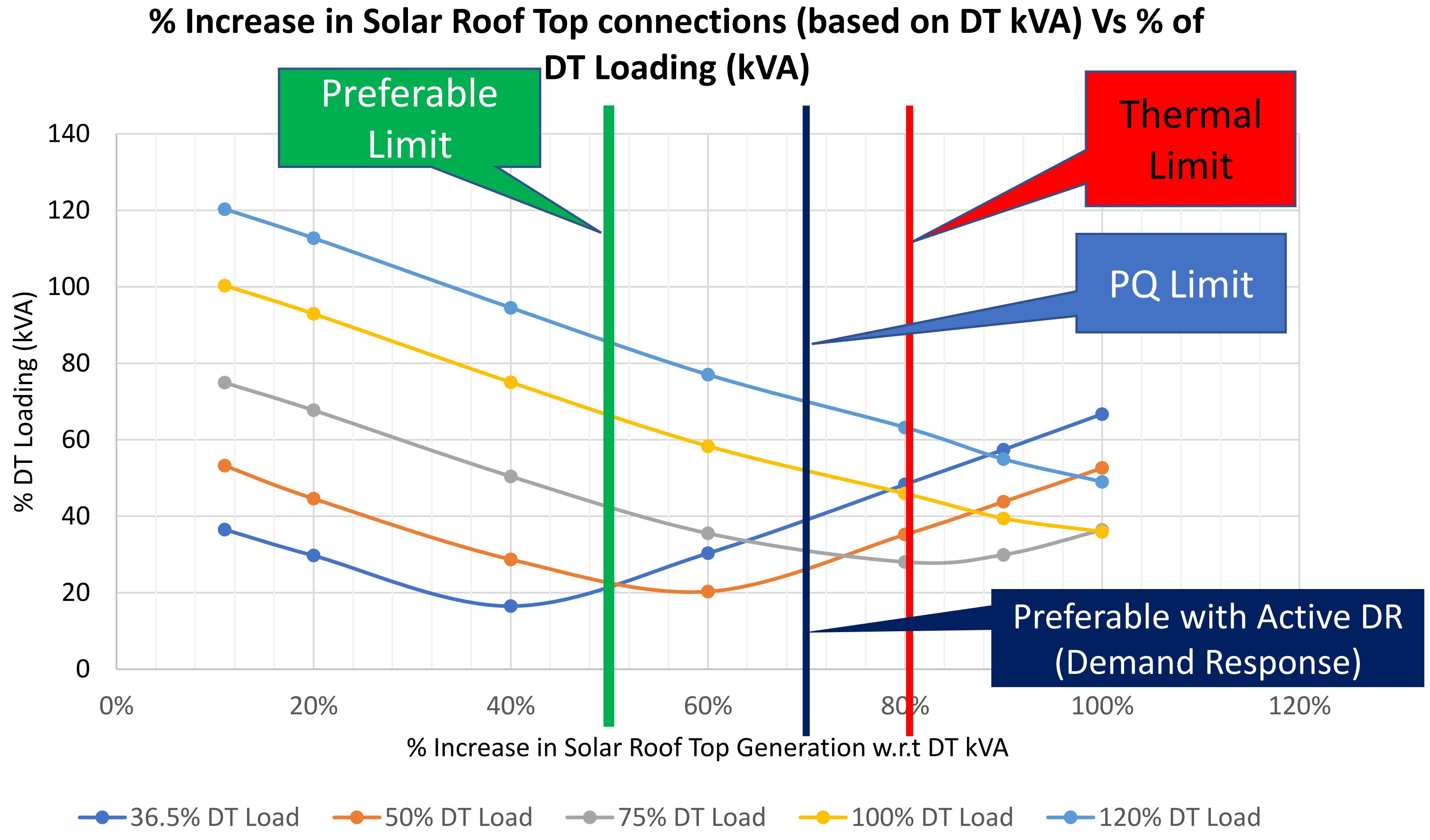
Observations

Thermal Limit: 80% of RTPV connections

PQ Limit: 75% of RTPV connections

Considering harmonics and uncertainty of clouds, permissible limit for RTPV connections can be 50% of DT Capacity



Solutions and Recommendations

Solution to have RTPV up to PQ limit successfully:

- Smart inverters that
  - can be set to below 0.7 pf. Lead/lag
  - control nodal voltage at the PCC
  - integrate PV, Grid, Load and ESS as one single system
- Dynamic load management and VAR management

Recommendations

Domestic Consumer

RTPV can be applied up to 50 % of DT capacity

Beyond 50 to 75 %, RTPV is preferable with Active DR and Energy Storage devices due to PQ issues

Beyond 80 %, thermal issues and overloading is observed ,so RTPV is not preferable

HT and Industrial Consumer

RTPV can be applied up to 50% of DT Capacity

Between 50 - 80%, RTPV can be applicable with smart inverters and active demand response. Energy storage devices are applicable

Beyond 80%, low power factor is found on sections, so power factor correction is needed. Thermal loading and voltage violation are observed

Agricultural Consumer

RTPV can be applied up to 50% of DT Capacity

RTPV will help agriculture consumer for their loads other than pumps when supply is not there

RTPV cannot supply motor loads effectively and often result in voltage trips from PV inverters (particularly for agriculture feeders)

Between 50% - 80%, PQ issues are observed. Energy Storage and Active Demand Response is applicable

Beyond 80%, low power factor and thermal issues are found

Energy Storage Roadmap for India: 40 GW RTPV on MV/LV Grid by 2022

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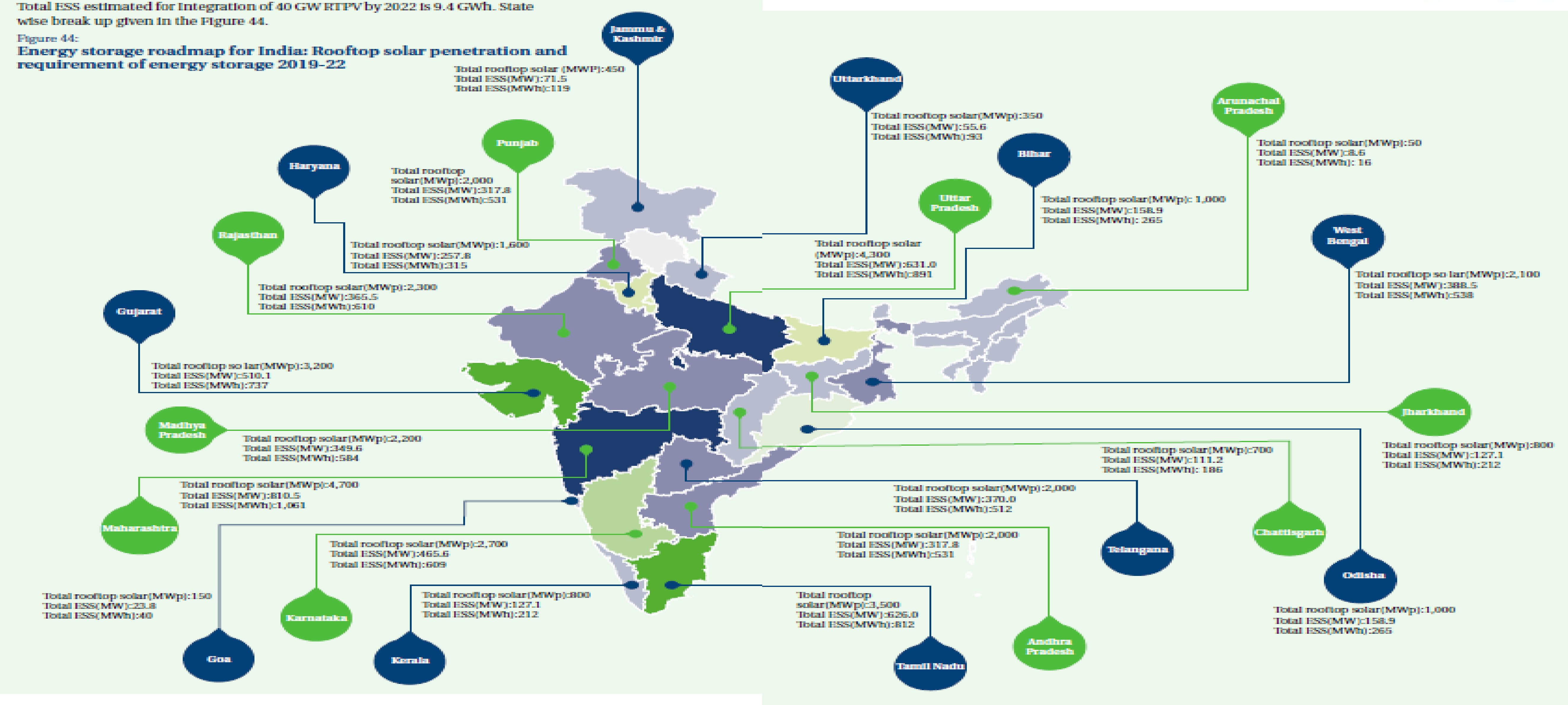
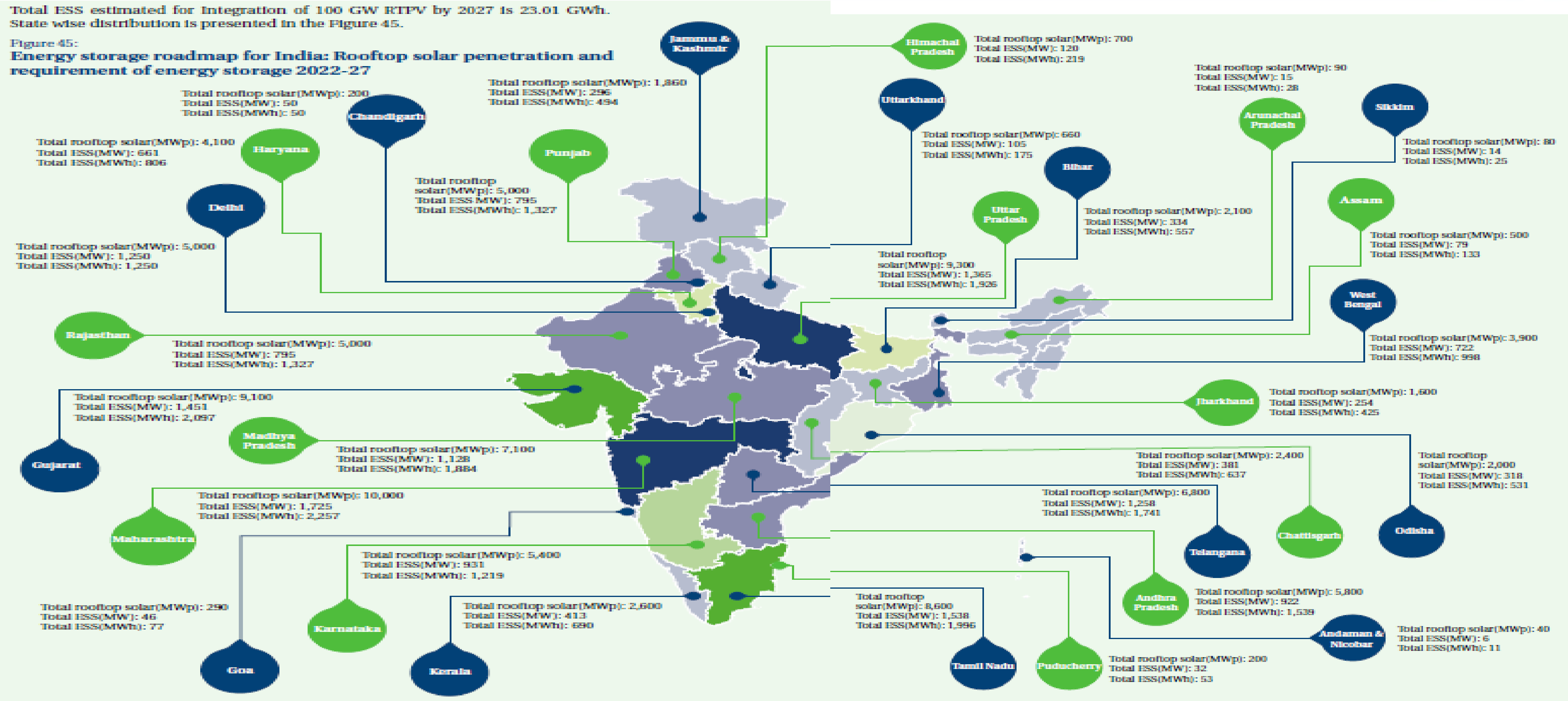
Total ESS estimated for Integration of 40 GW RTPV by 2022 is 9.4 GWh. State wise break up given in the Figure 44.

Figure 44:
Energy storage roadmap for India: Rooftop solar penetration and requirement of energy storage 2019-22



Energy Storage Roadmap for India: 100 GW RTPV on MV/LV Grid by 2027



Energy Storage Roadmap for India: 150 GW RTPV on MV/LV Grid by 2032

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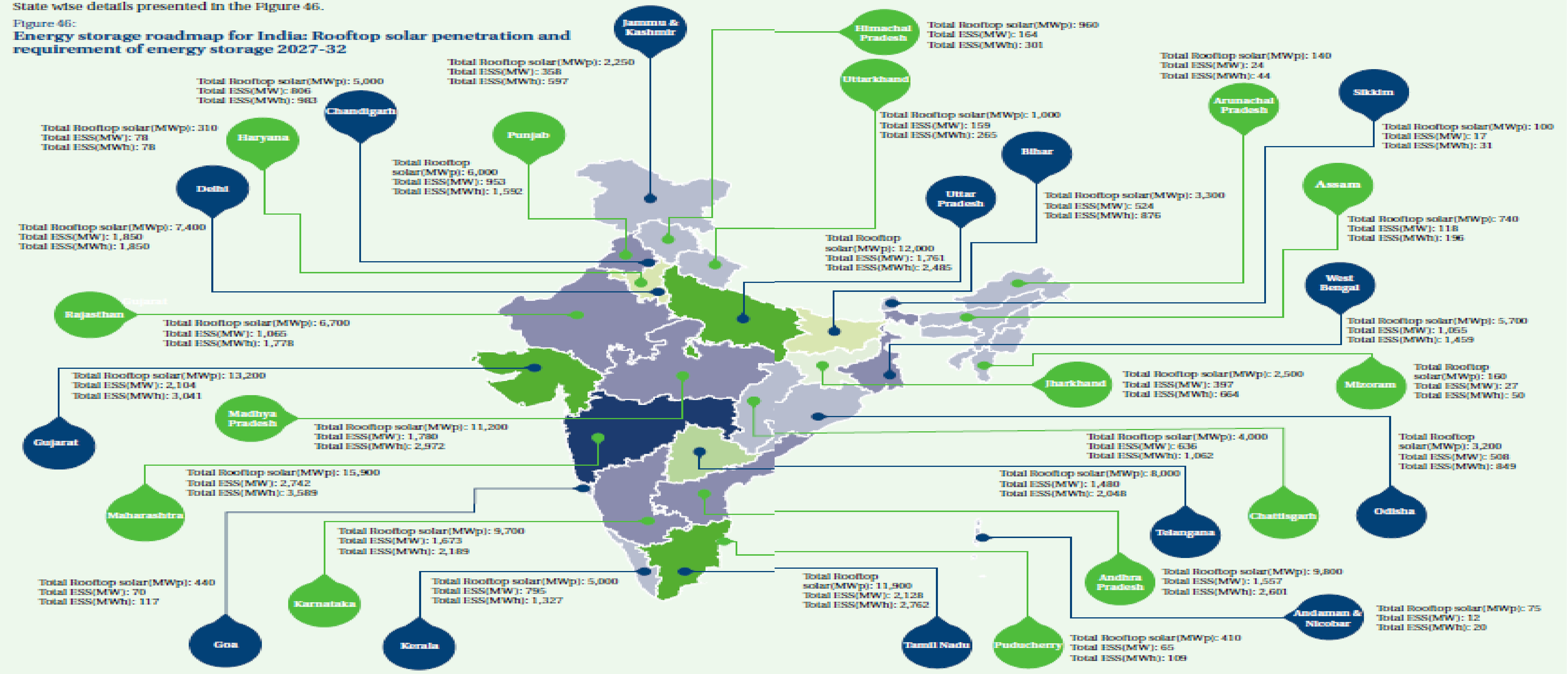
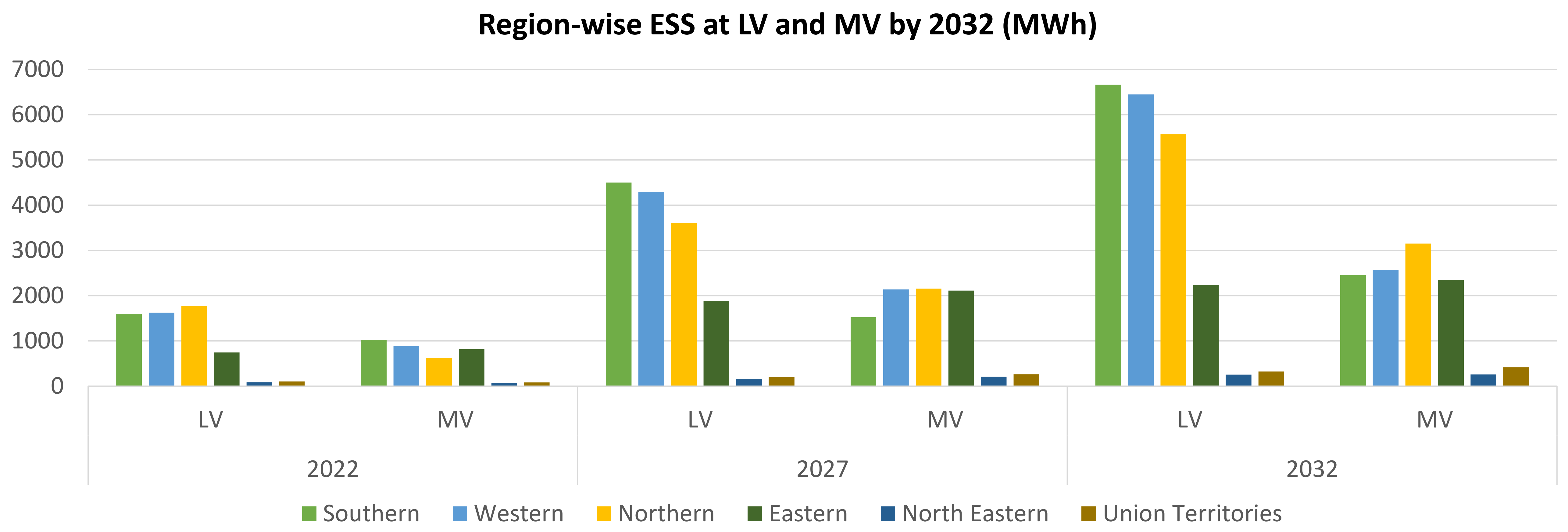
Total ESS estimated for integration of 150 GW RTPV by 2032 is 32.675 GWh.
State wise details presented in the Figure 46.

Figure 46:
Energy storage roadmap for India: Rooftop solar penetration and requirement of energy storage 2027-32



Region wise ESS at LV and MV (MWh) by 2032



	2022		2027		2032	
	LV	**MV**	**LV**	**MV**	**LV**	**MV**
Total (MWh)	5908	3482	14617	8393	21484	11191

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		0	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**	**1,710**	**2,416**

Energy Storage Roadmap for India: 2019 - 2032

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Estimations	2018-19	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	1,192	1,905	2,710	3,710
Storage Recommended (MWh)				
Battery (LV)	241	5,908	14,617	21,484
Battery (MV)	1,054	3,482	8,393	11,191
Total (MWh)	**1,295**	**9,390**	**23,010**	**32,675**

Monetizable and Non-Monetizable Benefits

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

ESIT Tool: General Overview

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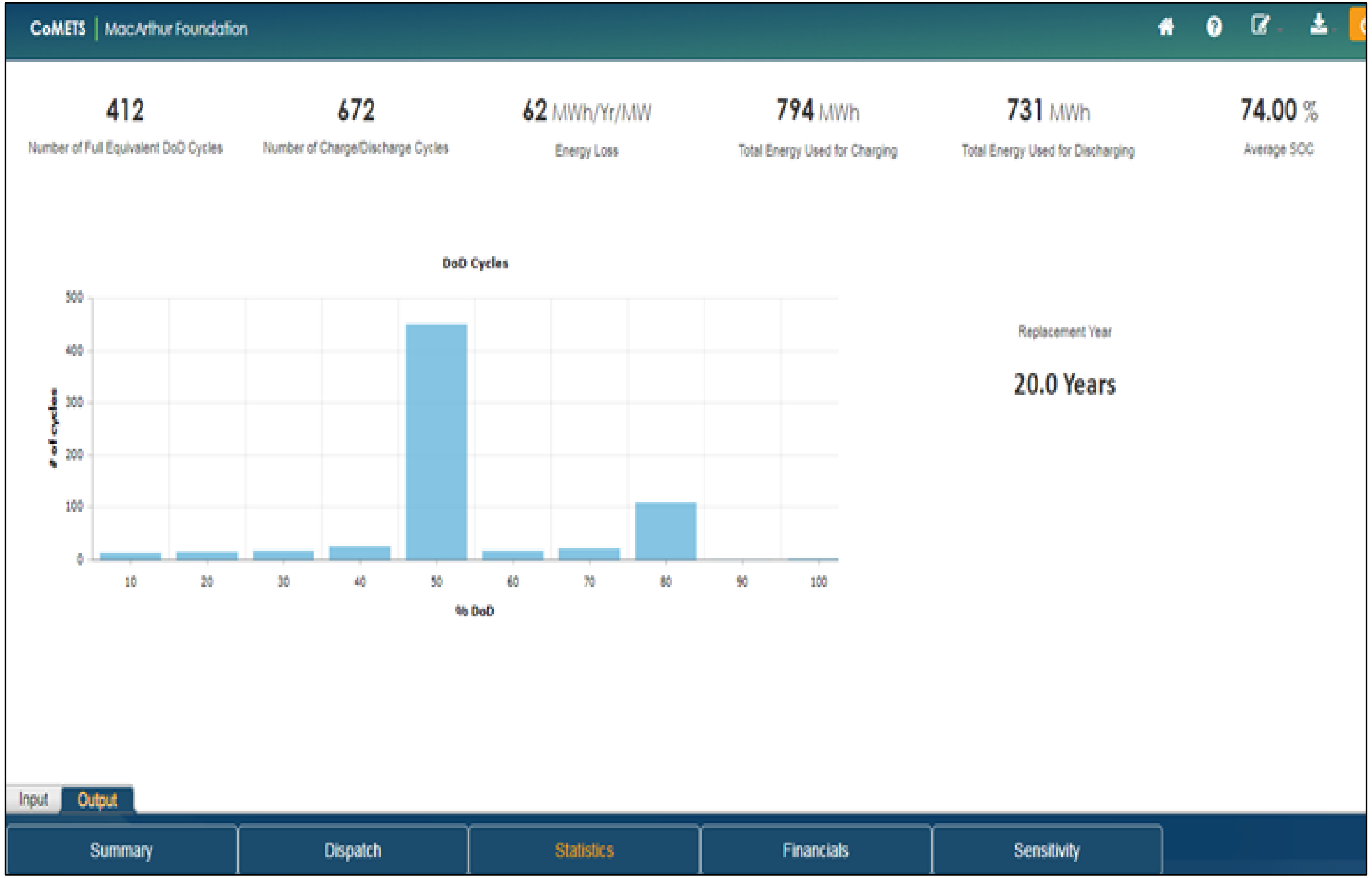
- ESIT tool is able to model the operation of ESS when given inputs related to the site and parameters of the project and derive the possible value benefits
- Some of the value benefits for ESS at feeder level are Loading Reduction, System peak shave benefits, Time shifting, Penalty Payment savings, Economic Adder, etc
- The value streams captured change based on the site of the ESS project: Feeder level, DT level or Customer level

ESIT Tool: Statistics Tab



- The tool takes in comprehensive input parameters.
- For inputs various tabs are provided to take in data
- Load and irradiance data can be easily uploaded. Model prefers annual data but can automatically annualize if data is of shorter duration
- A separate section is provided to model the feeder and supply side parameters such as power procurement cost (and its seasonal variation), power reliability, penalty payments, Economic adders

ESIT Tool: Outputs

- Tool gives out numerical as well as Visual outputs
- Summary tab helps the user to understand the various value streams captured as well as the implication of added solar and storage on technical parameters such as loading
- Further tabs provide actual interval dispatch of Load, Load+Solar and Load+Solar+Storage for a representative year. Clipping of the peak and reverse can easily be observed through such dispatch
- A tab is also provided to show cycling of ESS and technical parameters such as energy throughput, avg SoC, etc. Rainflow algorithm is used to calculate cycle count
- The financials tab helps quantify all the costs and benefits
- User gets the YoY outputs of Non-Monetizable and Monetizable benefits
- YoY costs such as Capex and Opex are also shown
- Income statement is generated
- Finally Cash Flows section is shown from which IRR and NPV of the project is calculated
- Tool can also perform sensitivities of Loading vs different penetration of Solar with and without storage

Multiple Use-Cases

- T&D Deferral
- System Peak Shavings Benefits
- Energy Arbitrage
- Time Shifting
- Penalty Savings
- DR Revenue
- Diesel Minimization

ESIT Tool: Value Streams

Utility Sited (Feeder/DT)

- **T&D Deferral:** The tool deploys storage when feeder/DTs are heavily loaded (Local peak shaving and reverse flow absorption). This defers the T&D upgradation. Benefits are calculated as savings on interest payments on upgradation costs due to deferral.
- **System Peak Shavings benefits:** System wide peak shaving benefits can be captured by the if a suitable program exists. Storage is deployed to reduce Utility loads during system peaks
- **Time Shifting:** The tool is able to look at the power procurement cost for the utility. If there exists an arbitrage, then storage is deployed to take advantage of price differentials
- **Penalty Savings:** Tool is able to quantify the savings on penalty payments to consumers during power cuts if storage is deployed to serve the load.

Utility Sited (Feeder/DT)

- **T&D Deferral:** The tool deploys aggregated storage when DTs are heavily loaded (Local peak shaving and reverse flow absorption). This defers the T&D upgradation. Benefits are calculated as savings on interest payments on upgradation costs due to deferral which are shared by the utility with the consumers
- **DR Revenue:** The tool can model a DR program. Utility calls are specified. If the customer sited storage responds during those calls, the benefits are calculated
- **Energy Arbitrage:** In the rate plan for the consumer, if there exits an arbitrage, then storage is deployed to capture those benefits.
- **Diesel Minimization:** Tool can calculate the benefits due reduction in Diesel consumption by DG if storage is deployed during power cuts

Cost-Benefit Analysis

Assumption Parameter	2020	2022	2025
Solar Penetration	20% & 50%	40% & 70%	70% & 90%
Peak load (GW) (Considering annual load growth is 3%)	106.6	116	127
PCS Cost trend($/kW)	224-405	182-328	133-239
Storage cost($/kWh)	220	184	150

Utility considered: CESC (Urban Heavily Loaded)

- **Feeder Capacity**: 2.9 MVA
- **No.of DTs**: 11
- **Cumulative DT Capacity**: 3.4 MVA
- **Feeder loading**: 85% to capture max. benefit of using storage with solar
- **Battery technology**: Li-ion NMC (10 years) and Lead Acid (3years)
- **Feeder Upgrade Planning**: 30 years

Summary of Different Level Analysis

Year	Different Level	Solar Penetration	Individual Storage capacity (KW)	Total storage capacity (MW)	Storage capacity (MWh)	NPV Project	IRR
2020	Feeder	50 %	290	0.29	0.58	-0.772	6.01 %
	DT	50 %	31.5	0.031	0.031	0.076	*21.6 %
	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

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Thank You

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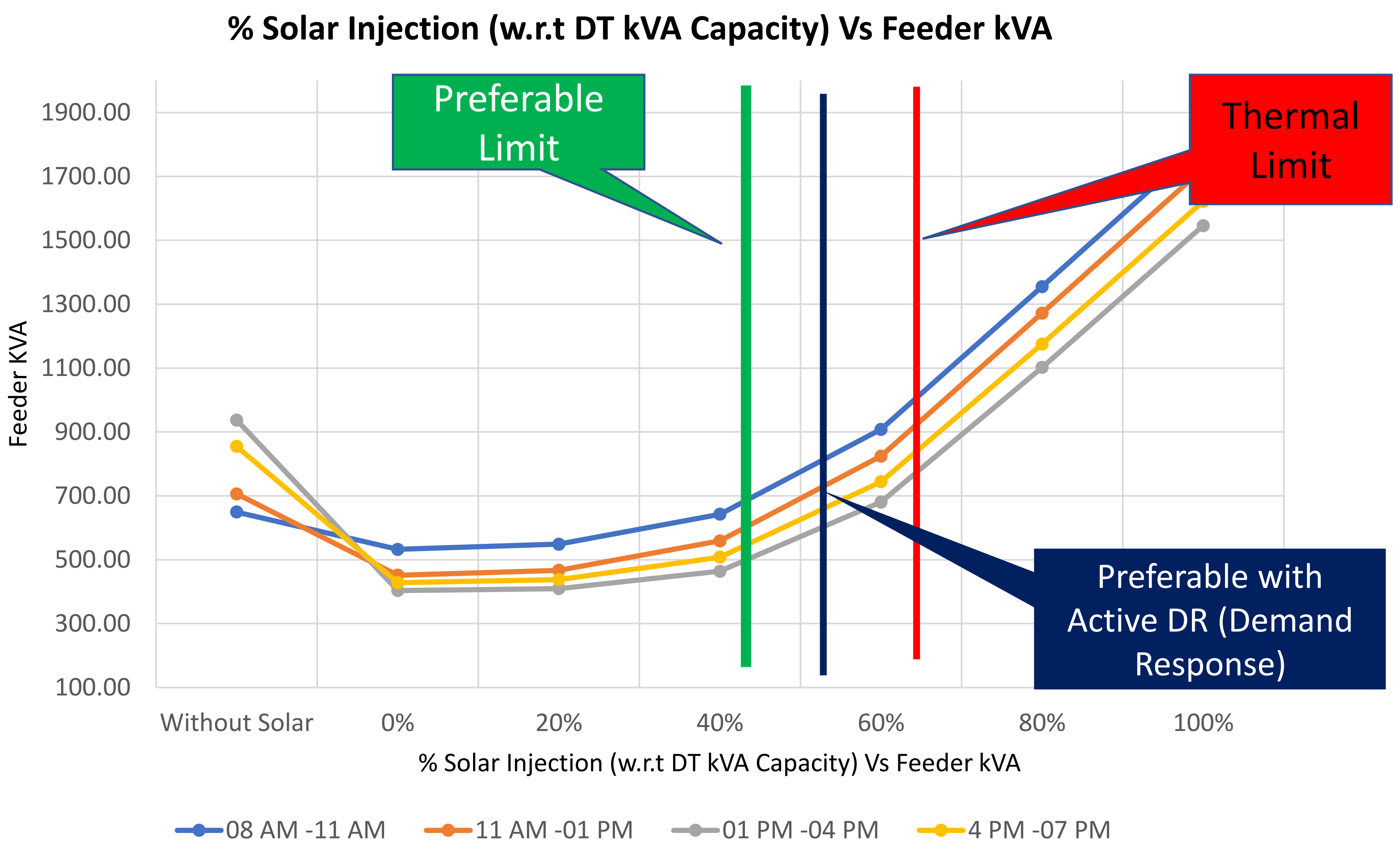
Analysis of Agricultural Feeder (UHBVN)

Observations

- Thermal Limit: 60% of RTPV connections
- PQ Limit: 50% of RTPV connections
- Considering Harmonics and uncertainty of clouds, permissible limit for RTPV connections can be 40% of DT Capacity



Load Flow Study Observations

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Time Slots	Over Voltage (V > = 1.06 pu)	Under Voltage (V <= 0.94 pu)	Observations
08AM - 11AM	NONE	0%, 20%, 40%	For both the DTs considered for the study, Undervoltage is observed at 0%, 20 %, 40 % of solar generation. After that, as RTPV increases, Undervoltage disappears.
11AM - 01PM	NONE	0%, 20%, 40%	Undervoltage observed: For one DT, till 20 % and for the other, till 40% of solar generation. After that, as RTPV increases, Undervoltage disappears.
01PM - 04PM	NONE	0%, 20%, 40%	Undervoltage observed: For one DT, till 20% and for the other, till 40% of solar generation. After that, as RTPV increases, Undervoltage disappears.
04PM - 07PM	NONE	0%, 20%, 40%	Undervoltage observed: For one DT, till 20% and for the other, till 40% of solar generation. After that, as RTPV increases, Undervoltage disappears.

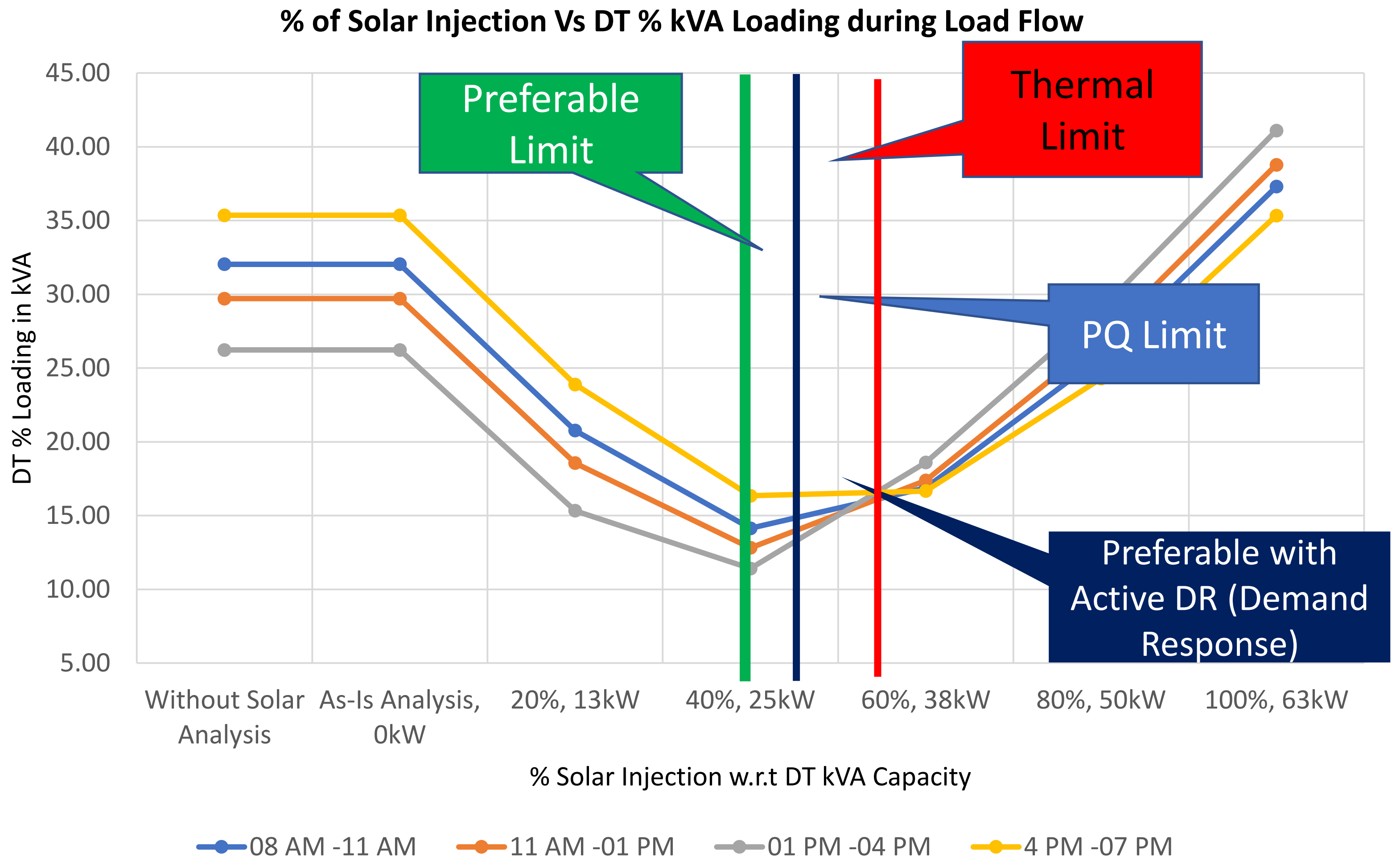
Analysis of 11 kV Feeder (BESCOM)

Observations

Thermal Limit: 60% of RTPV connections

PQ Limit: 50% of RTPV connections

Considering Harmonics and uncertainty of clouds, permissible limit for RTPV connections can be 40% of DT Capacity



Load Flow Study Observations

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<table>
<tr><th>Time Slots</th><th>Over Voltage (V > = 1.06 pu)</th><th>Under Voltage (V <= 0.94 pu)</th><th>Observations</th></tr>
<tr><td>08AM - 11AM</td><td>NONE</td><td>NONE</td><td rowspan="4">Undervoltage: No undervoltage is observed beyond permissible limit, but it improves as RTPV is increased
Overvoltage: No overvoltage is observed on any section as over size conductor of 90 mm^2 were used in LT side
Power factor:
○ Lower power is observed on DT when loading is decreased due to increased RTPV in each scenarios i.e. at 20% to 60%. After 60%, power factor improves due to more reverse power flow as loading on DT increased
○ In sections near RTPV generation e.g. 2354, 2345 XLPE cables, lower power factor is observed between 40 to 80% with increase in RTPV</td></tr>
<tr><td>11AM - 01PM</td><td>NONE</td><td>NONE</td></tr>
<tr><td>01PM - 04PM</td><td>NONE</td><td>NONE</td></tr>
<tr><td>04PM - 07PM</td><td>NONE</td><td>NONE</td></tr>
</table>

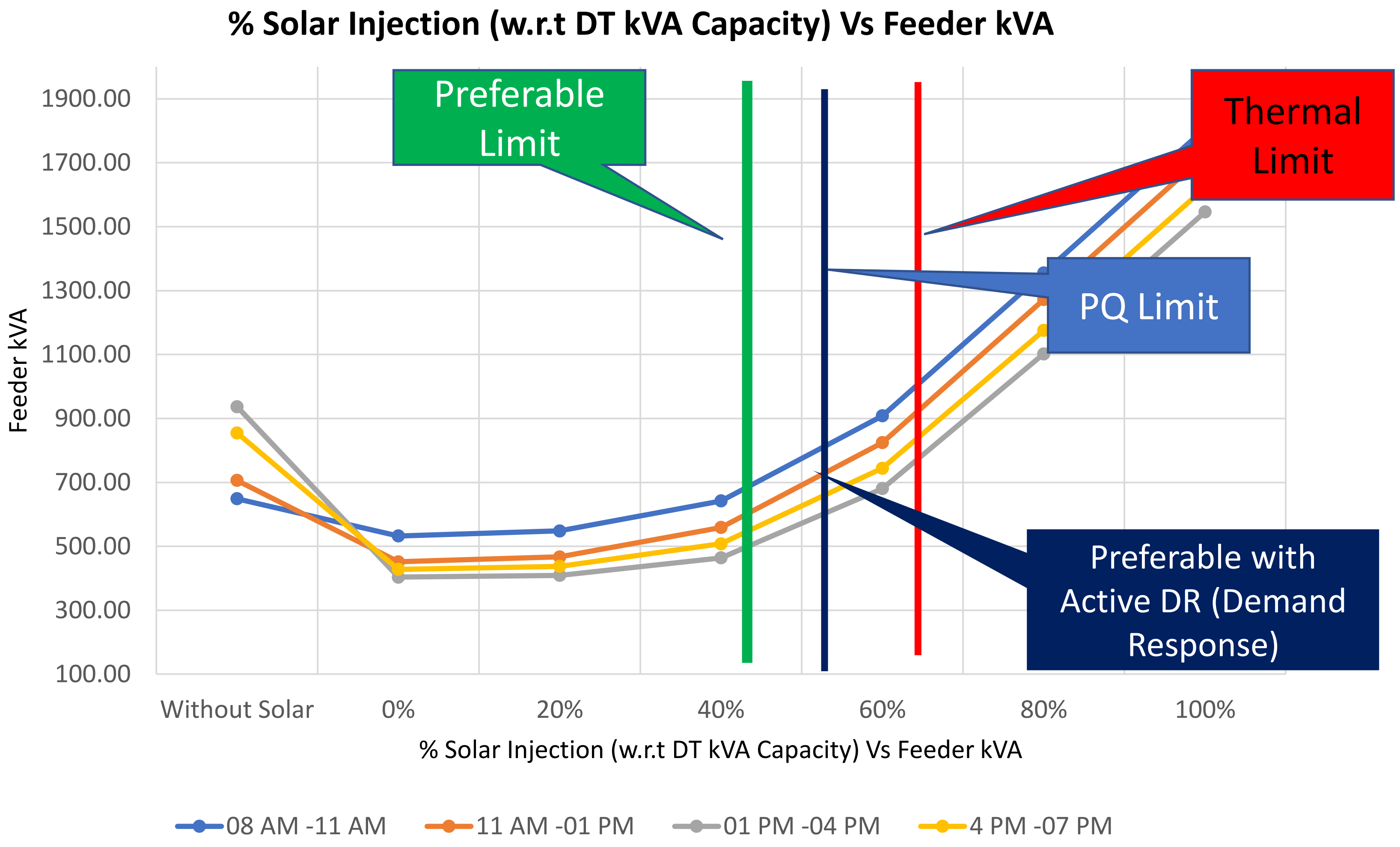
Analysis of Semi Urban Heavily Loaded Feeder (APSPDCL)

Observations

Thermal Limit: 60% of RTPV connections

PQ Limit: 50% of RTPV connections

Considering harmonics and uncertainty of clouds, permissible limit for RTPV connections can be 40% of DT Capacity



Load Flow Study Observations

Time Slots	Over Voltage (V > = 1.06 pu)	Under Voltage (V <= 0.94 pu)	Observations
08AM - 11AM	NONE	NONE	At 100% RTPV, overloading is observed for all HT consumers
11AM - 01PM	NONE	NONE	At 100% RTPV, overloading observed for all HT consumers. Power factor decreases with increase in RTPV.
01PM - 04PM	NONE	0% Solar, 1002 kWp (AS-IS), 1022kWp (20% RTPV)	Undervoltage observed on some LT section of DT and after 20% RTPV, Undervoltage is removed due to more injection of RTPV. At 100% RTPV, overloading observed for all HT consumers
04PM - 07PM	NONE	0% Solar, 1002 kWp (AS-IS)	Undervoltage observed on some LT section of DT and after 20% RTPV, Undervoltage is removed due to more injection of RTPV. At 100% RTPV, overloading observed for all HT consumers DT.

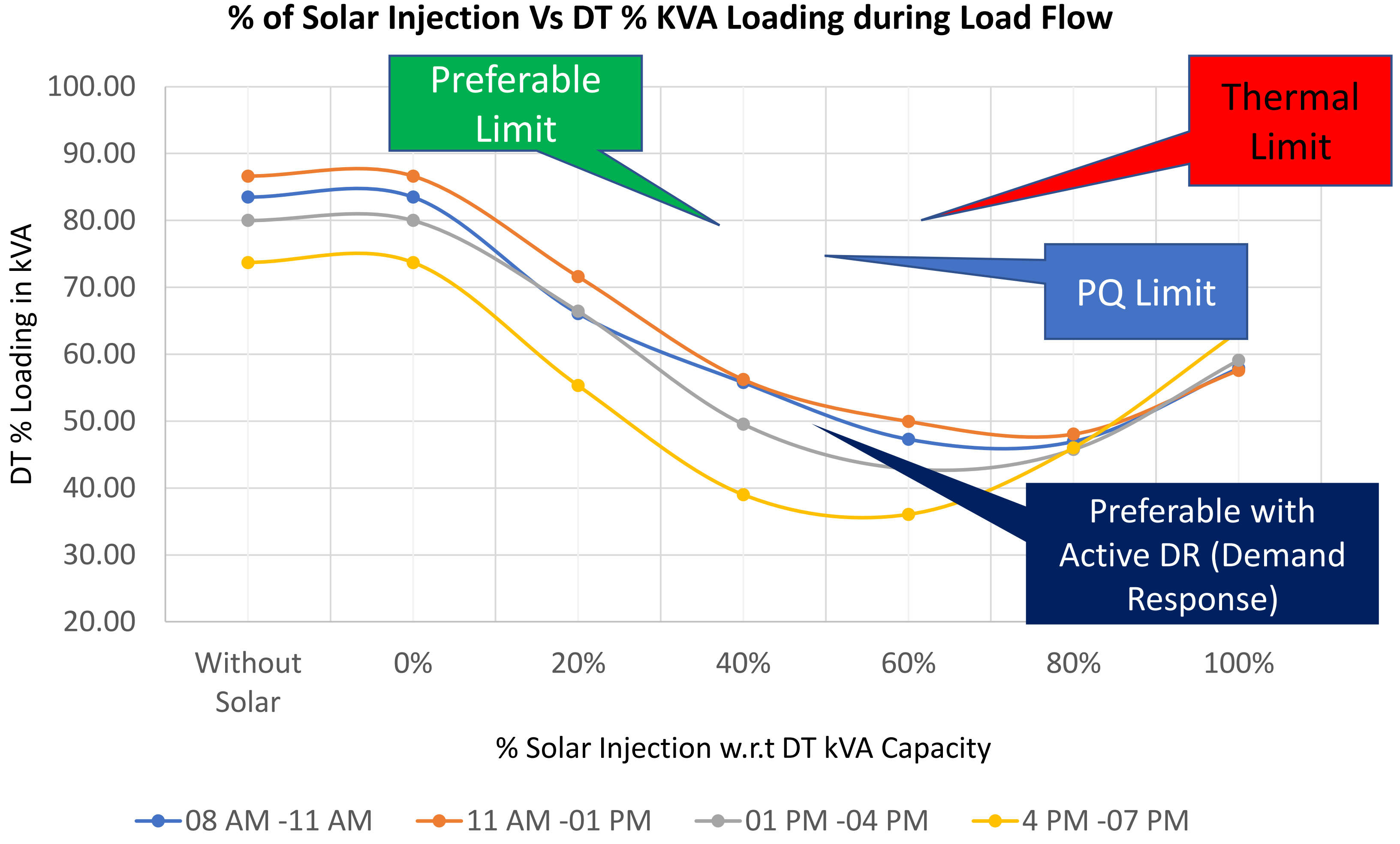
Analysis of Urban Heavily Loaded Feeder (CESC)

Observations

Thermal Limit: 60% of RTPV connections

PQ Limit: 50% of RTPV connections

Considering harmonics and uncertainty of clouds, permissible limit for RTPV connections can be 40% of DT Capacity



Load Flow Study Observations

Time Slots	Over Voltage (V > = 1.06 pu)	Under Voltage (V <= 0.94 pu)	Observations
08AM - 11AM	286kWp (80 % RTPV) & 346kWp (100% RTPV)	0% Solar, 46kWp (AS-IS), 106kWp (20% RTPV), 166kWp (40% RTPV), 226kWp (60% RTPV), 286kWp (80% RTPV)	**Overvoltage - O**bserved on some RTPV connection after increasing RTPV more than or equal to 80% **Undervoltage** – Observed on many sections of LT feeder up to 80% RTPV; but it gets cleared after 80% RTPV due to more loading at LT end
11AM - 01PM	286kWp (80 % RTPV) & 346kWp (100% RTPV)	0% Solar, 46kWp (AS-IS), 106kWp (20% RTPV), 166kWp (40% RTPV), 226kWp (60% RTPV), 286kWp (80% RTPV)	
01PM - 04PM	226kWp (60% RTPV), 286kWp (80 % RTPV) & 346kWp (100% RTPV)	0% Solar, 46kWp (AS-IS), 106kWp (20% RTPV), 166kWp (40% RTPV), 226kWp (60% RTPV), 286kWp (80% RTPV)	**Overvoltage -** Observed on some RTPV connection after increasing RTPV more than or equal to 60% **Undervoltage -** Observed on many section of LT feeder when RTPV increased from AS-IS to 80% RTPV; but it gets cleared after 80% RTPV due to more loading at LT end
04PM - 07PM	226kWp (60% RTPV), 286kWp (80 % RTPV) & 346kWp (100% RTPV)	0% Solar, 46kWp (AS-IS), 106kWp (20% RTPV), 166kWp (40% RTPV), 226kWp (60% RTPV), 286kWp (80% RTPV)	

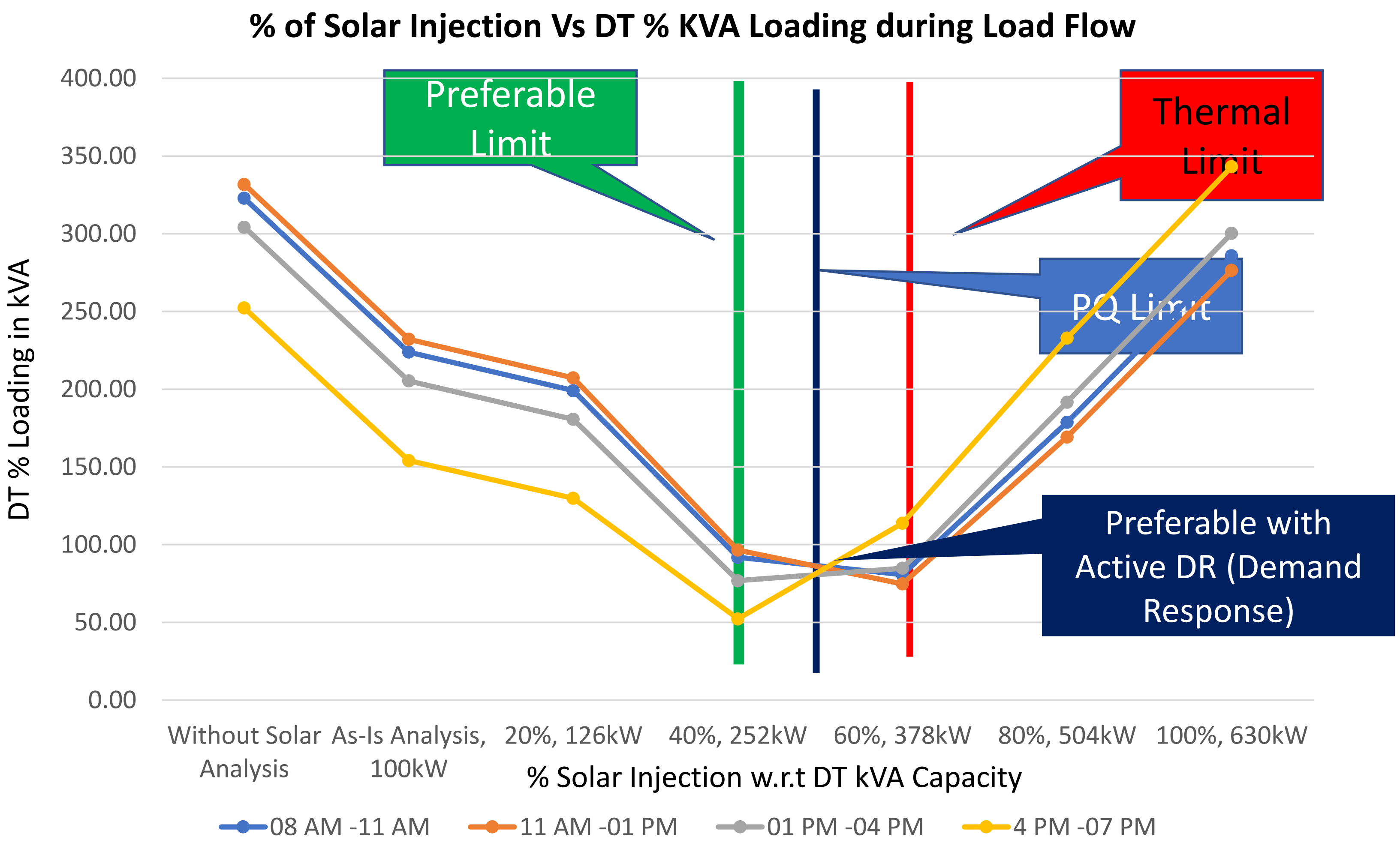
Analysis of Urban Lightly Loaded Feeder (AEML)

Observations

Thermal Limit: 60% of RTPV connections

PQ Limit: 50% of RTPV connections

Considering harmonics and uncertainty of clouds, permissible limit for RTPV connections can be 40% of DT Capacity



Load Flow Study Observations

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Time Slots	Over Voltage (V > = 1.06 pu)	Under Voltage (V <= 0.94 pu)	Observations
08AM - 11AM	60% PV, 80% PV, 100% PV	No Solar, AS-IS, 20% PV, 40% PV, 60% PV	**Overvoltage -** Observed on some RTPV connections after increasing RTPV more than or equal to 60% **Undervoltage** – Observed on many sections of LT feeder up to 60% RTPV.; but it gets cleared after 80% RTPV due to more loading at LT end **Overloading** – Up to 40% RTPV, overloading has decreased significantly. However, after 60% RTPV injection, it increased again
11AM - 01PM	60% PV, 80% PV, 100% PV	No Solar, AS-IS, 20% PV, 40% PV, 60% PV	
01PM - 04PM	60% PV, 80% PV, 100% PV	No Solar, AS-IS, 20% PV, 40% PV, 60% PV	
04PM - 07PM	60% PV, 80% PV, 100% PV	No Solar, AS-IS, 20% PV, 40% PV, 60% PV	