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Decentralized solar PV near the rural user end so as to minimize distribution losses

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Preface

Transformation of the power sector including reforms at grid level as well as at distribution transformer level is regarded crucial to India for achieving its Nationally Determined Contributions (NDCs). Apart from large-scale mega solar parks, rooftop solar is seen as an important segment that would help the power sector in moving towards a low carbon pathway, by serving the local demand. This is especially so in developing economies like India where the electricity demand is rapidly growing and there is a pressing need to look at all possible ways to augment the power supply through adoption of clean energy sources. Since 2016, MacArthur Foundation's key focus in India has been to support mitigation interventions that seek sustainable solutions to challenges India faces from climate change. In order to facilitate this decision making, the Foundation supports established civil society organisations with expertise in climate change mitigation to undertake projects that help reduce greenhouse gas emissions and build public demand for climate solutions.

Moutushi Sengupta
Director, India Office,
MacArthur Foundation

As an organisation working to prevent global climate change by supporting policy, regulatory and technological interventions to curb Greenhouse Gas (GHG) emissions, renewable energy and energy efficiency are key focus areas for us. Through adoption of rooftop solar, the Indian electricity distribution sector offers ample opportunities for improvement in the operational indices of DISCOMs. It is well-accepted that electric utilities have the potential to serve the demand of their consumers through localized sources. Therefore, feeder-level rooftop solar energy becomes a very vital resource. In this direction, TERI has performed a set of comprehensive studies in rural feeders of Chhattisgarh and semi-urban feeder of Delhi, having the potential to provide a possible roadmap for adoption of rooftop solar. The study looks into the likely technical impacts of rooftop solar power at tail-end into the distribution network in the state, and their contribution towards loss reduction. On behalf of MacArthur Foundation, I would like to compliment TERI, CSPDCL and BRPL for coming together and undertaking such a detailed study, which can also serve as a broad framework for other utilities and regulatory commissions to plan for integration of rooftop solar power capacities into their system and for smooth running of their networks.

Moutushi Sengupta
Director, India Office,
MacArthur Foundation

Foreword

In its commitment to install 100 GW of solar energy, India had set a target of setting up an installed capacity of 40 GW to be met through rooftop solar photovoltaic (PV) systems. The rate of deployment of rooftop solar calls for a closer look at ways and means to achieve the target of 40 GW installed capacity by 2022 in the first instance and make concerted efforts to exploit the potential so as to address energy security, environment, and climate change concerns.

The country has witnessed a steep rise in the interest for establishment of solar parks. The power from these centralized systems is transmitted over long distances before reaching consumers and consequently leading to substantial amount of distribution losses. There is wide spread concern to find ways to reduce these losses and to have viable business models. This study is an effort towards this end, wherein technical and financial implications of placing a solar PV plant at the substation are analysed under select real-life network. The findings from this in-depth analysis on the impact of decentralized solar photovoltaic (PV) systems in distribution networks would help in developing policy around this aspect for wider application of the principles.

Findings of the study carried out by TERI for Chhattisgarh State Power Distribution Company Limited (CSPDCL) in the state of Chhattisgarh and BSES Rajdhani Power Limited (BRPL) in Delhi, with funding support from the MacArthur Foundation, are presented in this report. The study is based on a load flow analysis for rural and semi-urban localities by considering the decentralized PV systems at a substation and tail end of a distribution network. The results are presented in the form of impact on tariff from the decentralized systems versus from the centralized solar power-generating systems. I look forward to the recommendations of the study getting translated into action, and to the report evoking interest among policymakers, regulators, utility officials, as well as consumer groups in the licensee area of CSPDCL, BRPL, and other states.

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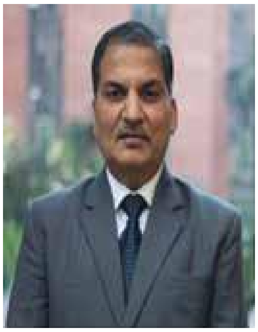

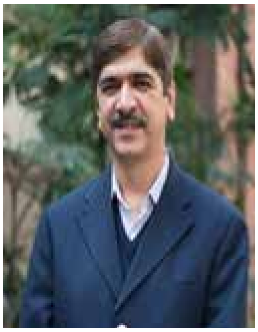

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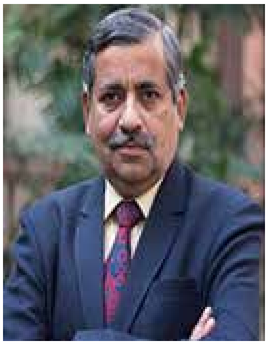

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List of Abbreviations

ARR	Aggregate revenue requirement
BRPL	BSES Rajdhani Power Limited
CAPEX	Capital expenditure
CERC	Central Electricity Regulatory Commission
CSPDCL	Chhattisgarh State Power Distribution Company Limited
CTU	Central Transmission Utility
CUF	Capacity-utilization factor
D	Delta
DT	Distribution transformer
DISCOM	Distribution company
GoI	Government of India
GW	Gigawatt
HV	High voltage
IREDA	The Indian Renewable Energy Development Agency
JNNSM	Jawaharlal Nehru National Solar Mission
kV	Kilovolt
kVA	Kilovolt-amperes
kWp	Kilowatt peak
LT	Low tension
LV	Low voltage
MNRE	Ministry of New and Renewable Energy
MVA	Mega volt-amperes
MW	Megawatt
O&M	Operation and maintenance
p.u.	Per unit
PPA	Power purchase agreement
PV	Photovoltaic
SCADA	Supervisory control and data acquisition
SERC	State Electricity Regulatory Commission
SLD	Single line diagram
SLM	Straight line method
SNA	State Nodal Agency
T	Terminal
T&D	Transmission and distribution
TF	Transformer
X/R	Ratio of reactance to resistance
Y	Star
YN	Star Neutral

Executive Summary

Solar has the maximum potential for generating power among the renewable energy sources. The Government of India launched National Solar Mission in 2010 with a target of solar capacity addition of 20 GW by 2022 envisaged to be achieved through a framework of innovative policy and regulatory steps. In view of great success of the policy in its initial stages, the capacity addition target for solar was revised to 100 GW during the same period. Out of 100 GW solar capacity target, 60 GW was set for utility-scale solar facility, and it has progressed well so far. The balance 40 GW was expected to be generated from the rooftop or ground-mounted-distributed solar plants. The growth of this segment has been sluggish so far in view of the variety of challenges; however, it is agreed upon by the experts that it can enable meeting the mission targets. In addition, utility-scale power projects began to face challenges in terms of the need to create additional transmission and distribution infrastructure and availability of land.

The power from the centralized plants is transmitted over long distances before reaching end user. Any large solar PV plant, located at one end of a transmission network supplying power at the remote end of a distribution network is subjected to T&D losses, which are quiet significant in many plants. Apart from this, the transmission network utilization of such projects is less than 25% (due to low CUF of solar PV plants), thereby causing under-utilization of dedicated transmission system. For large-capacity utility-scale solar plants, finding large area (land) is also emerging as a critical issue. On the other side, decentralized systems produce power at the user end; thus minimizes the distribution loss. Their dependency on land availability is minimal as they can be on rooftop. The opportunities that solar rooftop brings on the operational aspects is in terms of reduction of T&D loss, help in meeting RPO obligations for the DISCOMs and improving the life of the assets utilized.

Under this study, two states have been chosen, which are Chhattisgarh and New Delhi; the former represents a rural example with daytime loads not being high, while the latter is an urban example where daytime loads are quite significant. In Chhattisgarh, rural networks of the Chhattisgarh State Power Distribution Company Ltd (CSPDCL) were selected whereas BSES Rajdhani Power Ltd, Delhi (BRPL) in Delhi was chosen as a semi-urban feeder. The factors considered in identification of the selected networks are type of consumer, number of consumers, land availability, and grid availability. For rural substations in CSPDCL, Amlipadar, Gohrapadar, Deobhog, and Jhakharpara substations were selected, while for semi-urban feeders one West Delhi feeder of BRPL (referred as Network-1) was considered. As per the prevailing regulations, the allowed cumulative capacity limit of the solar power plants which can be set up is 70% and 45% of the distribution transformer rating, respectively, for CSPDCL and BRPL.

State	Name of the substation	Number of the outgoing feeders	Grid availability
Chhattisgarh	Amlipadar	3	94.3%
	Deobhog	4	86.9%
	Jhakharpara	3	88.2%
	Gohrapadar	3	91.3%
Delhi	Network-1	18	100%

Key parameters of distribution network gathered during the site visits were detailed. The corresponding distribution networks have been modelled for conducting load flow analysis. Their annual load profile was analysed and the corresponding photovoltaic (PV) generation profile was simulated. Five scenarios (PV maximum, PV and load maximum, PV minimum, load minimum, and load maximum) were built to account extremities in load and PV generation. In each scenario, load flow is conducted for the following three cases: without PV, PV at LV side of grid substation, and distributed PV at LT level. Load flow analysis results in terms of voltage levels, transformer loading, power generated from remote conventional and/or renewable power plant, and distribution losses have been detailed. This simulation studies had demonstrated the application of decentralized solar PV systems in reducing transformer loading, improving voltage, and reducing technical losses. Sizing and placement of solar PV systems are crucial. Results from various scenarios have indicated that placing PV plants at the tail end of a network is beneficial technically.

The financial viability of decentralized power plants when interfaced at LT side or substation is studied in comparison to procurement from a centralized solar plant. They are compared on the basis of annual electricity generation, transmission losses, levelized cost of solar power generation (for project lifetime), and capital investment. The landed cost of solar power generation is compared to the cost of supply at corresponding voltage levels. For a 400 kWp distributed PV at LT, the results are given below:

Particulars	State	Distributed PV at LT	Distributed PV at substation	Solar park (with transmission and wheeling charges waived off)	Solar park (pooled transmission and wheeling charges considered)
Capacity (kWp)	Chhattisgarh	400	428	422	422
	Delhi	400	396	357	357
Landed cost of power (Rs/unit)	Chhattisgarh	5.51	5.35	4.43	6.07
	Delhi	5.14	4.58	3.75	5.71
Total investment (Rs Cr)	Chhattisgarh	1.8	2.14	2.62	2.62
	Delhi	1.8	1.98	2.21	2.21
Cost of supply, as per ARR (Rs/unit)	Chhattisgarh	6.61	5.43		
	Delhi	7.61	6.79		

In Chhattisgarh, the landed cost of solar power generation for distributed PV at LT is 16.6% less than the average cost of supply at LT level. Similarly in Delhi, the landed cost of solar power generation for distributed PV at LT is 32% less than the average cost of supply at LT level. It can be concluded that with the present cost of solar power generation, distributed PV systems at load or substation level are viable as they produce power less than the present cost of supply. At present when transmission and wheeling charges for solar power of CTU system are waived off, power from solar park is a better option. It is clearly seen that the difference between the landed cost of power produced from centralized and decentralized systems becomes very small by considering transmission and wheeling charges on solar park. Therefore, solar parks at present are incentivized. By providing revenue-neutral incentive for distributed PV, compared to centralized solar plants, their deployment can be increased in distribution systems.

For solar PV plants design, load profile acts as a reference for the quantum of solar power that can be integrated into a system. Between the five substations in this study, availability of adequate accurate data is varied. In rural network, data are typically manually recorded at hourly interval, and in urban network, supervisory control and data acquisition systems are used for automated data logging. Hence, there is a need for standardization in data collected at distribution transformer level. Also, lack of uniform accurate data is a limiting factor for design of decentralized solar power plants.

Although the findings on the benefits of decentralized PV systems are specific to the five substations, the following are the recommended interventions that will aid in adoption towards small-scale-distributed PV systems in distribution networks:

» Distribution transformers are capable of bidirectional power flow and short-term overloading. This implies PV installation up to 100% of their rating is technically feasible. This study has reviewed the variation in PV limits across states. There is a need for uniformity in these regulations at national level.

» The cost involved in transmission network for large solar parks is being pooled on all non-renewable generation and therefore the power of solar parks will be low-priced. However, solar power of distributed solar plant is akin to solar power for a solar park and T&D losses. This suggests that liberal tariffs should be allowed for distributed solar plants.

» In rural areas, grid availability varies from time to time. In this study, it was observed that in sunshine hours grid availability is lesser than the rest of the day. Hence, the design configuration of solar PV system should account grid availability as a factor. For semi-urban feeders, in certain cases, it is noticed that during evening peak load conditions, solar PV is unable to bring the transformer loading below threshold limit, although significant reduction during daytime is noticed. In these situations, solar systems with storage need to be encouraged.

» At present, distribution losses are estimated on the basis of energy sent from substation and energy billed on consumers. The benefit of decentralized PV systems in distribution network loss reduction is not captured in this method. Hence, it is recommended that distribution losses should be calculated in relation to total generation. Monitoring instantaneous power generation from decentralized PV systems is also suggested.

» General awareness among DISCOM's field-level technical staffs on the impact of solar PV generation at tail-end grid is relatively low. There is a need for sensitization.

1. Decentralized Solar Photovoltaic Systems

1.1 Background

Solar has the maximum potential for generating power among the renewable energy sources. The Government of India launched National Solar Mission in 2010 with a target of solar capacity addition of 20 GW by 2022 envisaged to be achieved through a framework of innovative policy and regulatory steps. In view of great success of the policy in its initial stages, the capacity addition target for solar was revised to 100 GW during the same period [1]. Out of 100 GW solar capacity target, 60 GW was set for utility-scale solar facility, and it has progressed well so far. The balance 40 GW was expected to be generated from the rooftop or ground-mounted-distributed solar plants. The target is a part of India's commitment under the 2015 Paris Agreement on climate change, which also includes cutting the emission by one-third by 2030 from 2005 levels.

The government is trying to emphasize and improve the share of electricity from solar energy and has launched the Jawaharlal Nehru National Solar Mission (JNNSM). JNNSM is the initiative of central and state governments to instigate solar power production in India, which was started in 2010 and had been revised twice. The objective of the JNNSM is to establish India as a global leader in solar energy, by creating policies for its deployment across the country. Each phase of the JNNSM is supported by different targets and policies. The various phases of JNSM are shown in Figure 1.1.

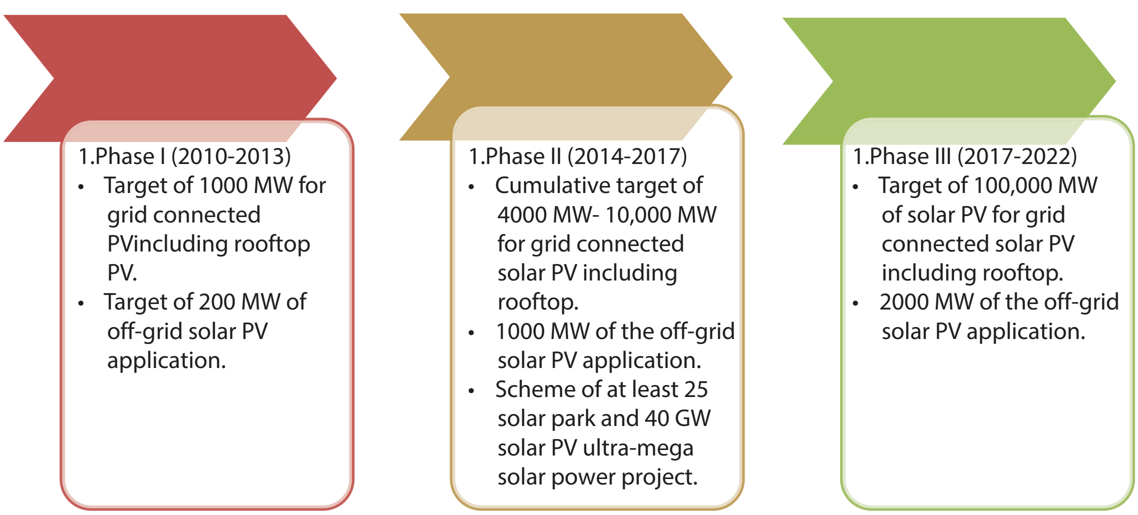


Figure 1.1. JNNSM action plan

Under this mission, the country is witnessing large-scale deployment of solar parks. The power from these centralized plants is transmitted over long distances before reaching end user. Any large solar PV plant, located at one end of a transmission network supplying power at the remote end of a distribution network is subjected to the same T&D losses, as applicable to other conventional power plants. Apart from this, the transmission network utilization of such projects is less than 25% (due to CUF of solar photovoltaic (PV) plants), thereby causing under-utilization of dedicated transmission system. Also, land availability is an issue as these systems are majorly ground-mounted. On the other side, decentralized systems produce power at the user end; thus minimizes the distribution loss and leads to less requirement of transmission and distribution infrastructure. Their dependency on land availability is minimal as they can be on rooftop.

In [2], DISCOMs perceive challenges in integration of increasing penetration of solar rooftop, which are presently not apparent on account of injection of solar rooftop in the grid being quite nominal. There is a need for power flow simulation studies to understand the technical impacts of increased penetration of solar rooftop on the distribution network, and corresponding mitigation measures. On the operational aspects, DISCOMs see metering, billing, and energy accounting as the main hurdle while implementing solar rooftop within their license area. The opportunities that solar rooftop brings on the operational front were also discussed, especially in terms of reduction of T&D loss, help in meeting their RPO obligations, and improving the life of the assets utilized due to reduction of net load in their network.

1.2 System configuration

Small-scale PV systems can be categorized into: ground mounted and rooftop based on area used; grid tied and off-grid depending on the dependence on utility grid; and with and without energy storage system. Figure 1.2 shows the factors affecting the choice of PV system for a given application. In this study, PV systems without energy storage systems have been considered. Factors related to nature of load profile, grid availability and cost of generation have been detailed in this report.

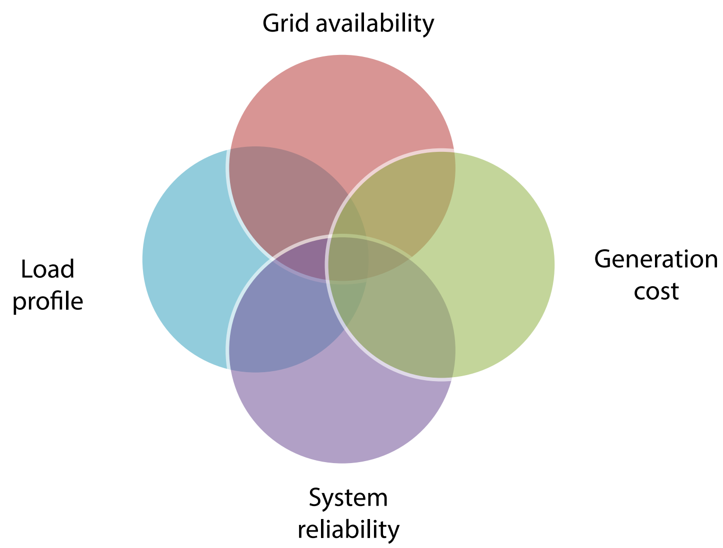


Figure 1.2. Photovoltaic system design considerations

1.3 Benefits of decentralized photovoltaic systems

Decentralized PV systems provide benefits on social, environmental, security, technical, and environmental domains. The details are given in Figure 1.3. Distributed PV systems lead to an increase in jobs and regional economic development. The environmental benefits are due to reduction in carbon emissions, and primarily due to reduction in power generated from conventional thermal power plants. These systems improve diversity of electricity generation, thereby improving energy security of the region. With current cost of solar power generation, the financial benefit is evident.

The technical benefits of decentralized systems in a distribution network are providing grid services to distribution companies. The solar PV power plants with active and reactive power control aid in voltage and frequency response at the point of interconnection. Impacts of solar PV on distribution network are overload related (capacity ratings, masked load, and cold load pickup), voltage related (feeder voltage, overvoltage, potential for increased substation voltage, flicker and automatic voltage regulation equipment), reverse power flow impacts (substation and bulk system impacts, temporary and transient overvoltage), system protection impacts, and circuit configurations [3]. In this study, the steady-state effects of solar PV systems in distribution network have been analysed.

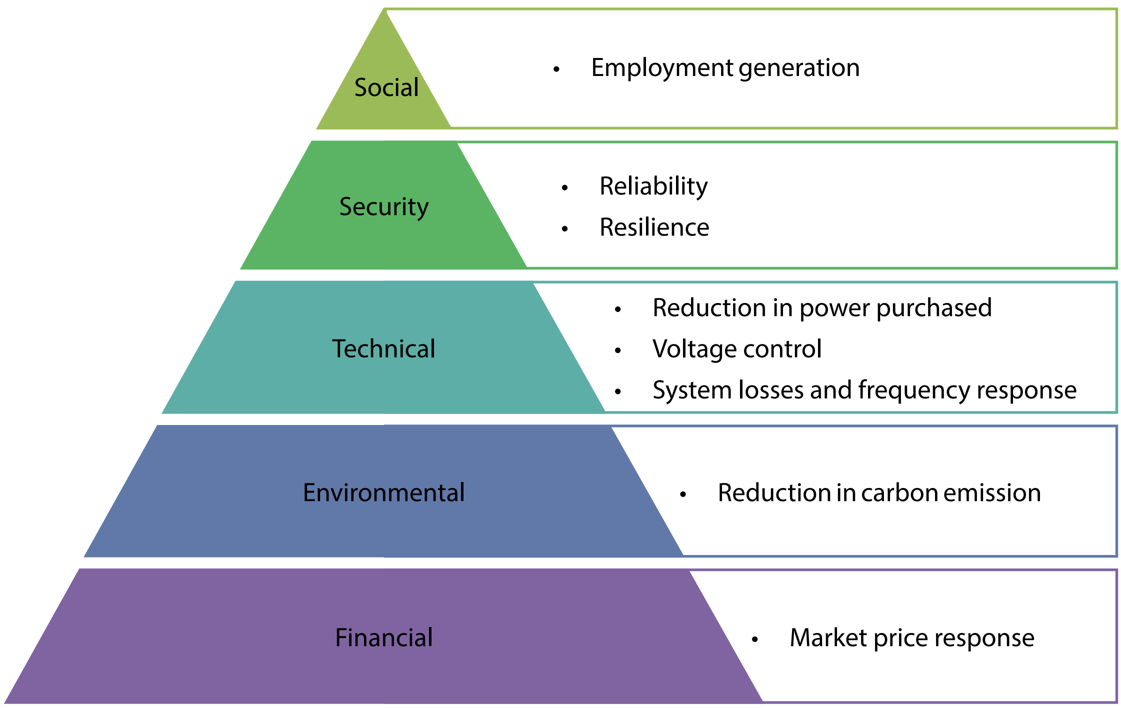


Figure 1.3. Key benefits of solar photovoltaic integration in distribution network

1.4 Study objectives

» This study aims to develop innovative alternative models for decentralized solar power generation by utilizing spare land available with utility substation for the solar power generation. The impact of solar power generation at the substation and in the downstream of the network is determined.

» The technical and financial implications of placing a solar PV plant at the substation level are studied.

» A detailed analytic comparison of techno-economic benefit of placing a solar PV plant at the substation (near the load point) and large-scale solar generation is conducted. The financial viability of such solar projects will be studied in relation to procurement from a centralized plant.

2. Approach and Methodology

The technical impact of solar photovoltaic (PV) plants on a distribution network would depend on several factors such as network type, load profile, characteristics of lines, distribution transformers, etc. In this regard, the load data monitored by a DISCOM are analysed. Solar PV plants are simulated with distribution networks to access the changes in network power flow. The approach and methodology adopted is detailed in this section.

The methodology of the study primarily consists of literature research, consultations with key stakeholders (details given in Appendix G), selection of the states and the utility, selection of the network, field visits to shortlisted states/utilities, field data collection, load flow, and cost-benefit analysis. The activities grouped in distinct phases are shown in Figure 2.1.

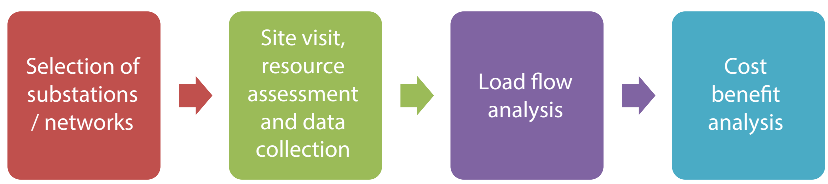


Figure 2.1. Approach and methodology

2.1 Selection of substations/networks

The potential impact of solar PV on distribution network is specific to the distribution network. In India, distribution companies are categorized as public and private based on ownership, catering to the urban and rural communities. The motive towards solar PV penetration shall vary for rural and urban locations. Rural networks (that are usually comprised of long radial lines) will majorly benefit from voltage support and reduction in distribution losses, while urban networks (that are mesh type with multiple feed-in points) will majorly benefit from network decongestion and additional capital expenditure avoided. For this study, four rural substations in Chhattisgarh and one semi-urban substation in Delhi have been selected (shown in Figure 2.2).

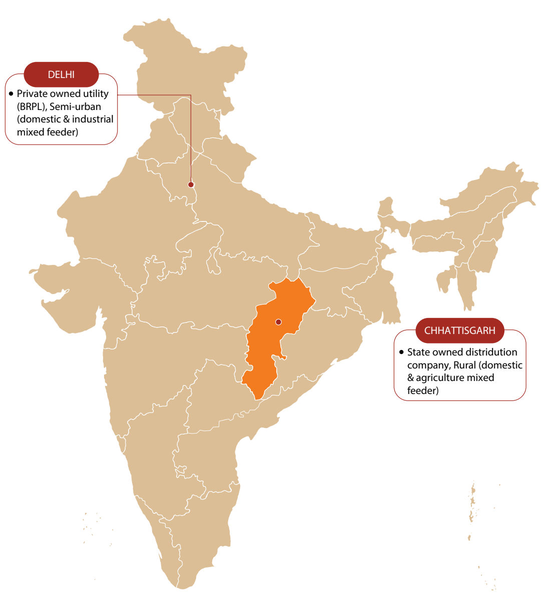


Figure 2.2. Map showing the identified substations

Table 2.1. Comparison of state rooftop solar photovoltaic regulations

DISCOM (State/UT)	Limit for individual customer	Installed capacity limit as % of DT capacity
BRPL (Delhi)	No limit specified (depends on feasibility)	75
CSPDCL (Chhattisgarh)	Solar system capacity allowed till 100% of sectioned load	40

Distribution companies with State Electricity Regulatory Commission formulate regulations for solar power plants in the license area. Table 2.1 compares rooftop solar capacity limits for BRPL and CSPDCL [4]. It can be observed that there is variation in limits for individual customer and cumulative capacity at distribution transformer.

Four rural substations in Raipur region of Chhattisgarh are Jhakharpara, Gohrapadar, Deobhog, and Amlipadar. One semi-urban substation is located in west-Delhi. Substation transformer ratings, voltage levels, and feeder length are tabulated in Figure 2.3.

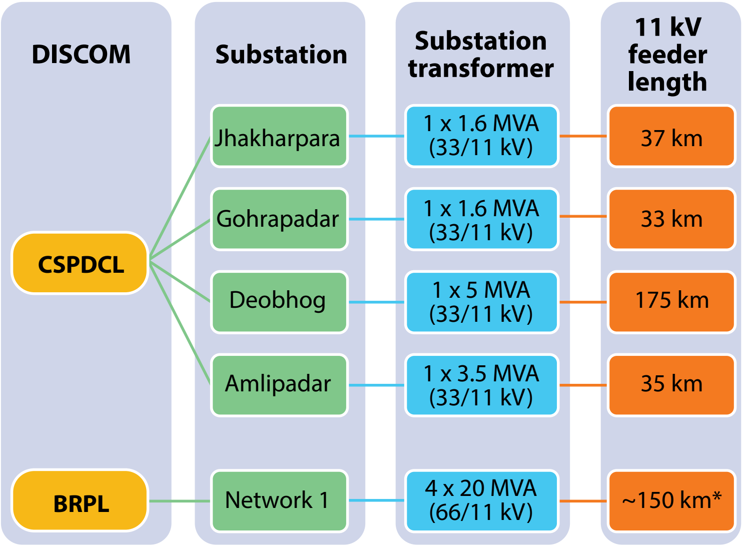


Figure 2.3. Details of substations

2.2 Site visit, resource assessment, and data collection

Understanding the distribution network and assessing rooftop PV potential are important to model the network and simulate critical conditions. Key parameters of distribution network were gathered during site visit. Based on the available area, PV potential in the distribution network was assessed. Historical load profile of the network was collected and analysed for daily variation. Using PV design software HelioScope [5], the hourly annual profile of a solar PV plant is obtained and studied with relation to load profile.

2.3 Load flow analysis

The distribution network from high-voltage side of substation transformer to low-voltage side of distribution transformer is modelled for simulation in power system software PowerFactory-DIgSILENT [6]. Technical parameters collected during site visit and literature review are used to configure the simulation model. Five scenarios were built to account the range of variation in load and PV generation. Detailed load flow analysis is conducted to understand the nature of power flow, which includes voltage levels, transformer loading, power generated from remote conventional and/or renewable power plant, and distribution losses. In each scenario, load flow is conducted for the following three cases: without PV, PV at LV side of grid substation, and distributed PV at LT level. The distribution loss for each simulation case is also studied from load flow results.

2.4 Cost-benefit analysis

The distributed solar PV will be viable only when the cost of solar power production is less than the existing cost of power supply. The financial viability of decentralized power plants when interfaced at LT side or substation is studied in comparison to procurement from a centralized solar plant. They are compared on the basis of annual electricity generation, transmission losses, levelized cost of solar power generation (for project lifetime), and capital investment. The landed cost of solar power generation is compared to the cost of supply at corresponding voltage levels. As the comparison is based on solar power from the centralized plant and the remote load side plant, the impacts of RPO, carbon emission, fuel security, and fuel cost escalations are not considered.

3. Data Collection and Analysis

In this section, the details of the data collected during site visit on consumer load profile, distribution network specifications, and land availability near substation are presented. Line diagrams of all distribution networks have been used in modeling electrical networks. From outages recorded in log sheets, variation in grid availability with respect to time is derived. Critical conditions of photovoltaic (PV) and load variation have been identified.

3.1 Key parameters

The complete understanding of distribution network is possible when parameters related to general, technical, and commercial aspects are studied in totality. Key parameters collected are given in Figure 3.1. General parameters provide an understanding on consumer and land availability; technical parameters are used in modeling network and define scenarios; and commercial parameters are used to assess viability of decentralized solar plants. The list of key technical parameters is given in Figure 3.2.

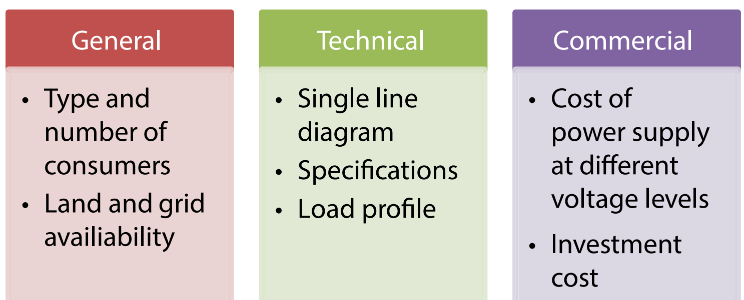


Figure 3.1. Summary of key parameters

Single-line diagram	Detailed network diagram with placement of transformers, feeders, and load	
Specifications	Transformer	Rating
		Voltage levels
		No-load losses
		Connection type and vector group
		Resistance and reactance
	Feeder/line	Type
		Length
		Voltage grade
		Maximum continuous temperature
		Maximum continuous resistance at 20^{0}C
Loading	Instantaneous active and reactive power	

Figure 3.2. List of key technical parameters

3.2 Amlipadar

Amlipadar is a region in southern part of Raipur with about 12,200 households and population of about 45,000 [7]. It receives power supply from a 33 kV feeder at Gariaband. There is a 3.5 MVA 33/11 transformer at the substation with three outgoing feeders. Jungli is the longest feeder with the length of 18 km, catering to 27 villages; Urmal feeder has the length of 12 km, catering to 19 villages; and Gurjibhata feeder has the length of 5 km, catering to 4 villages. Grid availability of its incoming feeder is shown in Figure 3.3. It can be observed that during daytime, there are outages and mean grid availability is 94.3%. Single-line diagram of the substation is given in Appendix A.1; each village is represented with a distribution transformer and a lumped load. As mentioned in Section 2.1, PV capacity is considered at 40% of distribution transformer capacity.

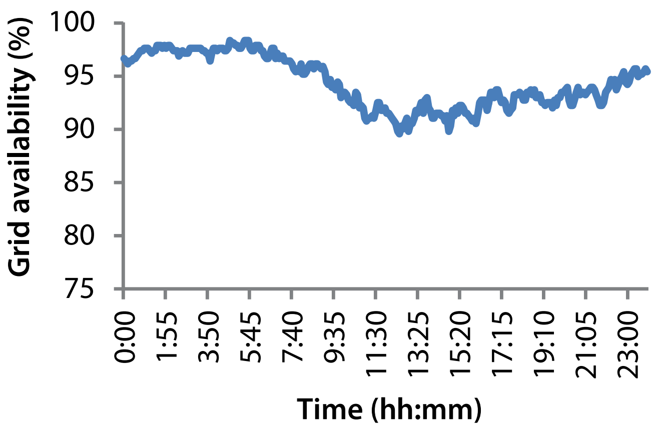


Figure 3.3. Graph showing grid availability at Amlipadar substation

Table 3.1. Identified dates for Amlipadar substation

Scenario	Date	PV output as % of its capacity	Transformer load (MVA)
Load max	February 13, 2019	55	1.084
PV max, PV, and load max	February 17, 2019	82	1.006
PV min	March 2, 2019	5	0.752
Load min	March 11, 2019	56	0.373

The daily load profile and its corresponding simulated PV generation are given in Appendix B.1. From analysis of these profiles, five scenarios (PV minimum, PV maximum, load minimum, load maximum, and PV and load maximum) have been considered. The details are given in Table 3.1. In proximity to the substation, there is an area of 130,680 sq. ft. that can be used for solar power generation. This translates into potential of about 1.2 MWp. At village level, both rooftop and ground-mount PV systems are possible.

3.3 Deobhog

Deobhog is a region in southern part of Raipur with about 16,000 households and population of about 56,700 [7]. It receives power supply from a 33 kV feeder at Gariaband. There is a 5 MVA 33/11 transformer at the substation with four outgoing feeders. Diwanmuda is the longest feeder with the length of 50 km, catering to 9 villages; Grisul feeder has the length of 40 km, catering to 28 villages; Dharakot feeder has the length of 20 km, catering to 21 villages; and Town feeder has a length of 65 km, catering to 5 villages. Grid availability of its incoming feeder is shown in Figure 3.4. It can be observed that during daytime, there are outages and mean grid availability is 86.9%. Single-line diagram of the substation is given in Appendix A.2. As mentioned in Section 2.1, PV capacity is considered at 40% of distribution transformer capacity.

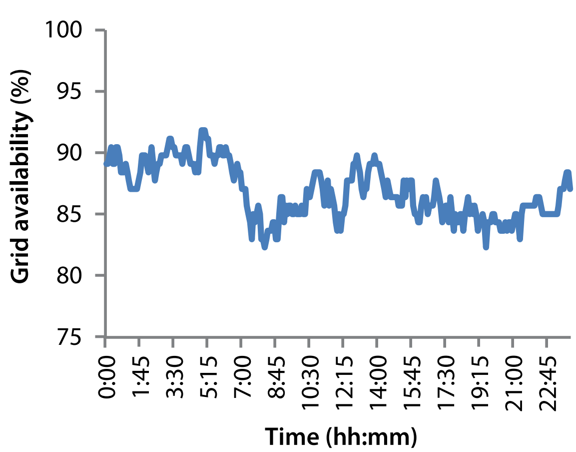


Figure 3.4. Graph showing grid availability at Deobhog substation

The daily load profile and its corresponding simulated PV generation are given in Appendix 0. From the analysis of these profiles, five scenarios (PV minimum, PV maximum, load minimum, load maximum, and PV and load maximum) have been considered. The details are given in Table 3.2. There is no limitation on the land available at the substation. At village level, both rooftop and ground-mount PV systems are possible.

Table 3.2. Identified dates for Deobhog substation

Scenario	Date	PV output as % of its capacity	Transformer load (MVA)
Load min	February 2, 2019	62	2.10
PV max	February 18, 2019	83	2.39
Load max	May 23, 2019	41	3.24
PV and load max	June 6, 2019	77	3.15
PV min	June 15, 2019	5	2.29

3.4 Jhakharpara

Jhakharpara is a region in southern part of Raipur with about 7100 households and population of about 24,700 [7]. It receives power supply from a 33-kV feeder at Gariaband. There is a 1.6 MVA 33/11 transformer at the substation with three outgoing feeders. Kodobeda is the longest feeder with the length of 20 km, catering to 20 villages; Jhakharpara feeder has the length of 10 km, catering to 11 villages; and Diwanmuda feeder has the length of 7 km, catering to 6 villages. Grid availability of its incoming feeder is shown in Figure 3.5. It can be observed that during daytime, there are outages and mean grid availability is 88.2%. Single-line diagram of the substation is given in Appendix A.3. As mention in Section 2.1, PV capacity is considered at 40% of distribution transformer capacity.

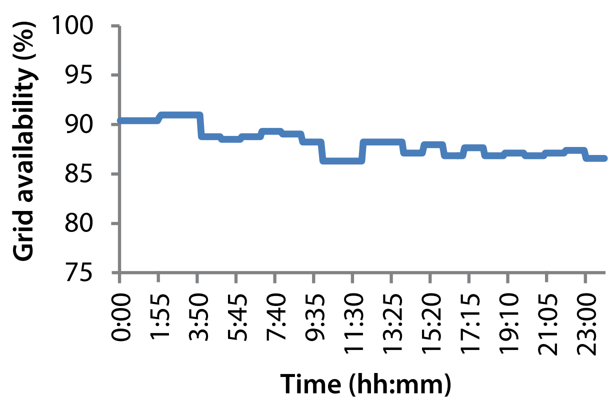


Figure 3.5. Graph showing grid availability at Jakharpara substation

The daily load profile and its corresponding simulated PV generation are given in Appendix B.3. From the analysis of these profiles, five scenarios (PV minimum, PV maximum, load minimum, load maximum, and PV and load maximum) have been considered. The details are given in Table 3.3. There is no limitation on the land available at the substation. At village level, both rooftop and ground-mount PV systems are possible.

Table 3.3. Identified dates for Jhakharpara substation

Scenario	Date	PV output as % of its capacity	Transformer load (MVA)
Load min	July 7, 2018	51	0.38
PV max	February 17, 2019	82	0.66
PV min	March 3, 2019	5	0.76
PV and load max	March 29, 2019	79	0.85
Load max	April 9, 2019	69	1.04

3.5 Gohrapadar

Gohrapadar is a region in southern part of Raipur with about 5800 households and population of about 21,000 [7]. It receives power supply from a 33 kV feeder at Gariaband. There is a 1.6 MVA 33/11 transformer at the substation with three outgoing feeders. Chichya is the longest feeder with the length of 19 km, catering to 11 villages; Dhuvaguli feeder has the length of 12 km catering to 9 villages; and Gohrapadar feeder has a length of 2 km, catering to a village. Grid availability of its incoming feeder is shown in Figure 3.6. It can be observed that during daytime, there are outages and mean grid availability is 91.3%. Single-line diagram of the substation is given in Appendix A.4. As mentioned in Section 2.1, PV capacity is considered at 40% of distribution transformer capacity.

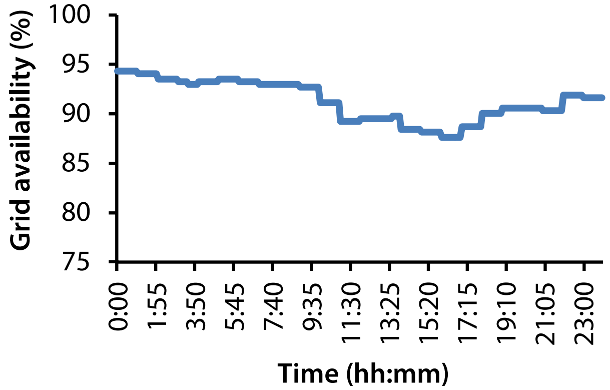


Figure 3.6. Graph showing grid availability at Gohrapadar substation

The daily load profile and its corresponding simulated PV generation are given in Appendix B.4. From the analysis of these profiles, five scenarios (PV minimum, PV maximum, load minimum, load maximum, and PV and load maximum) have been considered. The details are given in Table 3.4. There is no limitation on the land available at the substation. At village level, both rooftop and ground-mount PV systems are possible.

Table 3.4. Identified dates for Gohrapadar substation

Scenario	Date	PV output as % of its capacity	Transformer load (MVA)
Load max	July 1, 2018	32	0.95
PV min	July 6, 2018	8	0.91
Load min	July 22, 2018	52	0.19
PV max, PV and load max	February 17, 2019	82	0.78

3.6 Network-1

This is a region in western part of Delhi with residential and industrial mix of consumers. There are four 20 MVA 66/11 transformers at the substation with 18 outgoing feeders. Network-1 is an 11-kV feeder with 12 km of length and 17 distribution transformers. There are several feed-in points in this network (to ensure 100% grid availability), but it is mostly operated in a radial manner. As mentioned in Section 2.1, the solar PV is majorly viewed for network decongestion. Single-line diagram of the network is given in Appendix A.5. As mentioned in Section 2.1, PV capacity is considered at 75% of distribution transformer capacity.

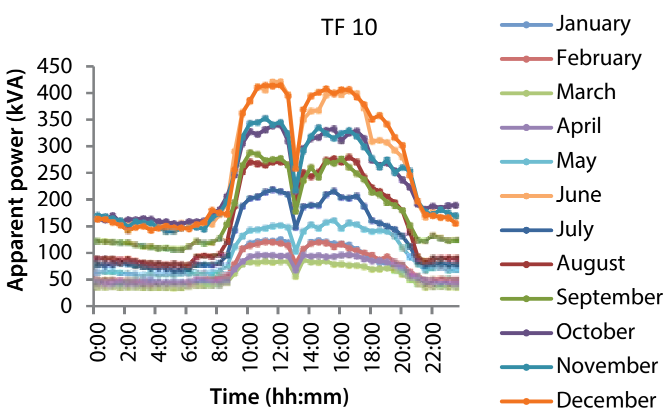


Figure 3.7. Bar graph showing number of hours of distribution transformer overload

The daily load profile and its corresponding simulated PV generation are given in Appendix B.5. From distribution transformer-loading data by considering a threshold of 95% of transformer capacity, the number of hours of overload was observed. Out of 17 transformers, there were 7 transformers with overload duration greater than 30 h/year. Number of hours of overload of these seven transformers is shown in Figure 3.7. The monthly load profile of the seven overloaded transformers is analysed and plotted in Figure 3.8 and Appendix A.5. It can

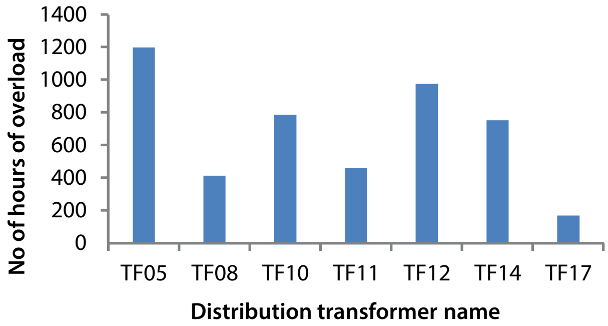


Figure 3.8. Monthly load profile of overloaded distribution transformer TF10

Surplus land is not available in sub-station complexes. As the area is densely populated, installation of rooftop PV is possible in the buildings of the area being fed by distribution line. Figure 3.9 shows the map of this network. It can be observed that roofs with area greater than 100 m^2 and within 5 km of this network have been highlighted. The cumulative rooftop PV potential is estimated to be 10 MWp.

With the analysis of load and solar PV-generation profiles, five scenarios have been considered. The details are given in Table 3.5.

be observed that all the overloaded transformers have a day peak load profile. During summer, these transformers record maximum load. All load profiles have a dip during afternoon time. This may be due to the machines being shut down and workers taking a break in industries. This change in load in afternoon is critical because, in case solar PV maximum generation happens in afternoon, the probability of reverse power flow from PV to distribution transformer and upstream increases.

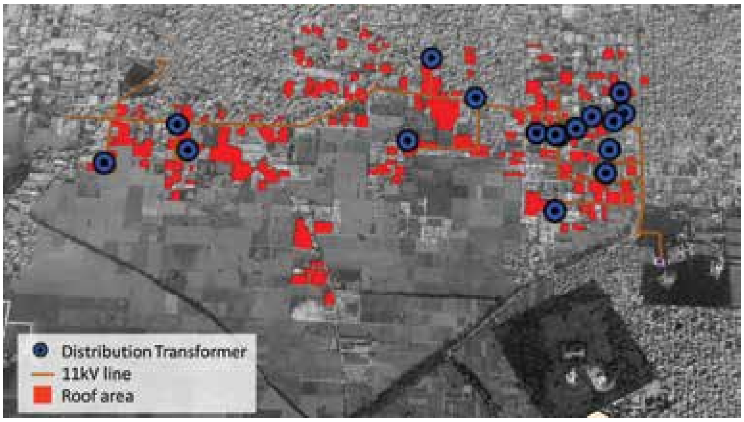


Figure 3.9. Map of distribution network and potential rooftop locations

Table 3.5. Identified dates for Network-1

Scenario	Date	PV output as % of its capacity	Transformer load (MVA)
PV max	March 13, 2018	79.3	27.59
PV and load max	April 17, 2018	72.3	55.87
Load max	April 20, 2018	67.8	58.09
PV min	August 10, 2018	15.6	52.34
Load min	October 1, 2018	73.4	8.49

4. Load Flow Analysis

The scenarios considering photovoltaic (PV) and load extremities have been detailed in the Chapter 3 of this report. For each scenario, load flow analysis is carried out in the following three cases: without solar PV, cumulative PV at low-voltage side of substation transformer, and distributed PV at low-voltage side of distribution transformer. Load flow analysis provides an understanding on power flow and voltage levels in a network. This chapter details the results of load flow for various scenarios and simulation cases.

4.1 Assumptions

The following are the assumptions taken for simulating the distribution network:

» Loads are lumped at village/locality level.

» The missing datapoints within a week (due to outage or error) have been corrected based on the assumption

$$P_{\text{outage}} = P_{\text{same instant of previous day}}$$

where,

P_{outage} is the corrected power during outage and $P_{\text{same instant of previous day}}$ is the power logged on the previous day at the same instant.

» All rural loads are considered to have a power factor of 0.9, where reactive power data is not available.

» The distribution network, under study, does not have any local generator and is connected to (infinite) grid. For the purpose of load flow, a reference machine (synchronous generator accounting for load power and distribution losses) is assumed to be located at high-voltage side of the substation transformer.

» On-load tap changer in transformers is assumed to be absent.

» In cases of lack of distribution transformer data for the entire year, loading of all transformers is considered on pro-rata basis.

» The solar PV system is providing only active power and its droop characteristics are disabled.

The detailed specifications of all the network elements are given in Appendix C.

4.2 Load flow analysis – Amlipadar

Load flow analysis has been performed for the scenarios described in Section 3.2. On each feeder, a solar PV plant is placed at LV side of the farthest distribution transformer from the substation. In the network model, feeders Urmal, Gurjibhata, and Jungli are arranged from left to right. Figure 4.1 shows the network map under 'PV maximum' scenario. It can be observed that Jungli feeder has low-voltage issues, and with solar PV, there is substantial improvement in its voltage.

Loading and voltage level of the substation transformer is given in Figure 4.2. It can be observed that there is reduction in loading and improvement in voltage proportional to the amount of PV power injected into the network. In all the scenarios, the observed maximum deviation from the nominal voltage is 0.27%. However, in 'PV and load maximum scenario', the voltage with cumulative PV is higher than distributed PV.

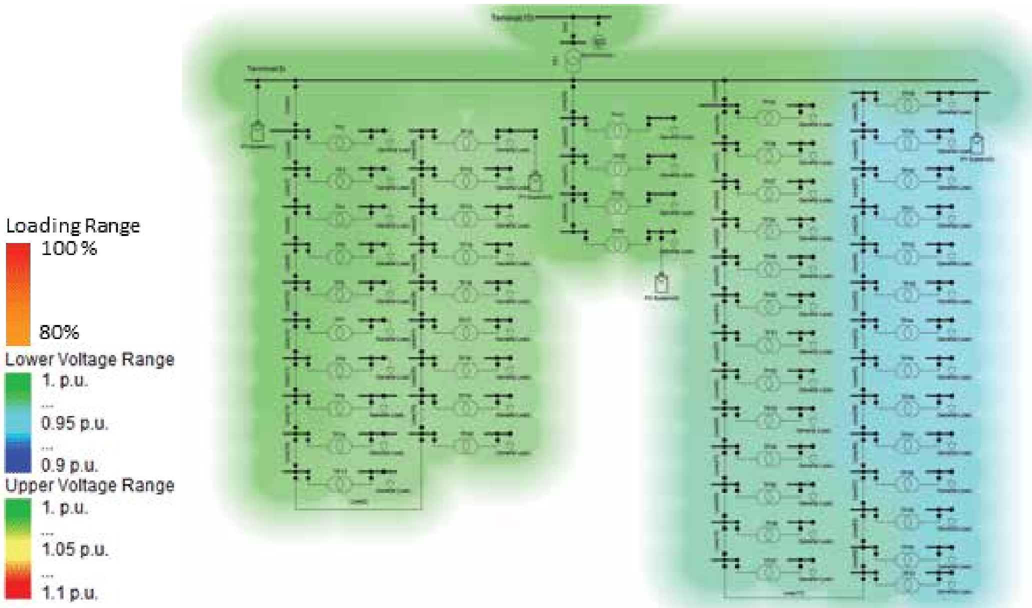


Figure 4.1. Heat map of Amlipadar network with voltage and transformer-loading levels under 'photovoltaic maximum' scenario

Note: In all simulation results, blue colour represents the case without solar PV, red colour represents the case with cumulative PV at the substation and green colour represents the case with distributed PV at the distribution transformer.

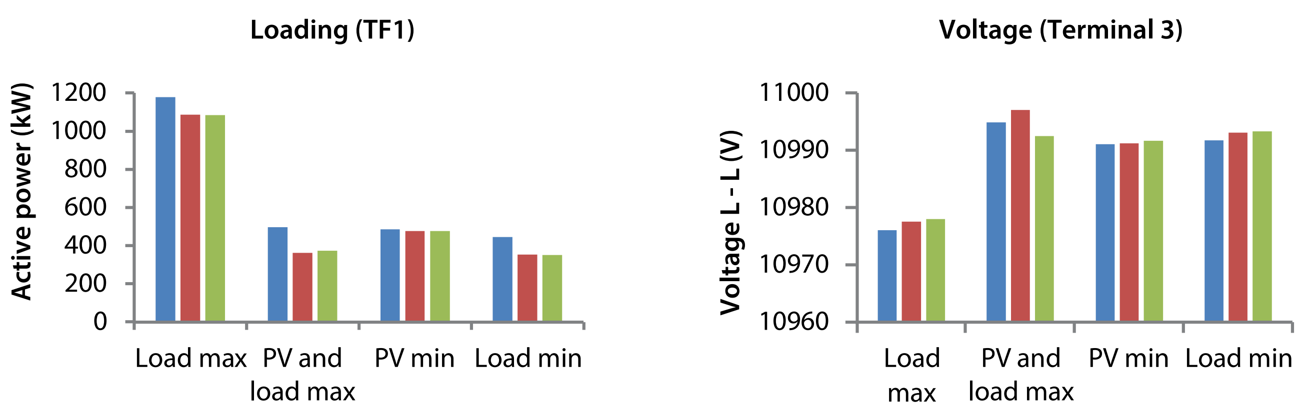


Figure 4.2. Loading and voltage level of substation transformer in Amlipadar network

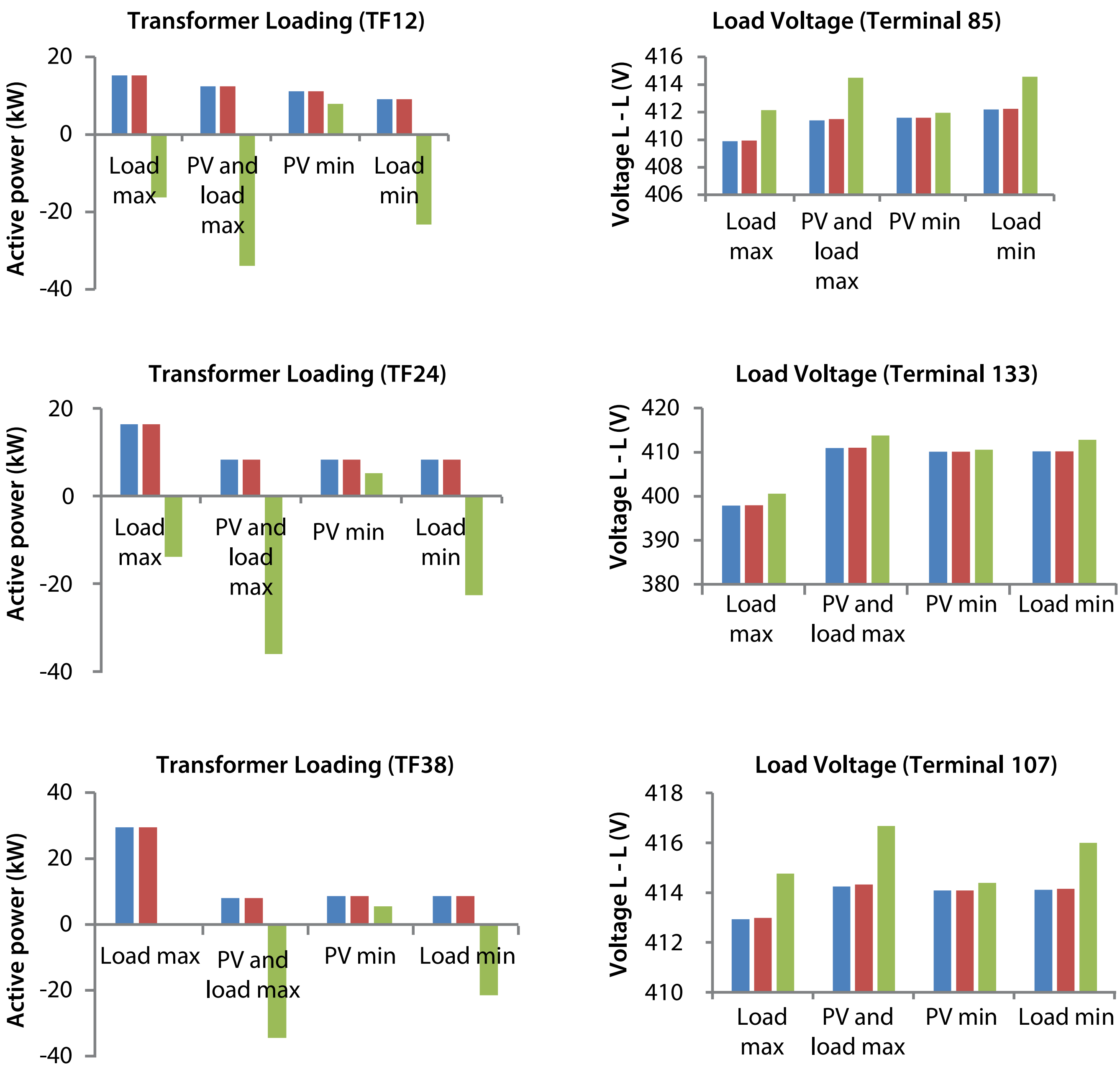


Figure 4.3. Loading and voltage level of key distribution transformers in Amlipadar network

Loading and voltage level of distribution transformers at the farthest end of each feeder from the substation (where PV is considered) is given in Figure 4.3. Transformers TF 12, TF 24, and TF 38 are located on feeders Urmal, Gurjibhata, and Jungli, respectively, and their corresponding LV terminals are 85, 133, and 107, respectively. It can be observed that in all the scenarios other than 'PV minimum', active power loading of transformer is negative. Also, in all the scenarios, the order of voltage between cases in each scenario is the same, and the observed maximum deviation from nominal voltage is 0.5% at 415 V level.

4.3 Load flow analysis–Deobhog

Load flow analysis has been performed for the scenarios described in Section 3.3. On each feeder, a solar PV plant is placed at LV side of the farthest distribution transformer from the substation. In the network model, feeders Dharakote, Diwanmuda, Town, and Grisul are arranged from left to right. Figure 4.4 shows the network map under 'PV maximum' scenario. It can be observed that distribution transformers in Diwnamuda feeder are overloaded. In Grisul feeder, voltage regulation is an issue.

Loading and voltage level of substation transformer is given in Figure 4.5. It can be observed that there is reduction in loading and improvement in voltage proportional to the amount of PV power injected into the network. Also, between 'cumulative PV' and 'distributed PV' the substation transformer loading is lower for 'distributed PV'. This is due to the reduction in generation as distribution losses are reduced (with load being constant in all the three cases). In all the scenarios, the observed maximum deviation from the nominal voltage is 0.5% at 415 V level.

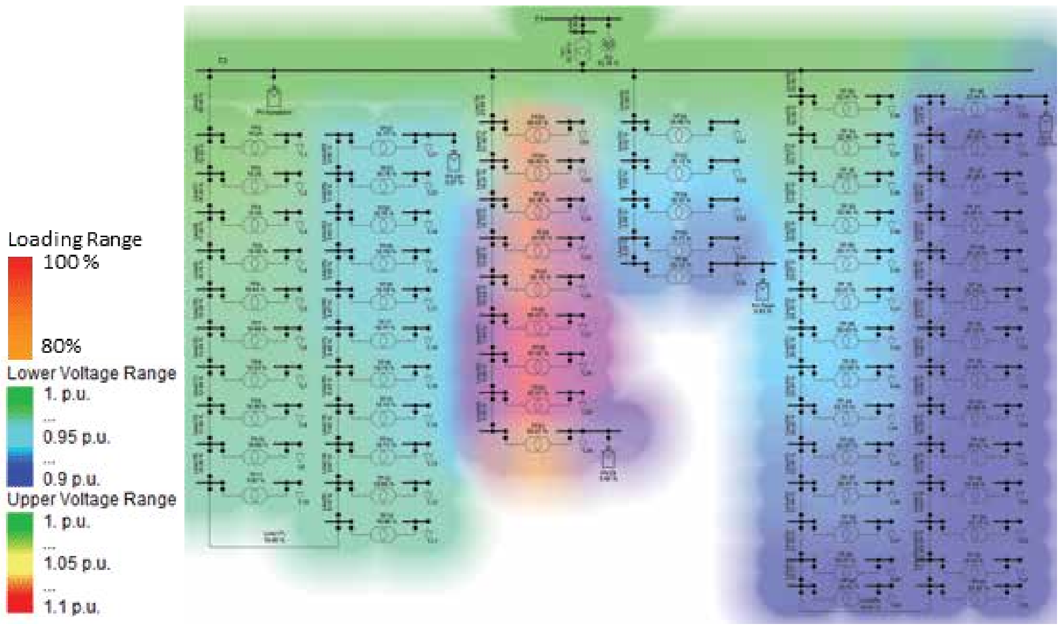


Figure 4.4. Heat map of Deobhog network with voltage and transformer-loading levels under 'photovoltaic maximum' scenario

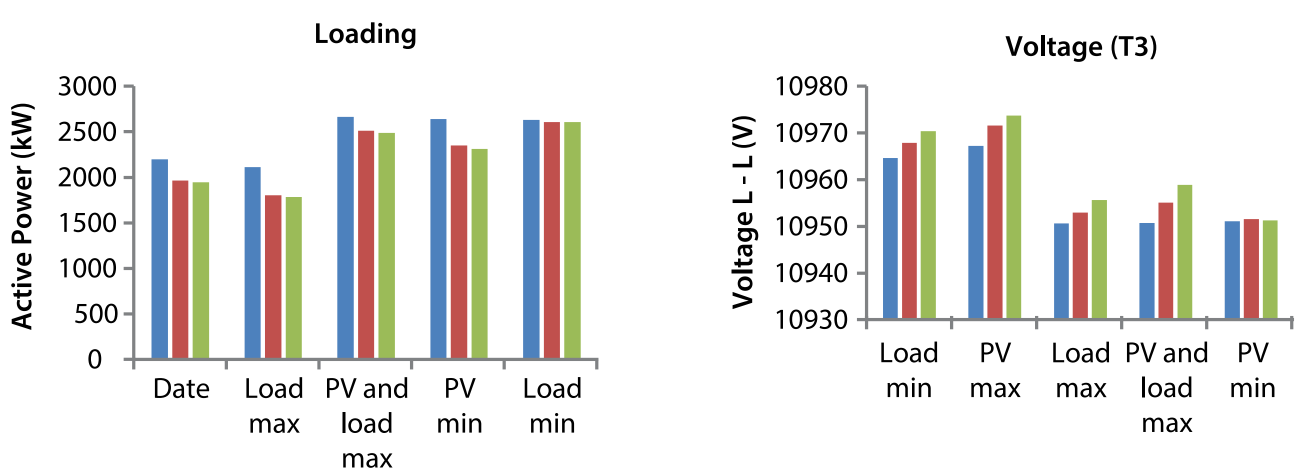


Figure 4.5. Loading and voltage level of substation transformer in Deobhog network

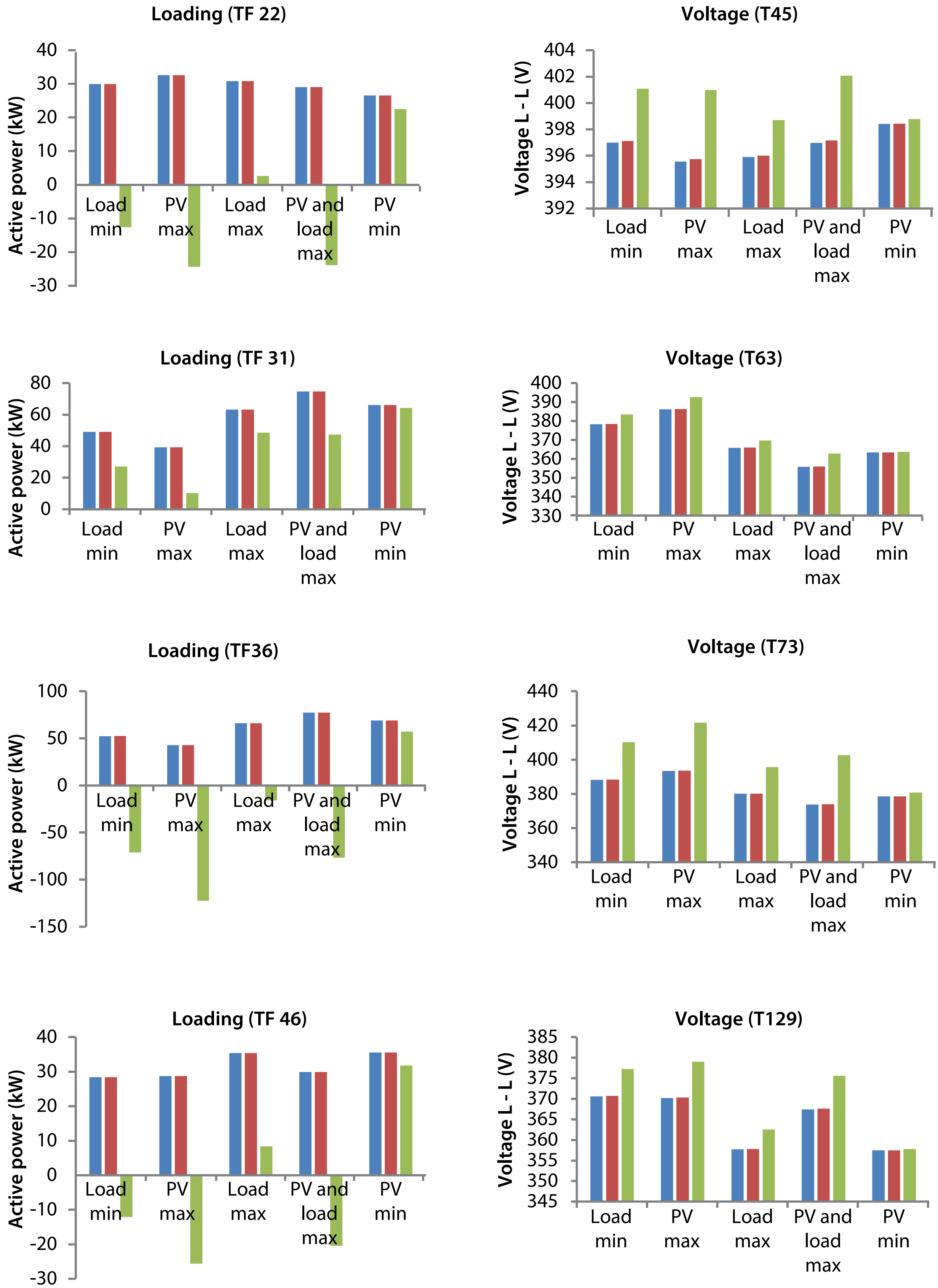


Figure 4.6. Loading and voltage level of key distribution transformers in Deobhog network

Loading and voltage level of distribution transformers at the farthest end of each feeder from the substation (where PV is considered) is given in Figure 4.6. Transformers TF 22, TF 31, TF 36, and TF 46 are located on feeders Dharakote, Diwanmuda, Town, and Grisul, respectively, and their corresponding LV terminals are 45, 63, 73, and 129 respectively. It can be observed that in all the scenarios other than 'PV minimum' and 'load maximum', active power loading of transformer is negative.

4.4 Load flow analysis – Jhakharpara

Load flow analysis has been performed for the scenarios described in Section 3.4. On each feeder, a solar PV plant is placed at LV side of the farthest distribution transformer from the substation. In the network model, feeders Kodobeda, Diwanmuda and Jhakharpara are arranged from left to right. Figure 4.7 shows the network map under 'PV maximum' scenario. It can be observed that distribution transformers in Kodobeda feeder are overloaded. The voltage levels across the network are within 5% deviation from the nominal value.

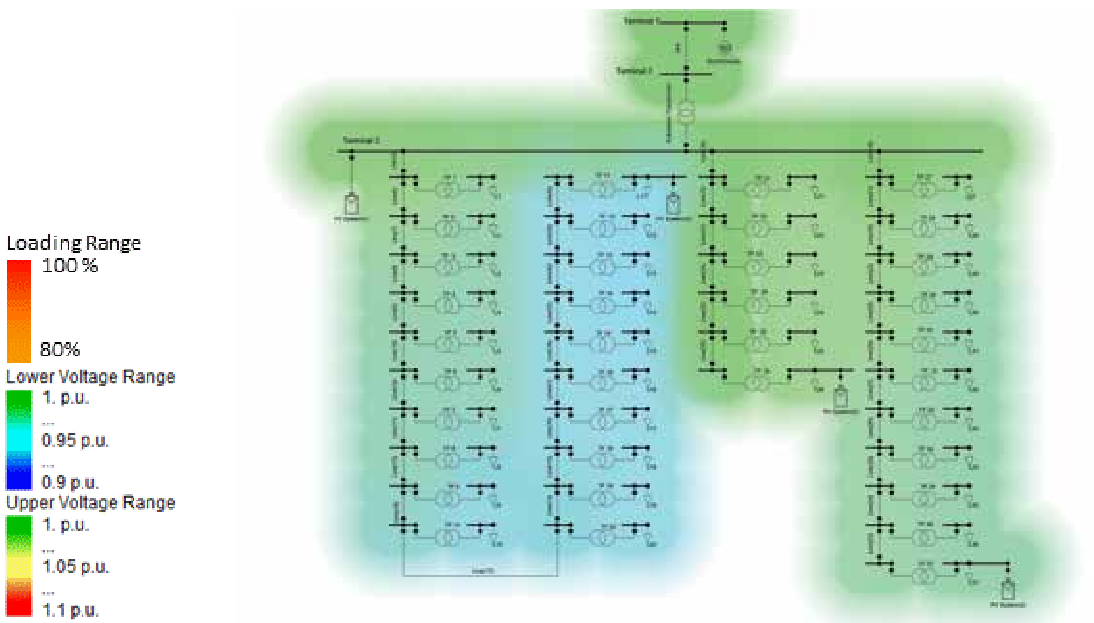


Figure 4.7. Heat map of Jakharpara network with voltage and transformer-loading levels under 'photovoltaic maximum' scenario

Loading and voltage level of the substation transformer is given in Figure 4.8. It can be observed that there is reduction in loading and improvement in voltage proportional to the amount of PV power injected into the network. In all the scenarios, the observed maximum deviation from the nominal voltage is 0.2% at 11 kV level.

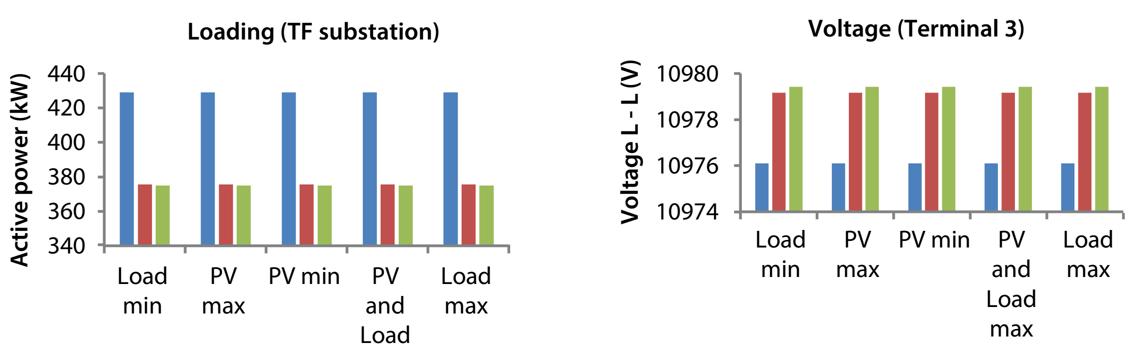


Figure 4.8. Loading and voltage level of substation transformer in Jhakharpara network

Loading and voltage level of distribution transformers at the farthest end of each feeder from the substation (where PV is considered) is given in Figure 4.9. Transformers TF 11, TF 26, and TF 37 are located on the feeders Kodobeda, Diwanmuda, and Jhakharpara, respectively, and their corresponding LV terminals are 25, 55, and 77, respectively. It can be observed that in all the scenarios for transformer TF 11 with 'distributed PV', there is reverse power flow leading to an increase in voltage at terminal T25. In all the scenarios, active power loading of transformer TF 37 is positive, for transformer TF 26 with 'distributed PV', active power is nearly zero, and the observed maximum deviation from the nominal voltage is 1.4% at 415 V level.

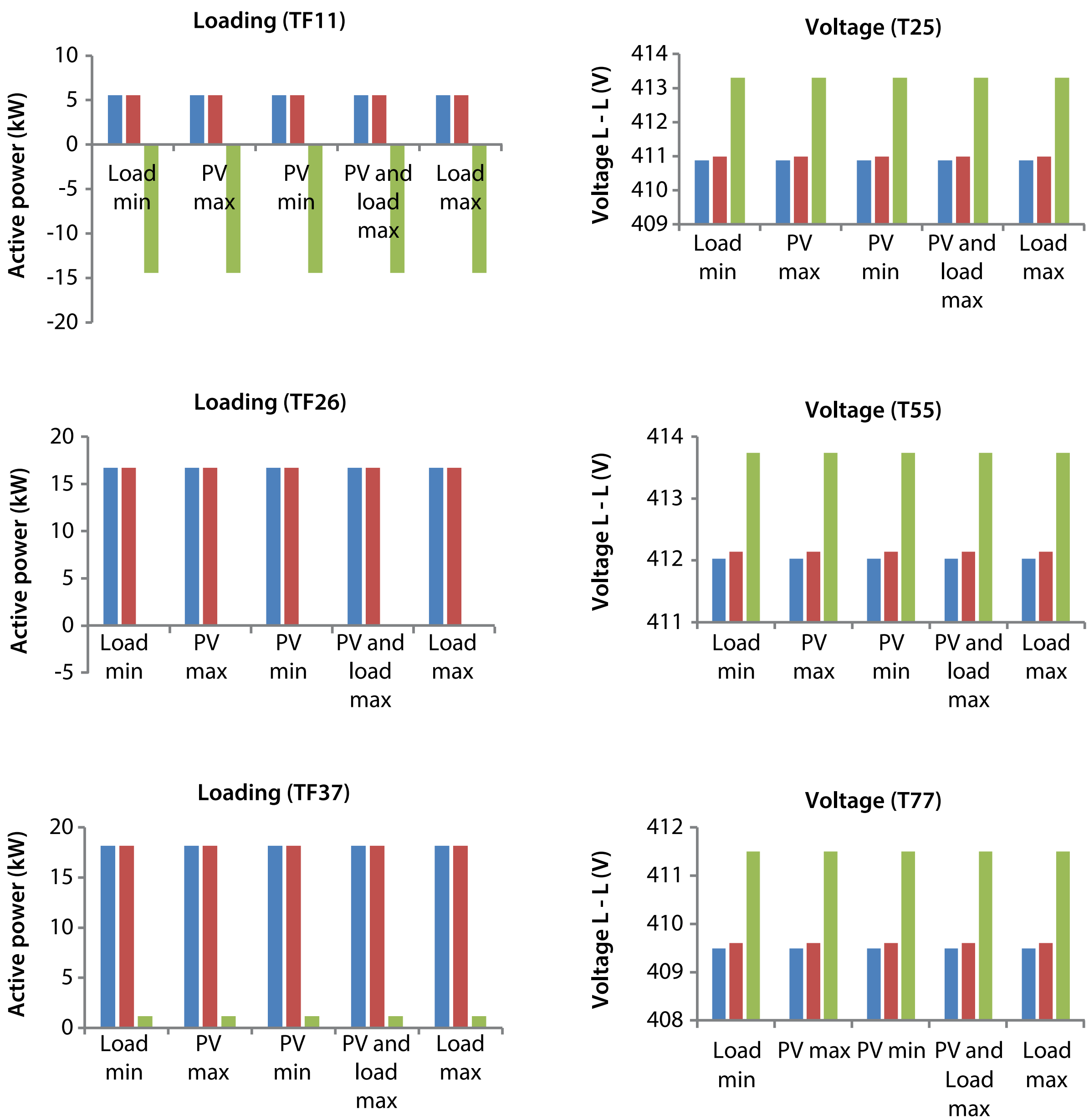


Figure 4.9. Loading and voltage level of key distribution transformers in Jhakharpara network

4.5 Load flow analysis–Gohrapadar

Load flow analysis has been performed for the scenarios described in Section 3.5. On each feeder, a solar PV plant is placed at LV side of the farthest distribution transformer from the substation. In the network model, the feeders Chichya, Gohrapadar, and Dhuvaguli are arranged from left to right. Figure 4.10 shows the network map under 'PV maximum' scenario. It can be observed that there is no overloaded distribution transformer. The voltage levels across the network are within 5% deviation from the nominal value.

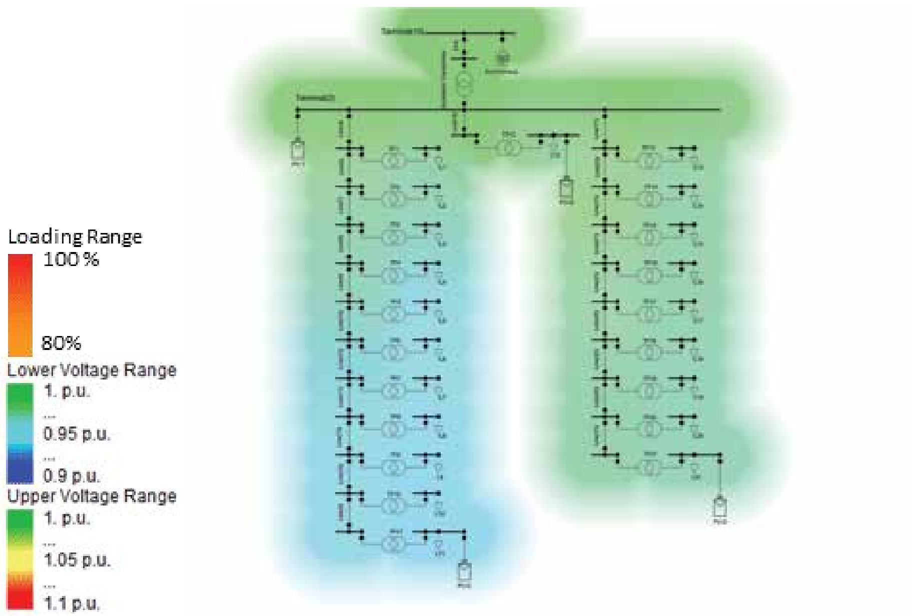


Figure 4.10. Heat map of Gohrapadar network with voltage and transformer-loading levels under 'photovoltaic maximum' scenario

Loading and voltage level of the substation transformer is given in Figure 4.11. It can be observed that there is reduction in loading and improvement in voltage proportional to the amount of PV power injected into the network. In all the scenarios, the observed maximum deviation from the nominal voltage is 0.4% at 11 kV level.

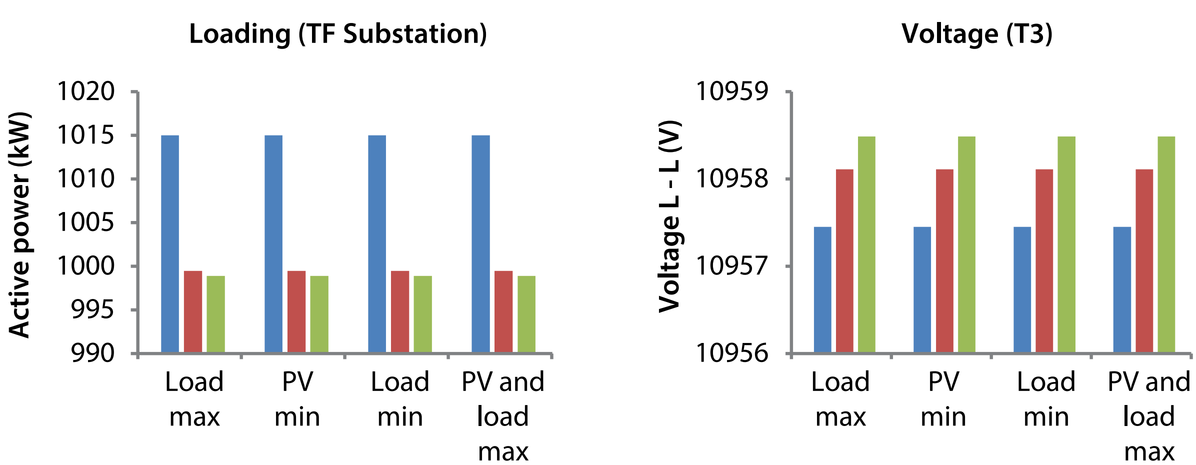


Figure 4.11. Loading and voltage level of substation transformer in Gohrapadar network

Loading and voltage level of distribution transformers at the farthest end of each feeder from the substation (where PV is considered) is given in Figure 4.12. Transformers TF 11, TF 12, and TF 21 are located on the feeders Chichya, Gohrapadar, and Dhuvaguli, respectively, and their corresponding LV terminals are 8, 61, and 69, respectively. It can be observed that in all the scenarios, active power loading of the transformers is positive. The order of the transformer loading across the network is same, and distribution transformer TF 11 on Chichya feeder has the lowest voltage with maximum deviation from the nominal voltage of 4.5 % at 415 V level.

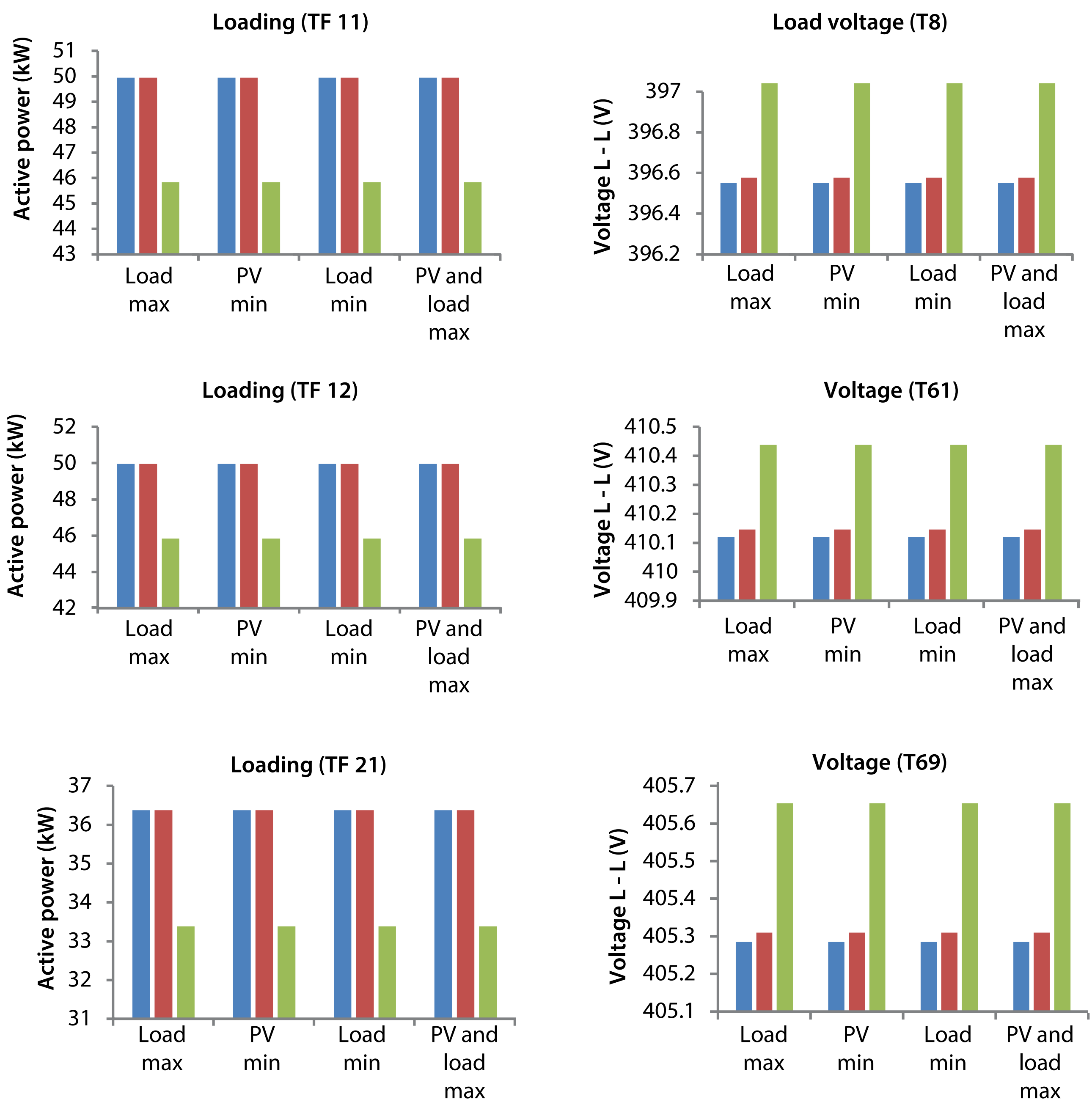


Figure 4.12. Loading and voltage level of key distribution transformers in Gohrapadar network

4.6 Load flow analysis–Network-1

Load flow analysis has been performed for scenarios described in Section 3.6. On each overloaded transformer, a solar PV plant is placed at the LV side of the distribution transformer. In the network model, a feeder is shown on top-left end and remaining 17 feeders of the substation are lumped. Figure 4.13 shows the network map under 'PV maximum' scenario. It can be observed that there are a few overloaded distribution transformers. The voltage levels across the network are within 5% deviation from the nominal value.

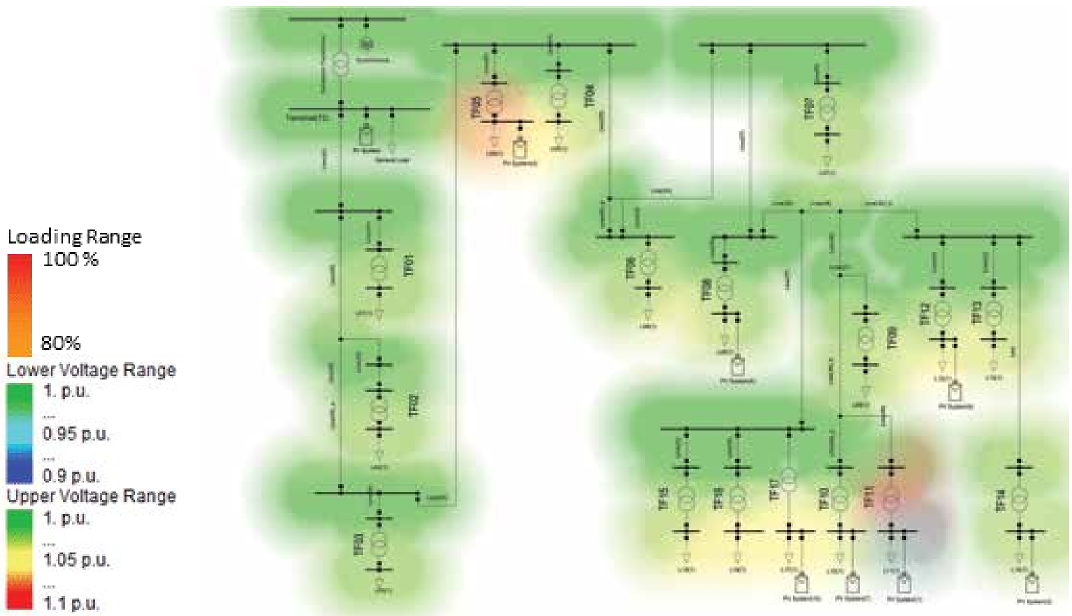


Figure 4.13. Heat map of Network-1 with voltage and transformer-loading levels under 'photovoltaic maximum' scenario

Loading and voltage level of the substation transformer is given in Figure 4.14. It can be observed that there is reduction in loading of the transformer due to local solar PV production. In all the scenarios, the observed maximum deviation from the nominal voltage is 0.4% at 11 kV level.

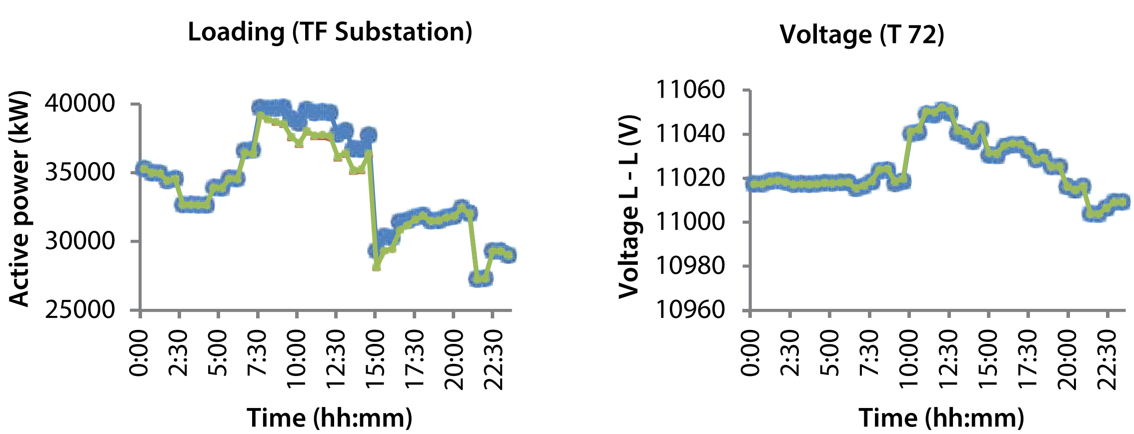
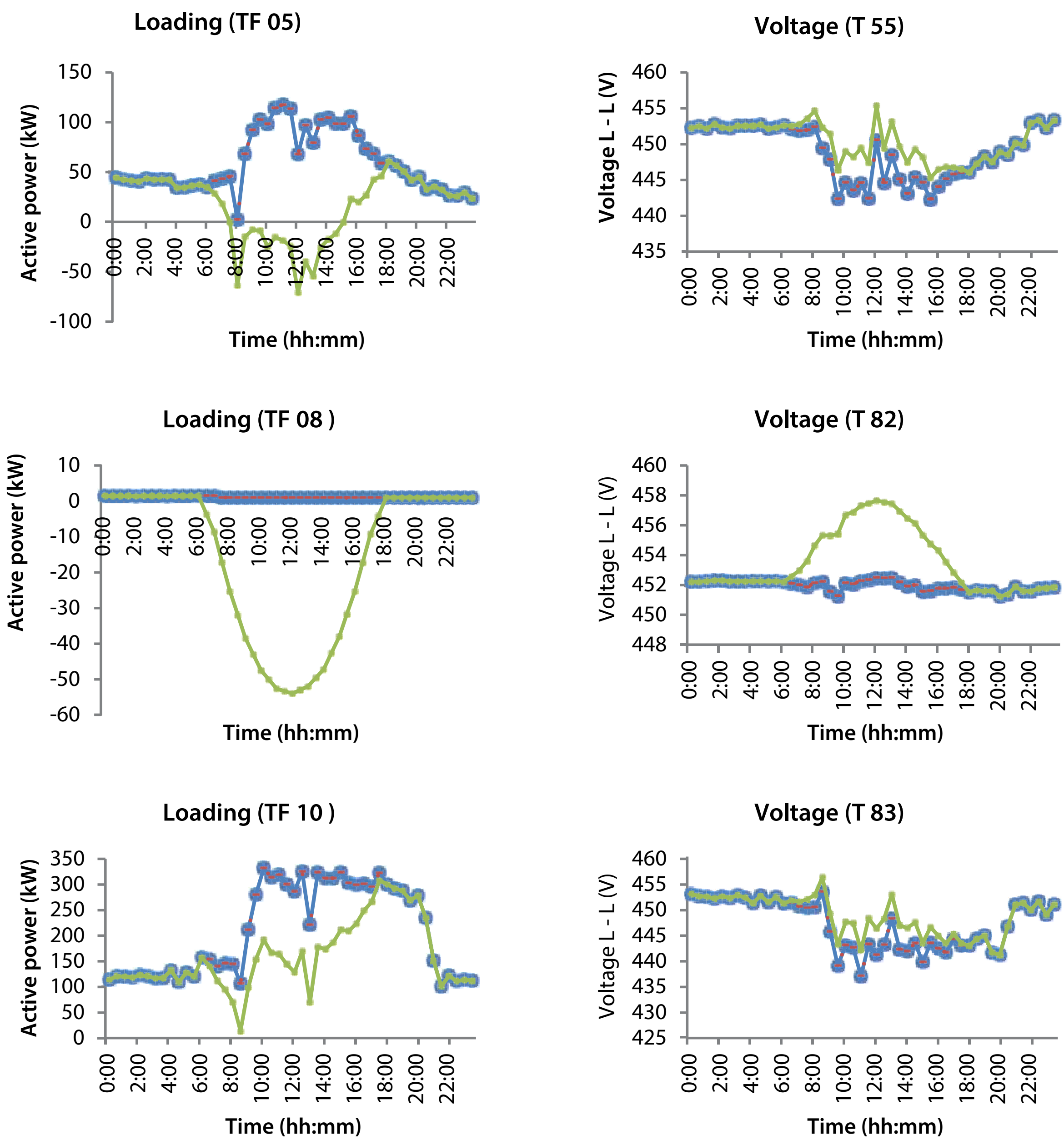


Figure 4.14. Loading and voltage level of substation transformer in Network-1

Loading and voltage level of the key distribution transformers (where PV is considered) is given in Figure 4.15. It can be observed that in 'PV maximum' scenario for transformer TF 05, there is a significant reduction in peak load with distributed PV placed on its LV side. However, for the transformers TF 10, TF 11, and TF 12, the daytime loading had reduced and peak load (at evening) persists with PV at its LV side. This is due to the limitation of grid-tied solar PV system that provides power in sunshine hours only. Hence, solar PV systems with energy storage are recommended at the LV side of the transformers TF 10, TF 11, and TF 12. In case of the transformers TF 08, TF 14, and TF 17 with 'distributed PV', there is reverse power flow observed during the sunshine hours.



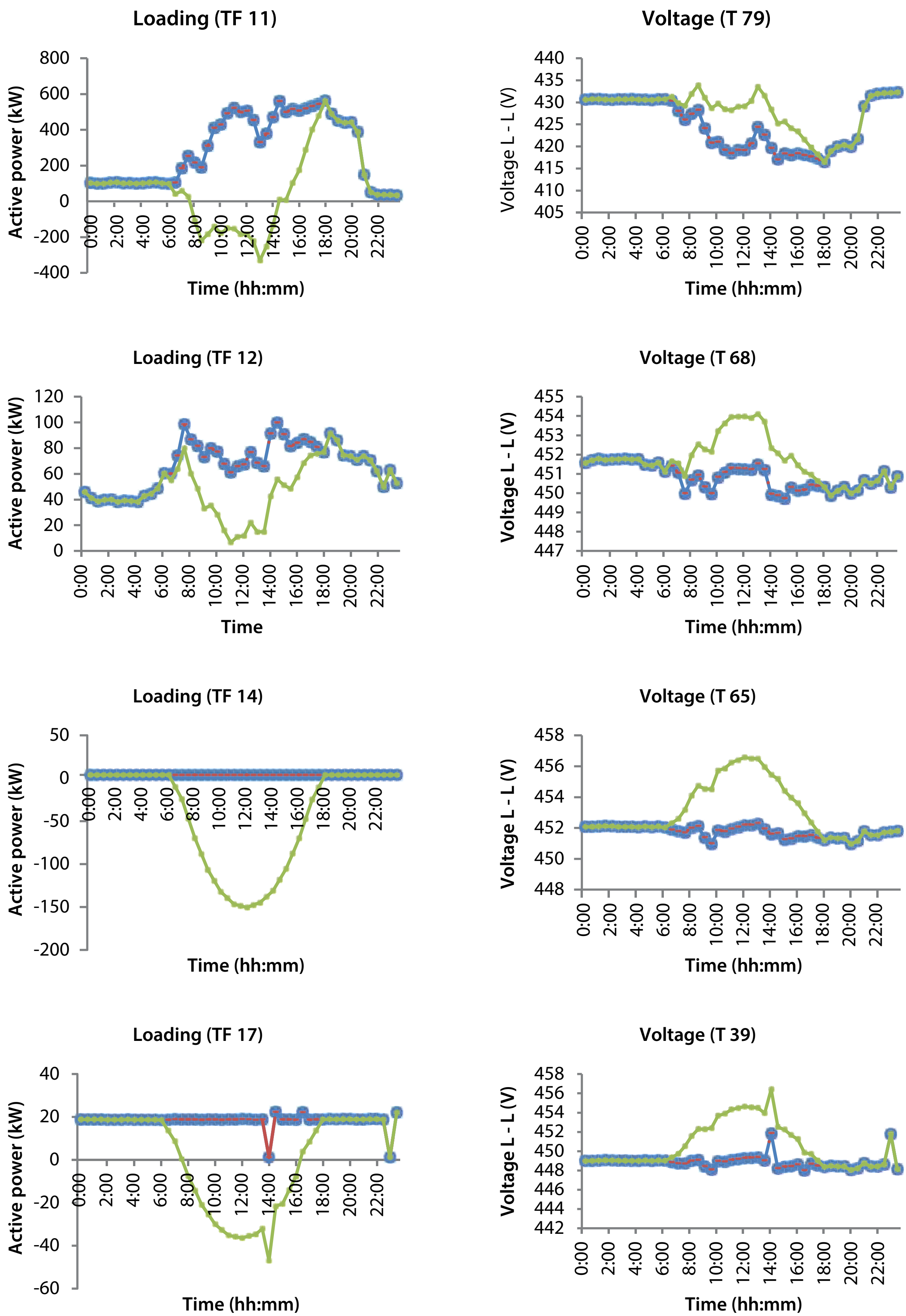


Figure 4.15. Loading and voltage level of key distribution transformers in Network-1 under 'photovoltaic maximum' scenario

4.7 Distribution losses

For this study, absolute power loss and power loss as a ratio of load, power injected from a substation, and total power generation, are calculated. These results are shown in Appendix E. It can be observed that the order of power loss is 80 kW, 300 kW, 50 kW, 80 kW, and 800 kW for substations Amlipadar, Deobhog, Jhakharpara, Gohrapadar, and Network-1, respectively. This is directly proportional to the length of feeders modelled and its loading in each distribution network. As a ratio, power loss with respect to total load and total generation reflects the expected trends in distribution loss. That is, power loss without distributed PV is greater than the losses with PV at a substation. And, power loss with PV at a substation is greater than the losses with PV at LT side of a distribution network. Practically, capturing instantaneous load power at several points in distribution network is a challenge. In general, distribution companies calculate losses in a network as difference between energy recorded at a substation and energy billed on consumers. This takes into account both the technical and commercial losses, but, distribution losses calculated in this manner may not reflect the reduction in losses, in percentage terms, due to localized generation in the network. Hence, it is recommended that distribution losses should be calculated in relation to the total power generation.

4.8 Summary

From the simulation results of all the substations, it can be concluded that distributed solar PV helps in voltage improvement and reduction of transformer loading. The localized generation at low-voltage side of a distribution transformer leads to maximum reduction in distribution loss as the power imported from upstream section of a substation reduces. Sizing and placement of solar PV systems in a distribution network play a crucial role. For effective utilization, solar PV systems should be integrated at points with adequate daytime load. Else, there could be reverse power flow in the transformer. A transformer can transfer bidirectional power until its rated power.

Best case scenario is to put solar at a village level/LT network. However, considering land availability and operation and maintenance of a solar plant, the LV side of a substation can also be considered.

The technical benefits of using solar photovoltaic (PV) systems in a distribution network have been detailed in the Chapter 4. The direct benefits of using decentralized PV systems are clean and renewable source, reduction in loss, reduction in transformer loading, and improvement in voltage. The indirect benefits are reduction in transmission and wheeling losses and charges. In this section, cost-benefit comparison of distributed photovoltaic (PV) at LT, PV at a substation, and power from a centralized plant is presented. In each case, the landed cost of solar power generation is compared with the cost of power supply at the corresponding voltage level.

5. Cost-benefit Analysis

5.1 Assumptions

The following are the key assumptions taken for performing cost-benefit comparison:

- Capacity-utilization factor of PV plant
- In general, a solar PV plant of MW capacity would have a better capacity-utilization factor (CUF) when compared to a kilowatt capacity plant. For higher capacity plants, better site selection, procurement efficiencies, and other customized design parameter result in better CUF at lower costs. Hence, for a plant integrated at the LT side of a distribution network, substation level, and solar park, the CUF is assumed as 16%, 18%, and 21%, respectively.
- Capital cost
- Capital cost of a solar PV plant depends on several factors such as plant capacity, site conditions, etc. MNRE benchmark cost for PV plants from 100 kWp to 500 kWp systems is Rs 45/Wp [8]. By the principle of economies of scale, as plant capacity increases, capital cost per unit decreases. Hence, for plants at a substation and at a solar park, capital cost is assumed to be Rs 40/Wp and Rs 32/Wp, respectively.
- Equity debt ratio
- This is assumed to be 30% equity and 70% debt.
- Operation and maintenance cost of power plant
- For solar park, it is assumed to be Rs 7 lakh/MWp, and for decentralized plant as Rs 4 lakh/MWp.
- Capital cost of transmission network for evacuating power from solar park is assumed as Rs 1 crore/MWp.

Appendix E has a list of various other assumptions taken for this activity.

5.2 Methodology

The annual energy produced from a PV plant (say 400 kWp) at the LT side of a distribution network is estimated as X units. The energy that is to be generated by a plant at a substation is a sum of useful energy (at load) and energy lost in distribution. Hence, the equivalent capacity of a plant at a substation that would be needed to generate X units (at load) is calculated. In a similar manner, equivalent capacity of a solar park that would be needed to generate X units (at load) is estimated by accounting inter-state transmission loss, intra-state transmission loss, wheeling loss, and distribution loss.

At present, the transmission losses for inter-state solar plants are waived off for the accounting purpose, although these losses are pooled with conventional power plants at the time of billing. Accordingly, pooled losses are considered for the purpose of realistic calculations of the desired generation from an inter-state solar plant to match the desired generation from a solar plant at a load point. Similarly, transmission charges for inter-state solar power plants are waived off for accounting and billing purposes, and pooled with the conventional plants for billing purposes. Although, the transmission and wheeling charges on actual basis, using current rupees/megawatt/month methodology would be quite high, we have considered per unit transmission and wheeling charges, based on the pooled transmission and wheeling charges for the calculations. Also for comparison, the calculations without considering the transmission charges are also provided.

By using CERC model [9], the levelized cost of power generation is derived. The calculation sheet used in determination of a levelized tariff is given in Appendix E. The landed cost of power generation is calculated by considering cost of generation and transmission (and wheeling) charges. The capital cost required is also estimated. The landed cost of power generation for various types of PV systems is compared with the present cost of supply at the corresponding voltage levels.

5.3 Chhattisgarh

Table 5.1. Detailed comparison of various parameters for solar photovoltaic at different level for Chhattisgarh

Particulars	Unit	Distributed PV 11 kV/LT	Distributed PV at 33 kV S/s	Solar park	
				with transmission and wheeling charges waived off	with transmission and wheeling charges
Capacity	**kWp**	**400**	**428**	**422**	**422**
Capacity-utilization factor	**%**	**16.00%**	**18.00%**	**21.00%**	**21.00%**
Annual electricity generation	**Million units**	**0.561**	**0.675**	**0.777**	**0.777**
Inter-state transmission losses [10]	%	0.00%	0.00%	3.00%	3.00%
Intra-state transmission losses [10]	%	0.00%	0.00%	3.00%	3.00%
Wheeling losses [10]	%	0.00%	16.97%	21.82%	21.82%
Energy available for consumption for LT user	Million units	0.561	0.561	0.561	0.561
Levelized cost of solar power generation	**Rs/kWh for 25 years**	**5.51**	**4.44**	**3.2**	**3.2**
Inter-state transmission charges	Rs/kWh pooled basis	0.00	0.00	0.00	0.39
Intra-state transmission charges	Rs/kWh pooled basis	0.00	0.00	0.00	0.29
Wheeling charges	Rs/kWh pooled basis	0.00	0.00	0.00	0.50
Total energy cost per annum	Cr Rs	0.31	0.30	0.25	0.25
Total transmission and wheeling cost	Cr Rs	0.00	0.00	0.00	0.09
Total landed cost of energy	Cr Rs	0.31	0.30	0.25	0.34
Landed cost of power	**Rs/unit**	**5.51**	**5.35**	**4.43**	**6.07**
Capital cost of solar plant	per Wp	45.00	40.00	32.00	32.00
Capital cost of transmission network	Rs Cr per MW			1.00	1.00
Capital cost of sub-transmission network	Rs Cr per MW			1.00	1.00
Capital cost of distribution network	Rs Cr per MW		1.00	1.00	1.00
Investment in power plant	Rs Cr	1.80	1.71	1.35	1.35
Investment in transmission and distribution network	Rs Cr	0.00	0.43	1.27	1.27
Total investment	**Rs Cr**	**1.80**	**2.14**	**2.62**	**2.62**
Cost of supply, as per ARR [10]	**Rs/unit**	**6.61**	**5.43**		

5.4 Delhi

Table 5.2. Detailed comparison of various parameters for solar photovoltaic at different level for Delhi

Particulars	Unit	Distributed PV 11 kV/LT	Distributed PV at 33 kV S/s	Solar park	
				with transmission and wheeling charges waived off	with transmission and wheeling charges
Capacity	**kWp**	**400**	**396**	**357**	**357**
Capacity-utilization factor	**%**	**16.00%**	**18.00%**	**21.00%**	**21.00%**
Annual electricity generation	**Million units**	**0.561**	**0.624**	**0.657**	**0.657**
Inter-state transmission losses [11]	%	0.00%	0.00%	1.65%	1.65%
Intra-state transmission losses [11]	%	0.00%	0.00%	0.98%	0.98%
Wheeling losses [11]	%	0.00%	10.19%	12.03%	12.03%
Energy available for consumption for LT user	Million units	0.561	0.561	0.561	0.561
Levelized cost of solar power generation	**Rs/kWh for 25 years**	**5.14**	**4.11**	**3.2**	**3.2**
Inter-state transmission charges	Rs/kWh pooled basis	0.00	0.00	0.00	0.29
Intra-state transmission charges	Rs/kWh pooled basis	0.00	0.00	0.00	0.35
Wheeling charges	Rs/kWh pooled basis	0.00	0.00	0.00	1.03
Total energy cost per annum	Cr Rs	0.29	0.26	0.21	0.21
Total transmission and wheeling cost	Cr Rs	0.00	0.00	0.00	0.11
Total landed cost of energy	Cr Rs	0.29	0.26	0.21	0.32
Landed cost of power	**Rs/unit**	**5.14**	**4.58**	**3.75**	**5.71**
Capital cost of solar plant	per Wp	45.00	40.00	32.00	32.00
Capital cost of transmission network	Rs Cr per MW			1.00	1.00
Capital cost of sub-transmission network	Rs Cr per MW			1.00	1.00
Capital cost of distribution network	Rs Cr per MW		1.00	1.00	1.00
Investment in power plant	Rs Cr	1.80	1.58	1.14	1.14
Investment in transmission & distribution network	Rs Cr	0.00	0.40	1.07	1.07
Total investment	**Rs Cr**	**1.80**	**1.98**	**2.21**	**2.21**
Cost of supply, as per ARR [11]	Rs/unit	7.61	6.79		

5.5 Summary

Tables 5.1 and 5.2 list the detailed comparison of PV systems at LT, substation, and solar park (with and without wheeling charges) for Chhattisgarh and Delhi, respectively. It can be seen that Chhattisgarh has higher transmission and distribution loss compared to Delhi, therefore, resulting in a higher capacity of equivalent PV capacity at substation and above. This results in higher investment in Chhattisgarh. In Chhattisgarh, the landed cost of solar power generation for distributed PV at LT is 16.6% less than the average cost of supply at LT level. Similarly in Delhi, the landed cost of solar power generation for distributed PV at LT is 32% less than the average cost of supply at LT level.

Table 5.3. Summary of cost-benefit analysis

Particulars	State	Distributed PV at LT	Distributed PV at substation	Solar park (with transmission and wheeling charges waived off)	Solar park (with transmission and wheeling charges)
Capacity (kWp)	Chhattisgarh	400	428	422	422
	Delhi	400	396	357	357
Landed cost of power (Rs/unit)	Chhattisgarh	5.51	5.35	4.43	6.07
	Delhi	5.14	4.58	3.75	5.71
Total investment (Rs Cr)	Chhattisgarh	1.8	2.14	2.62	2.62
	Delhi	1.8	1.98	2.21	2.21
Cost of supply, as per ARR (Rs/unit)	Chhattisgarh	6.61	5.43		
	Delhi	7.61	6.79		

Summary of key parameters for Chhattisgarh and Delhi is given in Table 5.3. It can be concluded that with the present cost of solar power generation, distributed PV systems at load or substation level are viable as they produce power less than the present cost of supply. The power produced from solar park (with transmission and wheeling charges waived) is the best cost-effective solution for Delhi and Chhattisgarh. However, the difference between the landed cost of power produced from centralized and decentralized systems reduces significantly by considering transmission and wheeling charges on solar park. The cost involved in transmission network for large solar parks is being pooled on all non-renewable generation and therefore the power of solar parks will be low-priced. However, solar power of distributed solar plant is akin to solar power for a solar park and T&D losses. This suggests that liberal tariffs should be allowed for distributed solar plants.

6. Key Study Findings, Gaps, and Proposed Interventions

Four rural substations in southern part of Raipur and one semi-urban substation in western part of Delhi were studied under this project. The rural substations were catering to agricultural and residential consumers. The semi-urban substation was catering to industrial and residential consumers. There were differences in data available, rooftop photovoltaic (PV) regulations, grid availability, and objective towards adopting solar PV in distribution network. Rural networks plan to reduce their distribution losses (resulting from long radial lines) from PV plants, and in case of urban networks, PV aids in network decongestion.

Detailed simulation studies were conducted considering the extremities in PV, and load variations have demonstrated the application of decentralized solar PV systems in reducing transformer loading, improving voltage, and reducing technical losses. Sizing and placement of solar PV systems is crucial. Simulation results highlight the importance of instantaneous load data in power system planning. By having adequate accurate data, critical points of distribution network can be identified for harnessing solar power. Also for solar photovoltaic plants designers, load profile acts as a reference for the quantum of solar power that can be integrated into a system. Between the five substations in this study, availability of adequate accurate data is varied. In rural network, data are typically manually recorded at hourly interval, and in urban network, supervisory control and data acquisition systems are used for automated data logging. Hence, there is a need for standardization in data collected at distribution transformer level. Thus, lack of uniform accurate data is a limiting factor for design of decentralized solar power plants.

Results from various scenarios have indicated that placing PV plants at the tail end of a network is beneficial technically.

The cost-benefit comparison of PV power generation at tail end to generation at substation and power procurement from solar park had been presented. The viability of decentralized plants is high as their landed cost of power is less than the cost of supply for Chhattisgarh and Delhi. At present, large-scale solar parks receive incentive in an indirect form as their transmission and wheeling charges are waived off. The study has shown that with transmission and wheeling charge on solar park, landed cost of power is comparable to decentralized systems.

Although the findings on the benefits of decentralized PV systems are specific to the five substations, the following are the recommended interventions that will aid in adoption towards small-scale distributed PV systems in distribution networks:

» Distribution transformers are capable of bidirectional power flow and short-term overloading. This implies PV installation up to 100% of their rating is technically feasible. This study has reviewed the variation in PV limits across states. There is a need for uniformity in these regulations at national level.

» The cost involved in transmission network for large solar parks is being pooled on all non-renewable generation and therefore the power of solar parks will be low priced. However, solar power of distributed solar plant is akin to solar power for a solar park and T&D losses. This suggests that liberal tariffs should be allowed for distributed solar plants.

» In rural areas, grid availability varies from time to time. In this study, it was observed that in sunshine hours grid availability is lesser than the rest of the day. Hence, the design configuration of solar PV system should account grid availability as a factor. For semi-urban feeders, in certain cases, it is noticed that during evening peak load conditions, solar PV is unable to bring the transformer loading below threshold limit, although significant reduction during daytime is noticed. In these situations, solar systems with storage need to be encouraged.

» At present, distribution losses are estimated on the basis of energy sent from substation and energy billed on consumers. The benefit of decentralized PV systems in distribution network loss reduction is not captured in this method. Hence, it is recommended that distribution losses should be calculated in relation to total generation. Monitoring instantaneous power generation from decentralized PV systems is also suggested.

» General awareness among DISCOM's field-level technical staffs on the impact of solar PV generation at tail-end grid is relatively low. There is a need for sensitization.

Appendix A

Single-line Diagrams of Distribution Network

A.1 Amlipadar

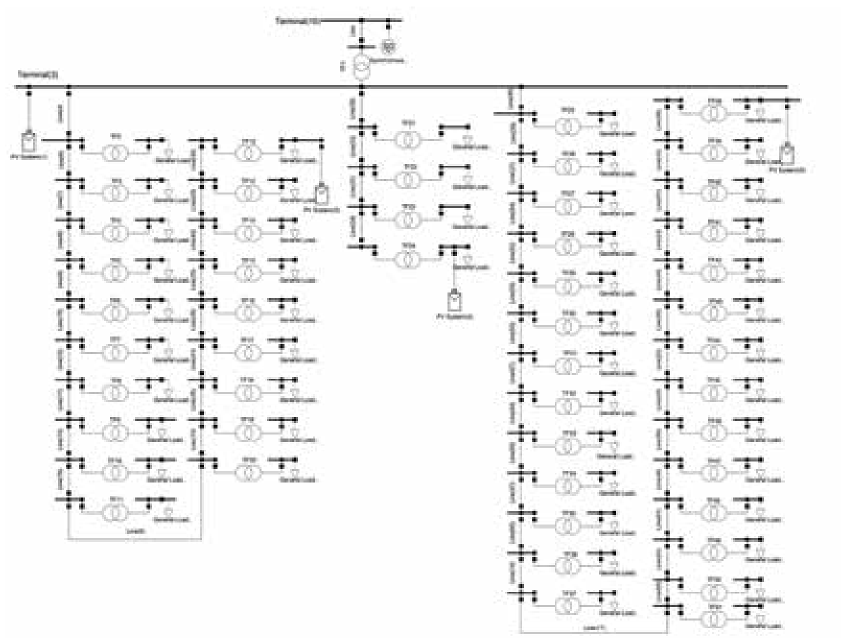


Figure A.1. SLD of Amlipadar network

A.2 Deobhog

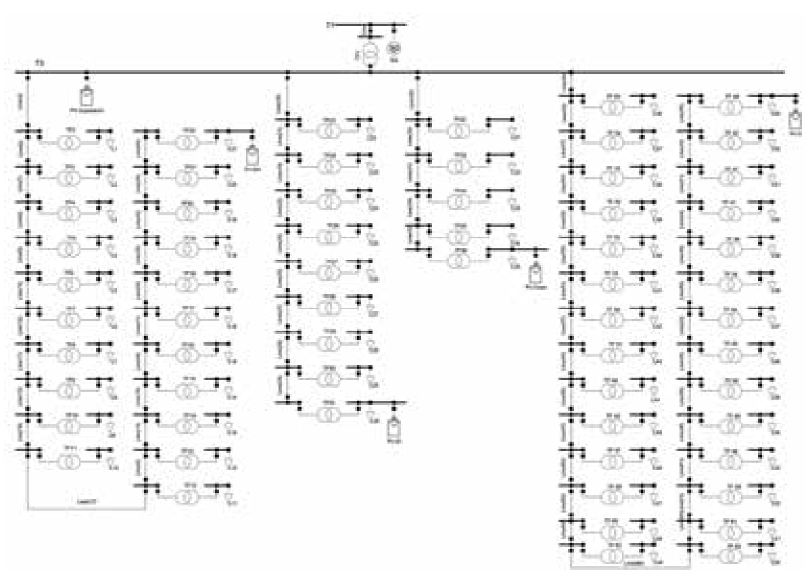


Figure A.2. SLD of Deobhog network

A.3 Jhakharpara

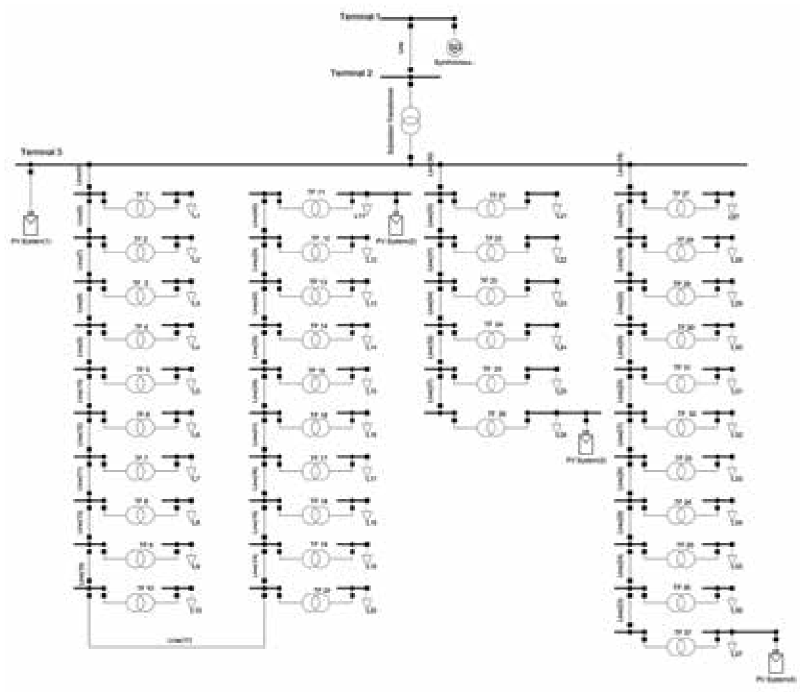


Figure A.3. SLD of Jhakharpara network

A.4 Gohrapadar

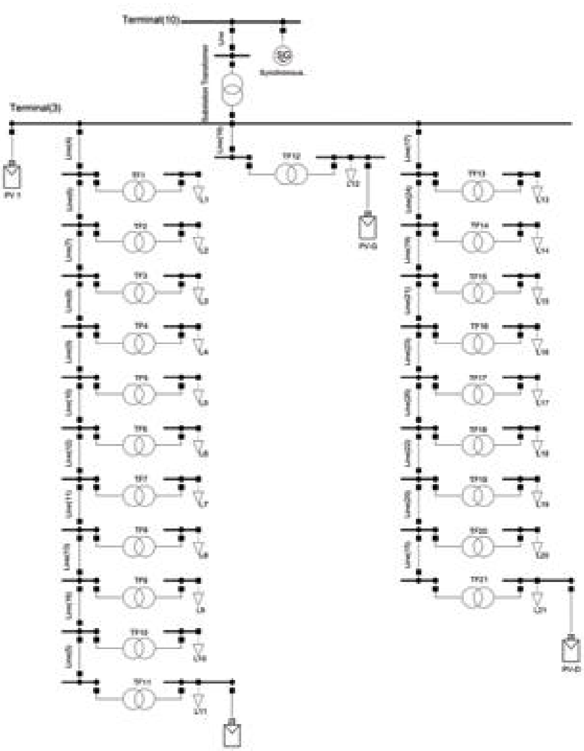


Figure A.4. SLD of Gohrapadar network

A.5 Network-1

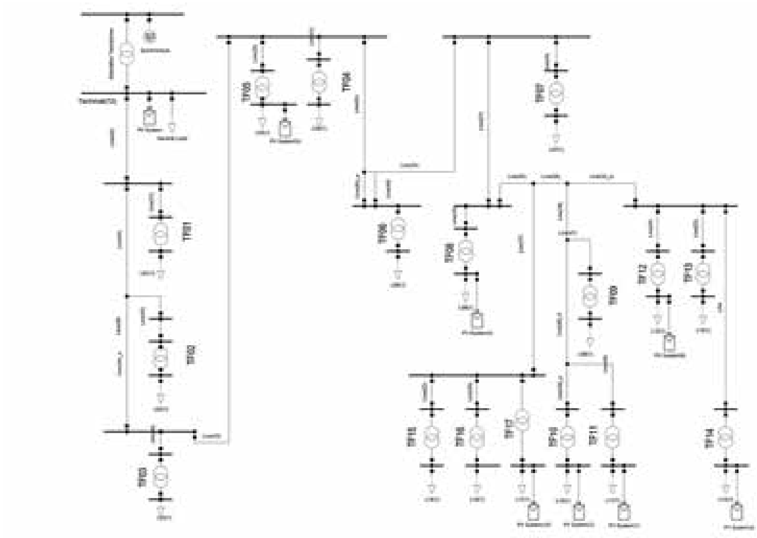


Figure A.5. SLD of Network-1

Substation Transformer-loading and PV Production Data

B.1 Amlipadar

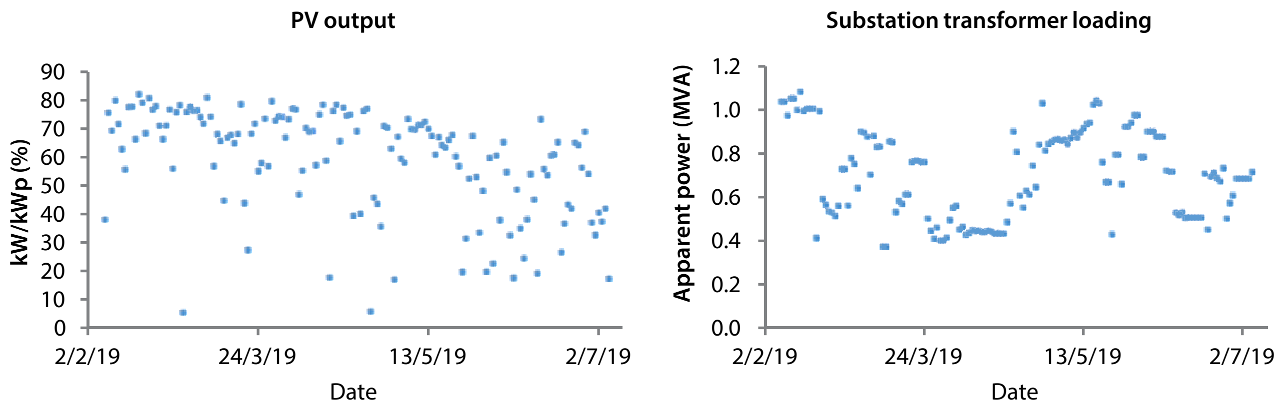


Figure B.1. Photovoltaic output and loading level of substation transformer in Amlipadar

B.2 Deobhog

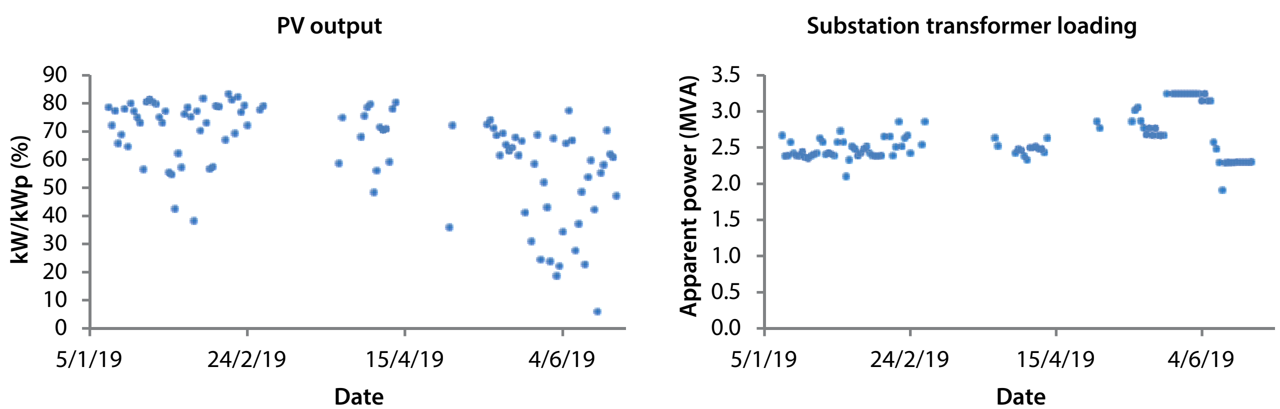
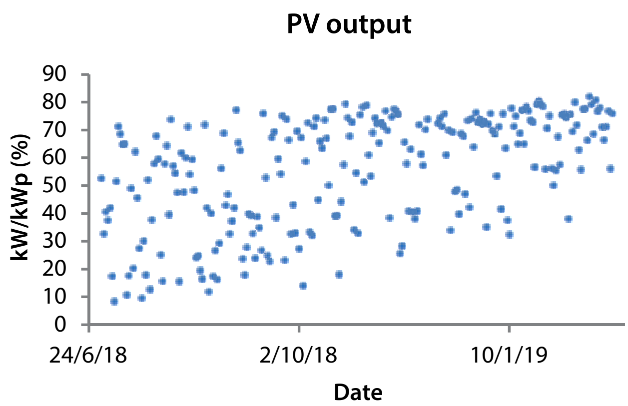


Figure B.2. Photovoltaic output and loading level of substation transformer in Deobhog

B.3 Jhakharpara



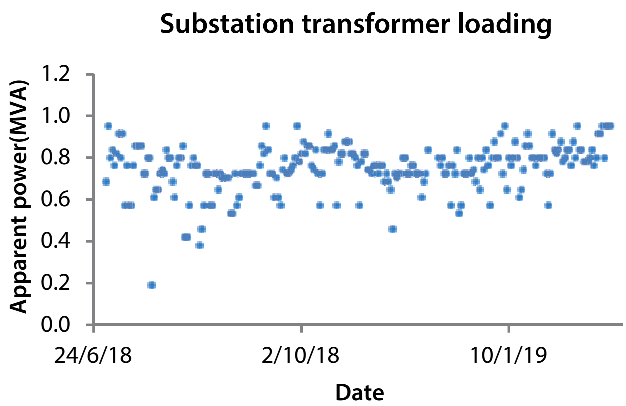
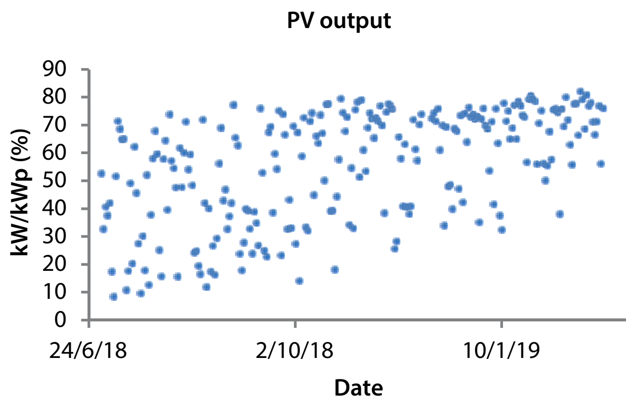


Figure B.3. Photovoltaic output and loading level of substation transformer in Jhakharpara

B.4 Gohrapadar



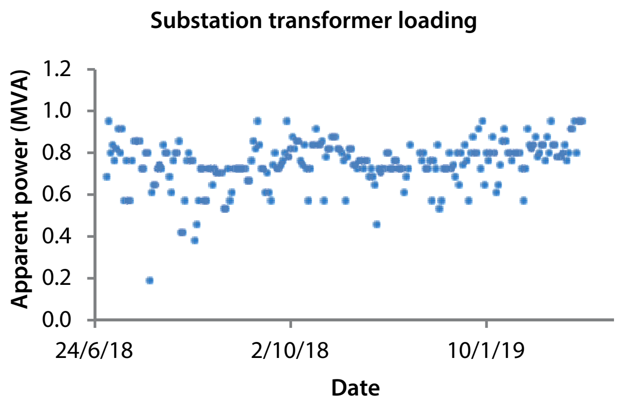


Figure B.4. Photovoltaic output and loading level of substation transformer in Gohrapadar

B.5 Network-1

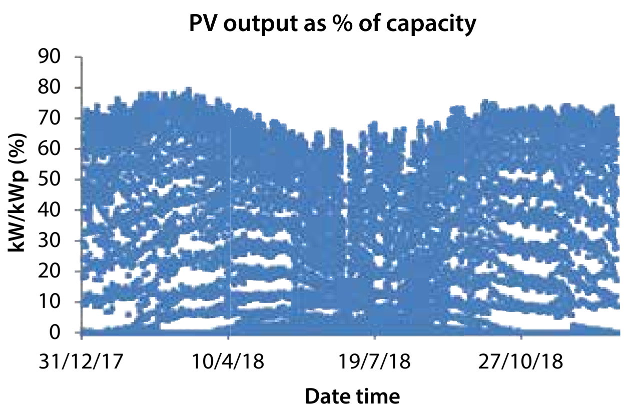


Figure B.5. Graph showing photovoltaic output of Network-1 substation

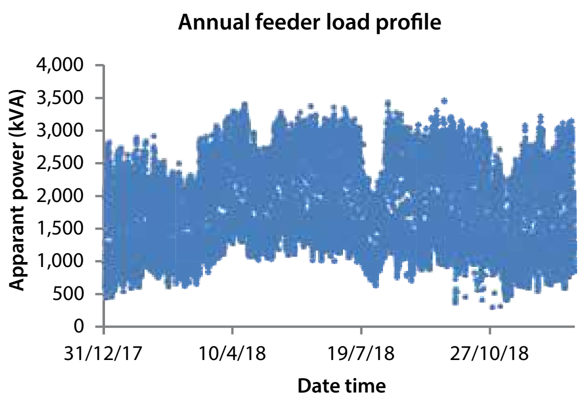


Figure B.6. Graph showing annual load profile of Network-1 substation

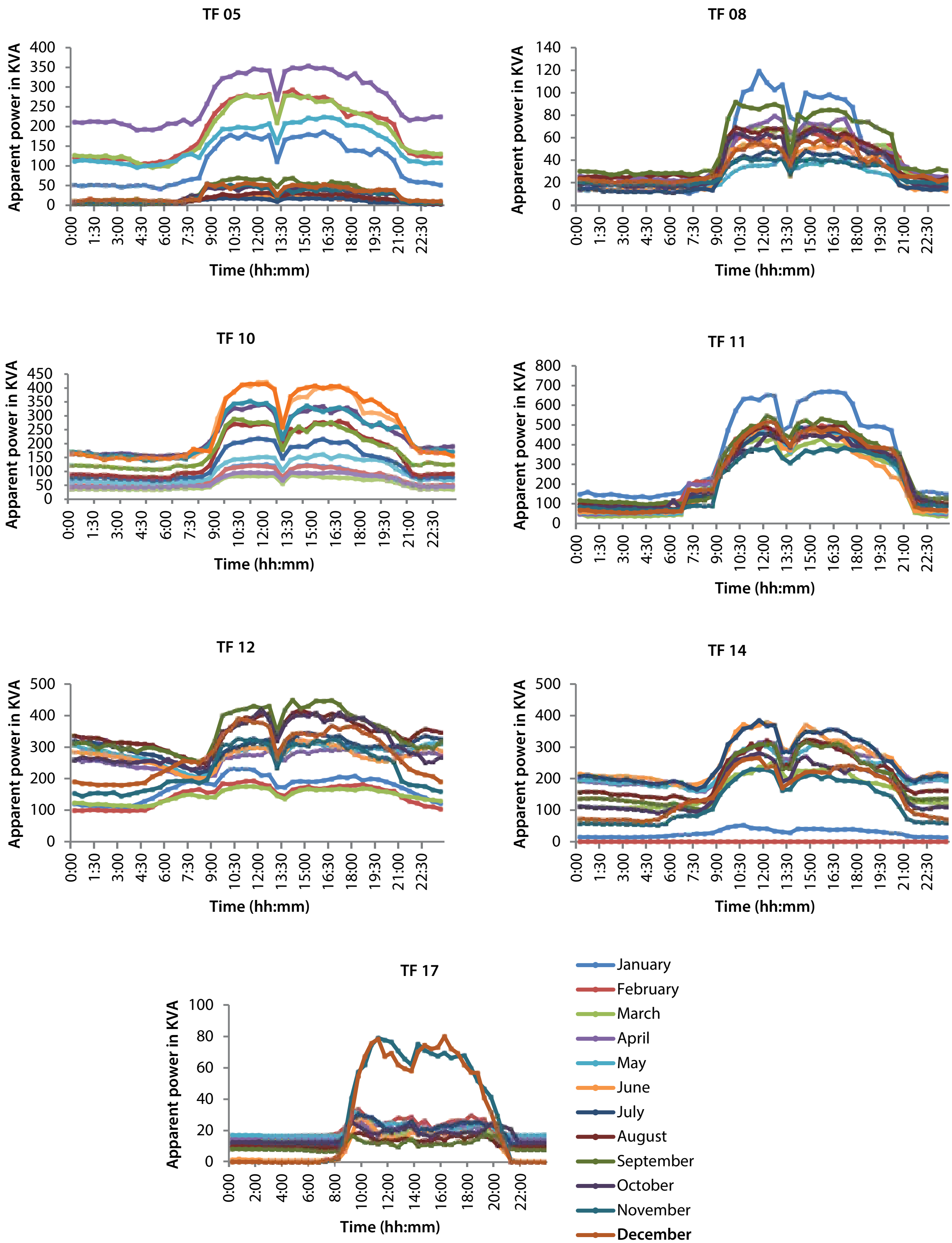


Figure B.7. Monthly load profile of overloaded distribution transformers in Network-1

Specifications of Distribution Network

Table C.1. Specifications of transformers

Transformer level	Network-1		Amlipadar		Jhakharpara		Deobhog		Gorapadar	
	Substation	Distribution	Substation	Distribution	Substation	Distribution	Substation	Distribution	Substation	Distribution
Rated power in kVA (Name)	85,000	630 (TF 11), 400 (TF 01, 02, 06, 09, 10, 12, 13,14), 250 (TF 05), 100 (TF 03, 04, 07, 08, 15, 16, 17)	3500	140	1600	100 (TF 1 to TF 20), 80 (TF 21 to TF 37)	5000	171 (TF 2 to TF 22), 87 (TF 23 to TF 31), 500 (TF 32 to TF 36), 163 (TF 15, TF 16, TF 34, TF 39 to TF 63)	1600	121 (TF 1 to TF 11), 250 (TF 12), 88 (TF 13 to TF 21)
Rated voltage in kV (HV side)	66	11	33	11	33	11	33	11	33	11
Rated voltage in kV (LV side)	11	0.433	11	415	11	415	11	415	11	415
Vector group HV side	D	D	D	D	D	D	D	D	D	D
Vector group LV side	Y	YN	Y	Y	Y	Y	Y	Y	Y	Y
X/R ratio	20	3	20	3	20	3	20	3	20	3
Positive sequence impedance in p.u.	0.1	0.18	0.1	0.18	0.1	0.18	0.1	0.18	0.1	0.18

Table C.2. Specifications of lines/feeders

Line	Network-1	Amlipadar	Jhakharpara	Deobhog	Gorapadar
Rated voltage kV	11	11	11	11	11
Rated current in kA (in ground)	0.355	0.157	0.157	0.157	0.157
Rated current in kA (in air)	0.45			5000	5000
Positive sequence reactance ohm/km	0.093	0.35	0.35	0.35	0.35
Positive sequence resistance ohm/km	0.1	0.5524	0.5524	0.5524	0.5524
Positive sequence susceptance µS/km	138.2	3.2	3.2	3.2	3.2
Conductor material	Copper	Copper	Copper	Copper	Copper

Table C.3. Specifications of reference synchronous generator

Synchronous machine	Network-1	Amlipadar	Jhakharpara	Deobhog	Gorapadar
Nominal apparent power in kVA	85,000	5000	5000	5000	5000
Nominal voltage in kV	66	33	33	33	33
Power factor	0.8	0.8	0.8	0.8	0.8
Connection	D	D	D	D	D

Additional Simulation Results

Network-1

Scenario: Load max

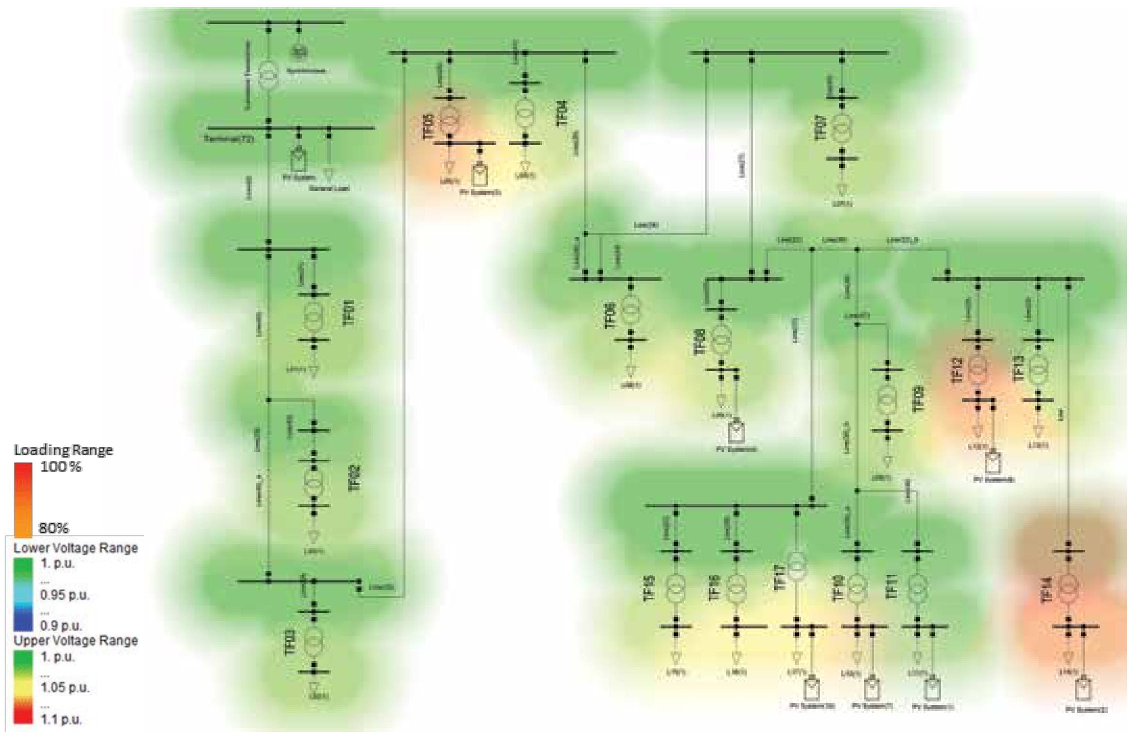
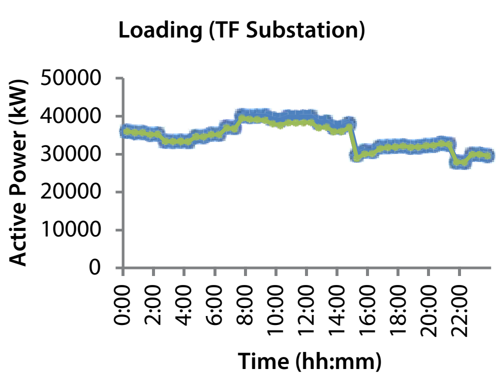
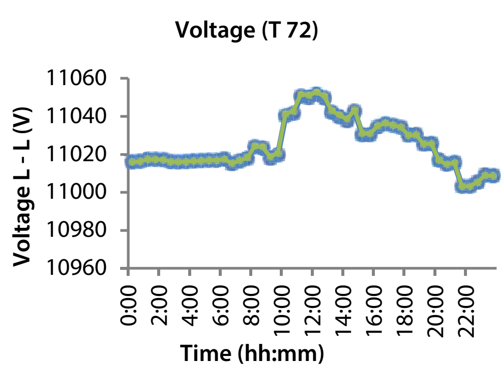
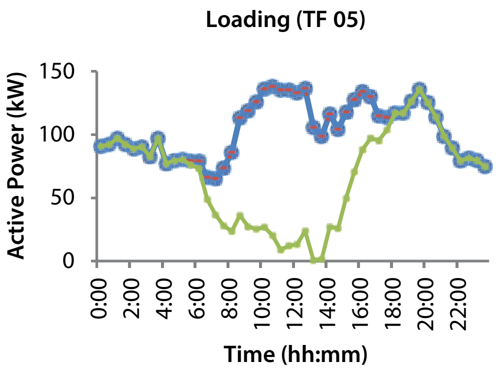
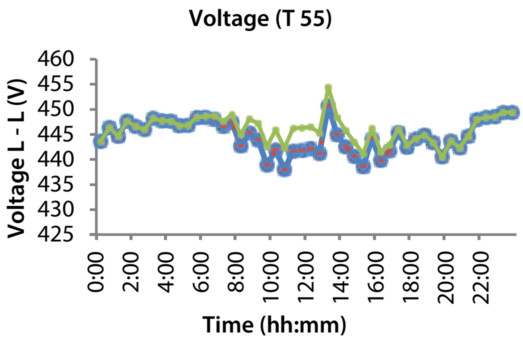


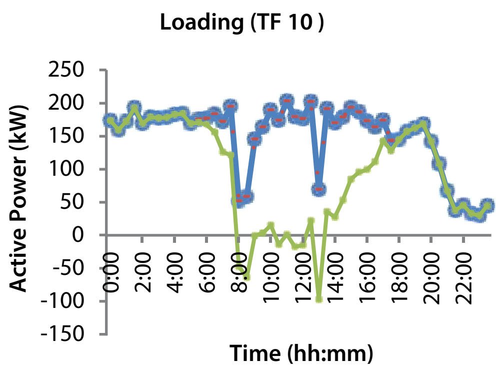
Figure D.1. Heat map of Network-1 with voltage and transformer-loading levels under 'load maximum' scenario

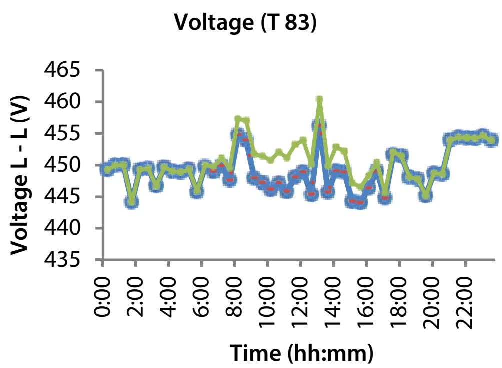


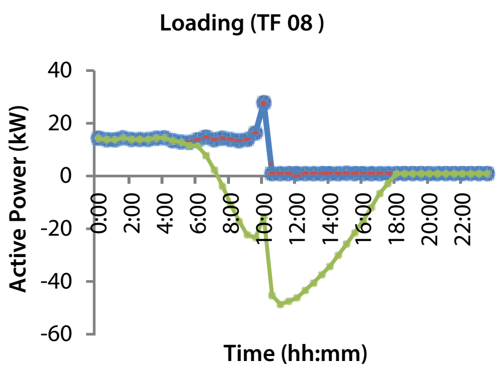


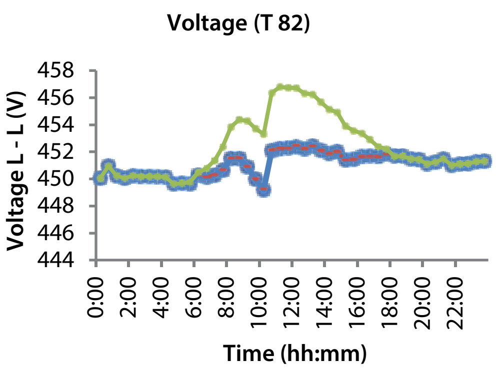

Loading (TF 05)
Active Power (kW)
Time (hh:mm)

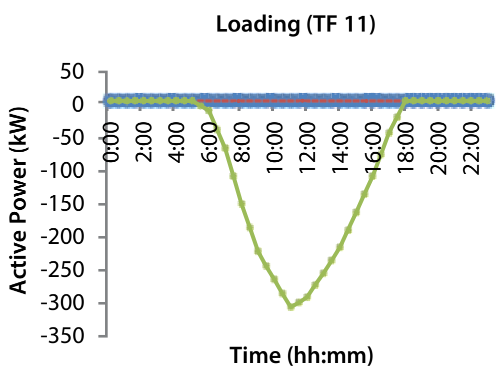

Voltage (T 55)
Voltage L - L (V)
Time (hh:mm)

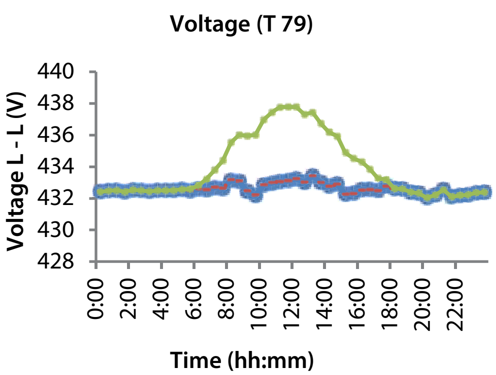

Loading (TF 10)
Active Power (kW)
Time (hh:mm)


Voltage (T 83)
Voltage L - L (V)
Time (hh:mm)


Loading (TF 08)
Active Power (kW)
Time (hh:mm)


Voltage (T 82)
Voltage L - L (V)
Time (hh:mm)


Loading (TF 11)
Active Power (kW)
Time (hh:mm)


Voltage (T 79)
Voltage L - L (V)
Time (hh:mm)

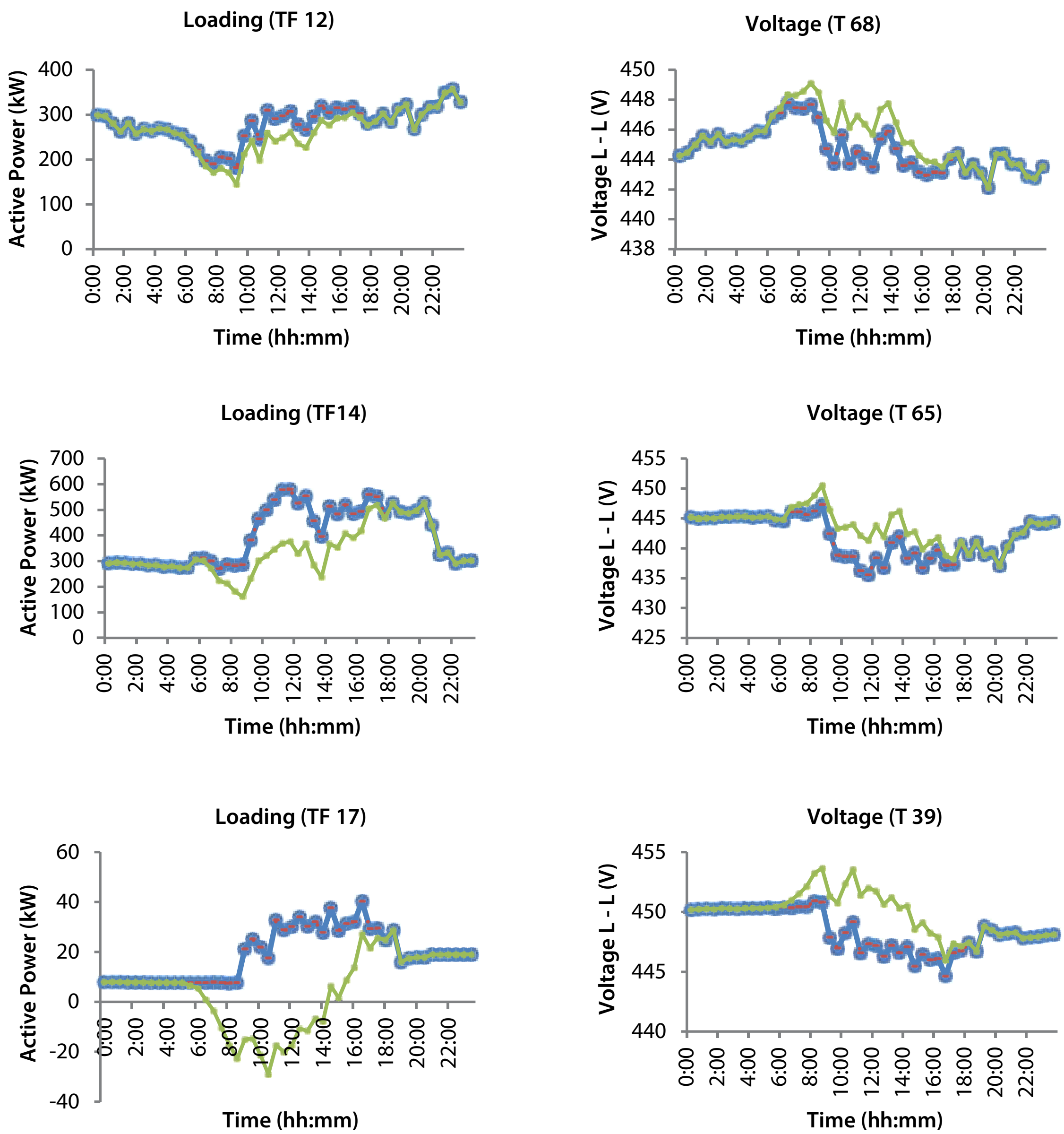


Figure D.2. Loading and voltage level of key transformers in Network-1 under 'load maximum' scenario

Scenario: Photovoltaic and load max

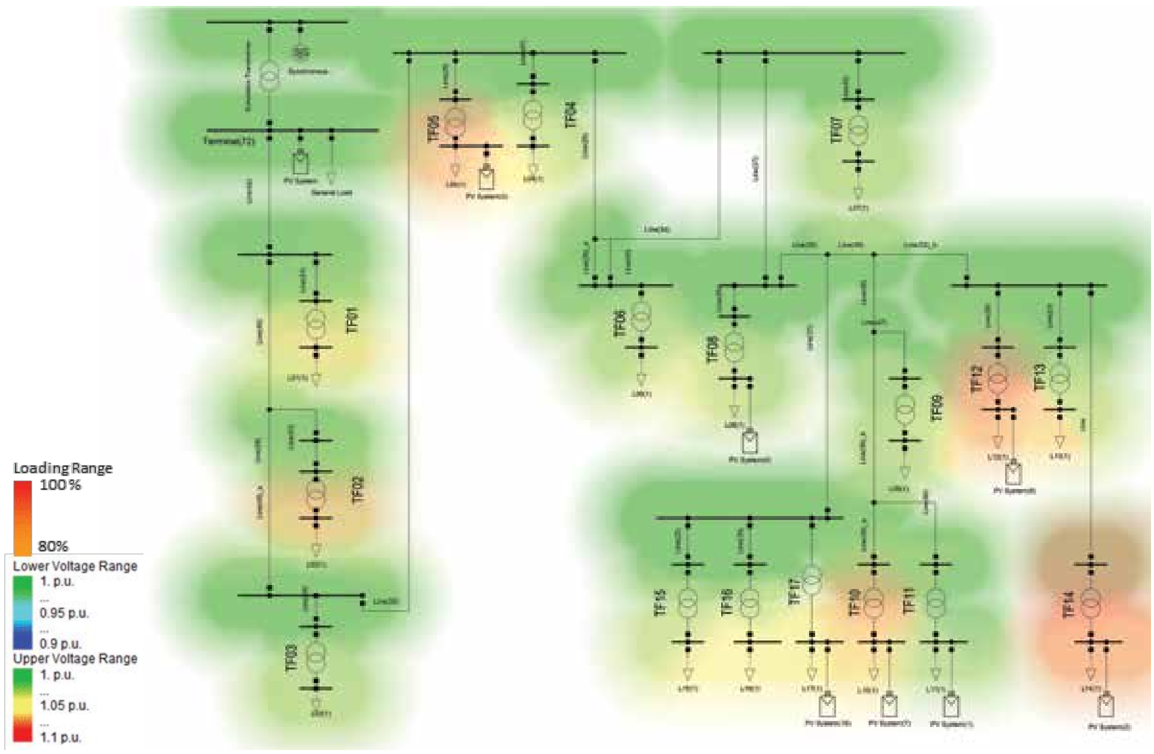
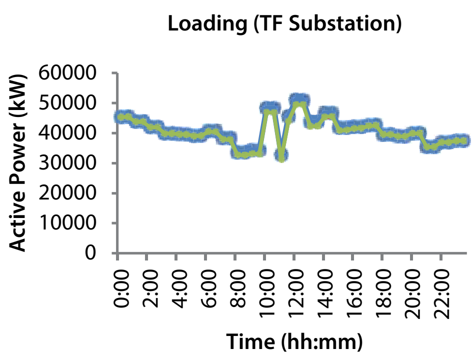
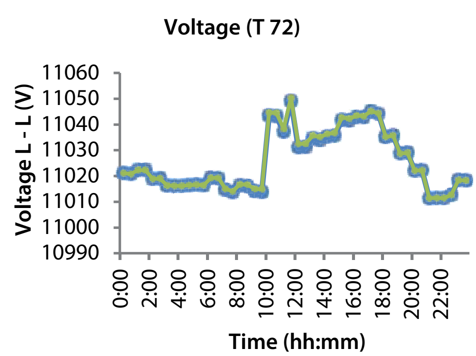
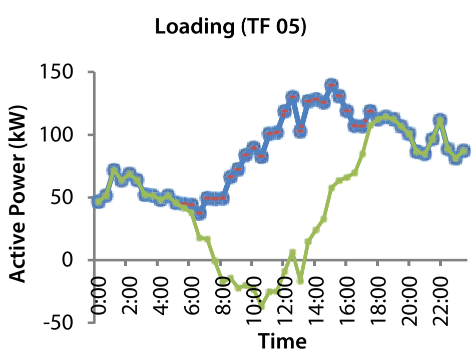
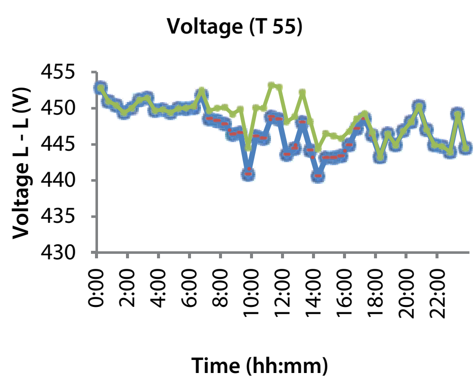


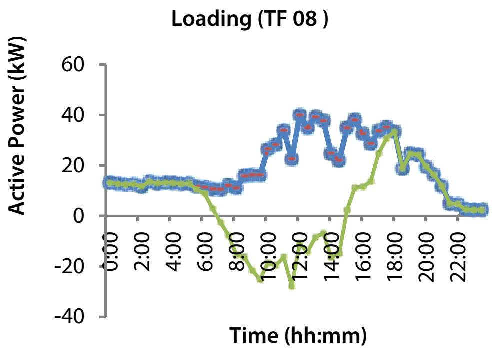
Figure D.3. Heat map of Network-1 with voltage and transformer-loading levels under 'photovoltaic and load maximum' scenario

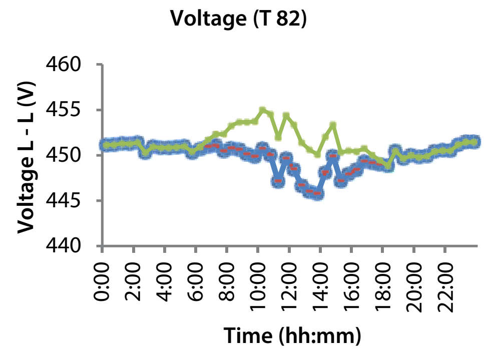


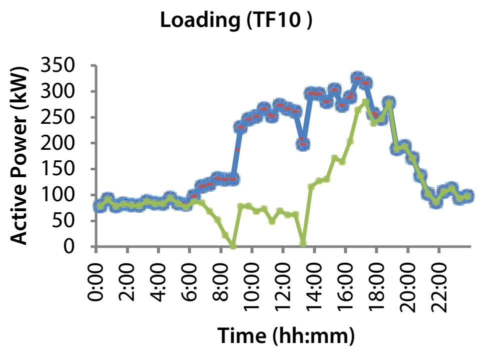


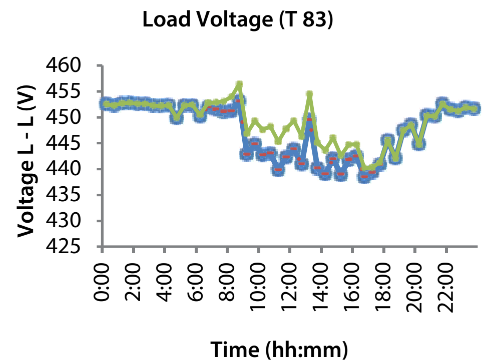


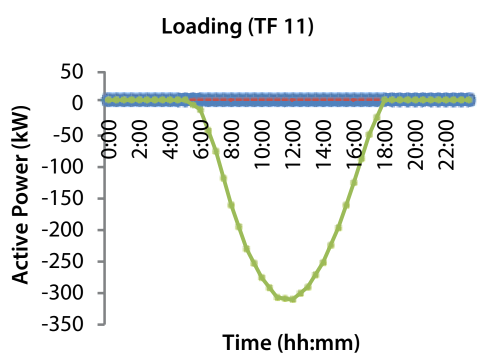


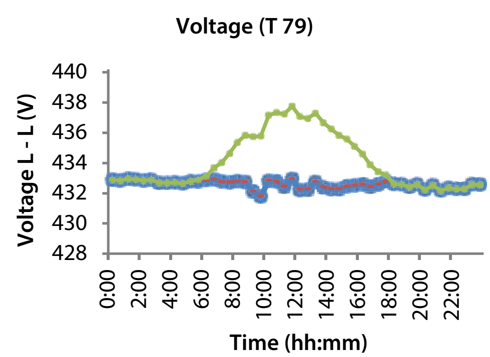

Loading (TF 08)
Active Power (kW)
60
40
20
0
-20
-40
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00
Time (hh:mm)

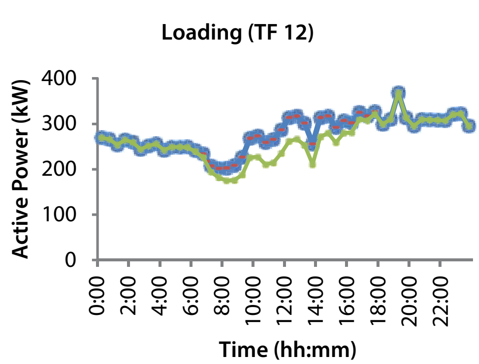

Voltage (T 82)
Voltage L - L (V)
460
455
450
445
440
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00
Time (hh:mm)

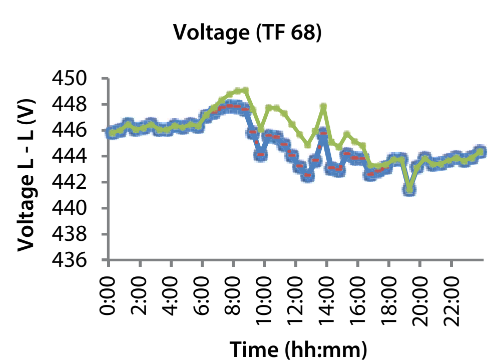

Loading (TF10)
Active Power (kW)
350
300
250
200
150
100
50
0
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00
Time (hh:mm)


Load Voltage (T 83)
Voltage L - L (V)
460
455
450
445
440
435
430
425
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00
Time (hh:mm)


Loading (TF 11)
Active Power (kW)
50
0
-50
-100
-150
-200
-250
-300
-350
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00
Time (hh:mm)


Voltage (T 79)
Voltage L - L (V)
440
438
436
434
432
430
428
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00
Time (hh:mm)


Loading (TF 12)
Active Power (kW)
400
300
200
100
0
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00
Time (hh:mm)


Voltage (TF 68)
Voltage L - L (V)
450
448
446
444
442
440
438
436
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00
Time (hh:mm)

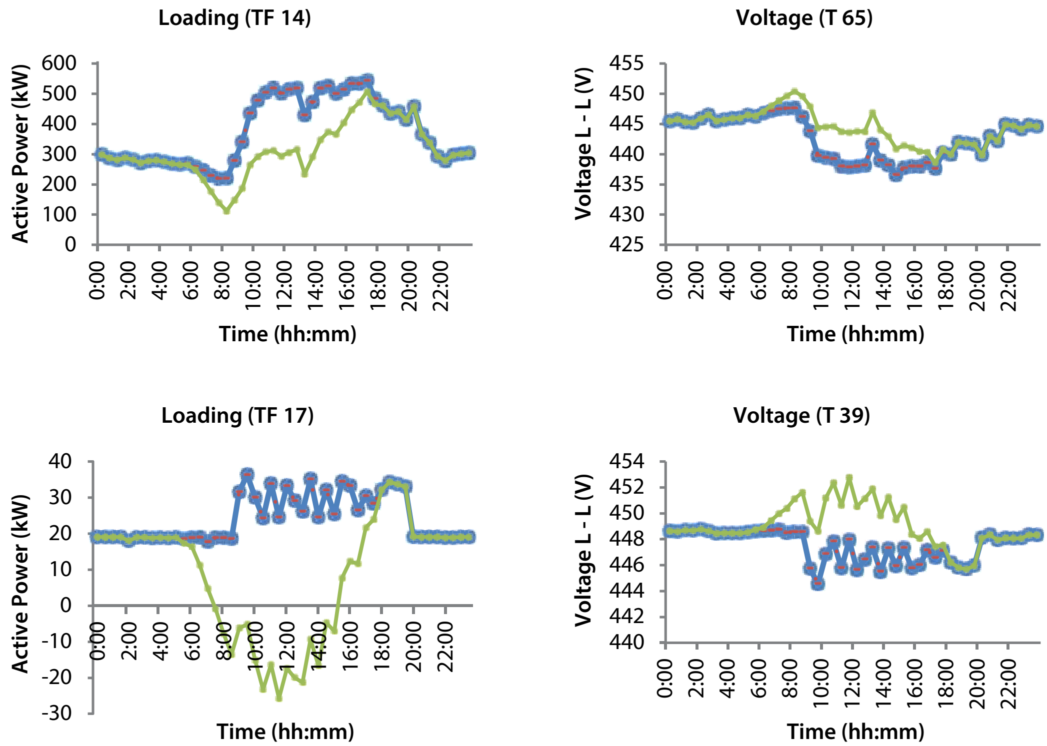


Figure D.4. Loading and voltage level of key transformers in Network-1 under 'photovoltaic and load maximum' scenario

Scenario: Load min

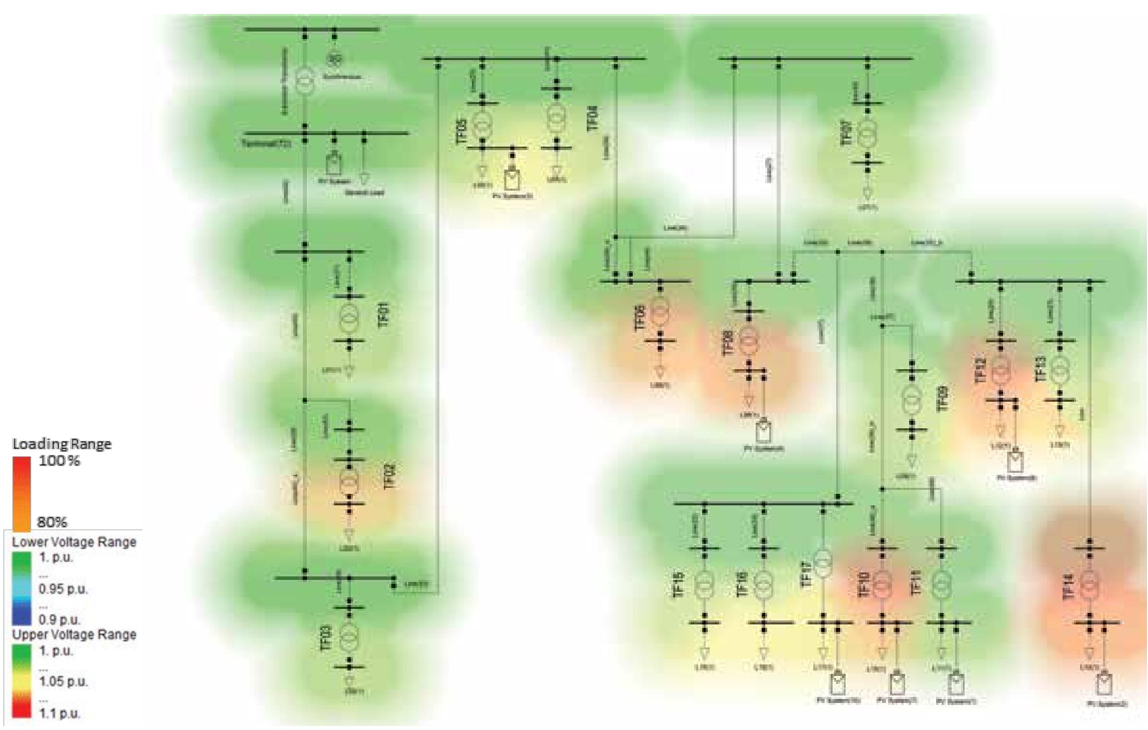
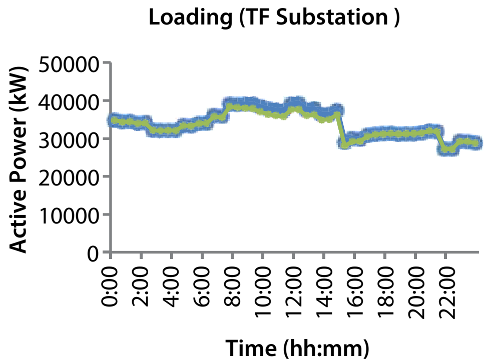
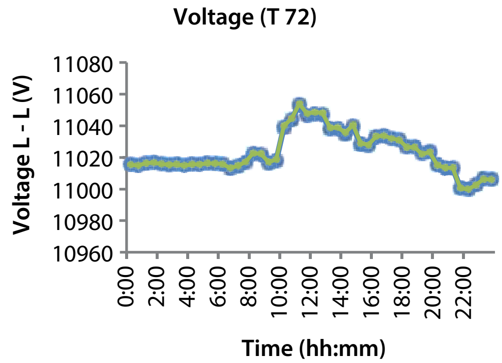
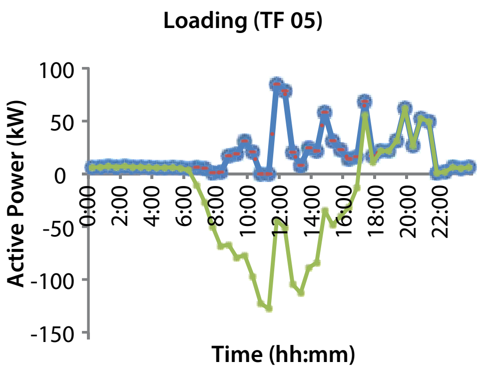
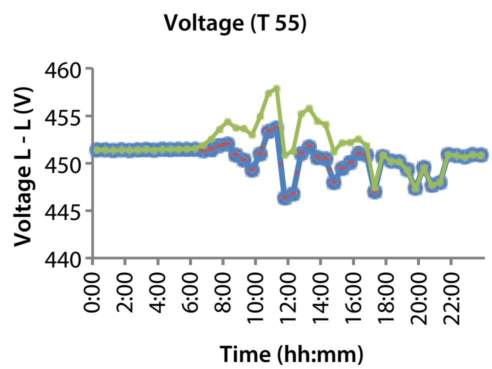


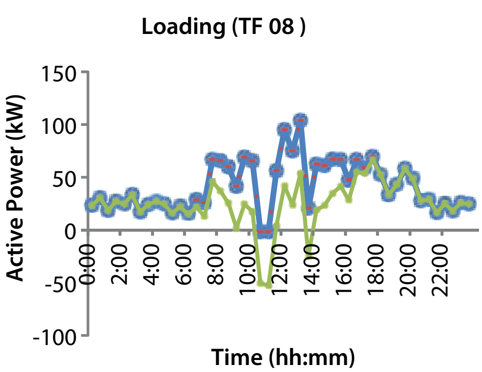
Figure D.5. Heat map of Network-1 with voltage and transformer-loading levels under 'load minimum' scenario

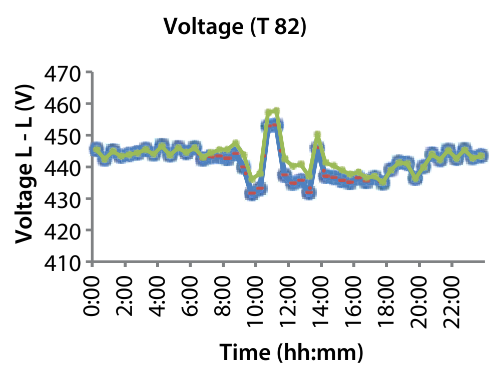

Loading (TF Substation)
Active Power (kW)
50000
40000
30000
20000
10000
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)

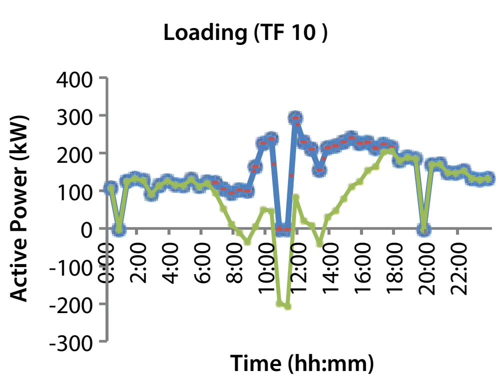

Voltage (T 72)
Voltage L - L (V)
11080
11060
11040
11020
11000
10980
10960
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)

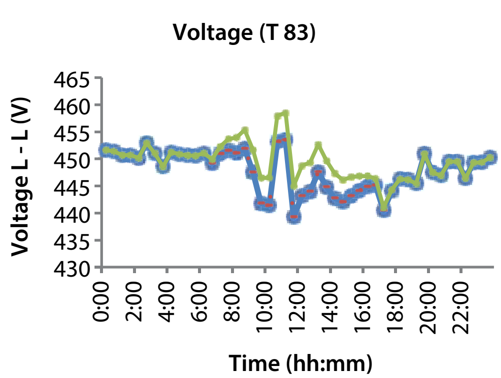

Loading (TF 05)
Active Power (kW)
100
50
0
-50
-100
-150
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)


Voltage (T 55)
Voltage L - L (V)
460
455
450
445
440
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)


Loading (TF 08)
Active Power (kW)
150
100
50
0
-50
-100
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)


Voltage (T 82)
Voltage L - L (V)
470
460
450
440
430
420
410
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)


Loading (TF 10)
Active Power (kW)
400
300
200
100
0
-100
-200
-300
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)


Voltage (T 83)
Voltage L - L (V)
465
460
455
450
445
440
435
430
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)

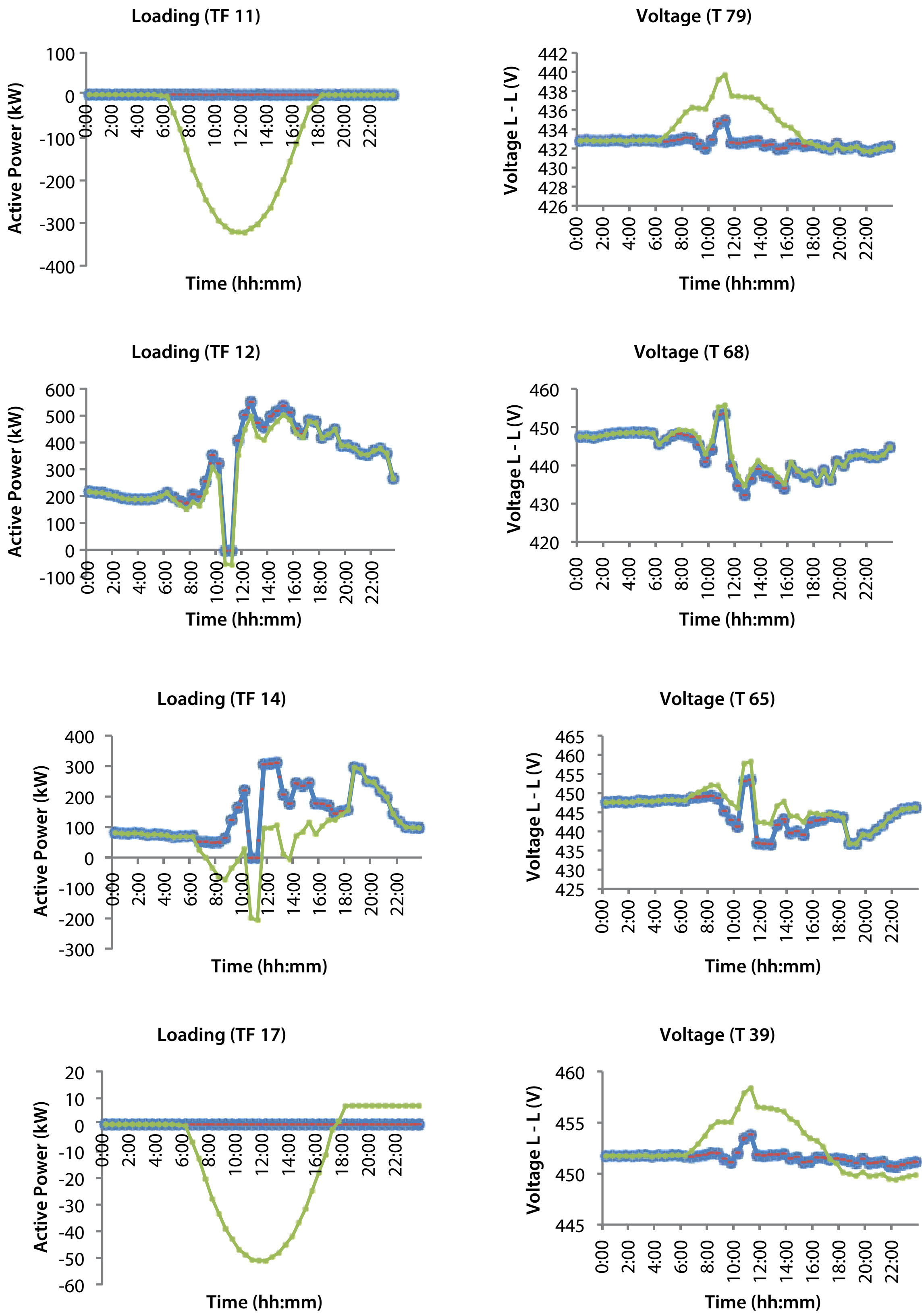


Figure D.6. Loading and voltage level of key transformers in Network-1 under 'load minimum' scenario

Scenario: Photovoltaic minimum

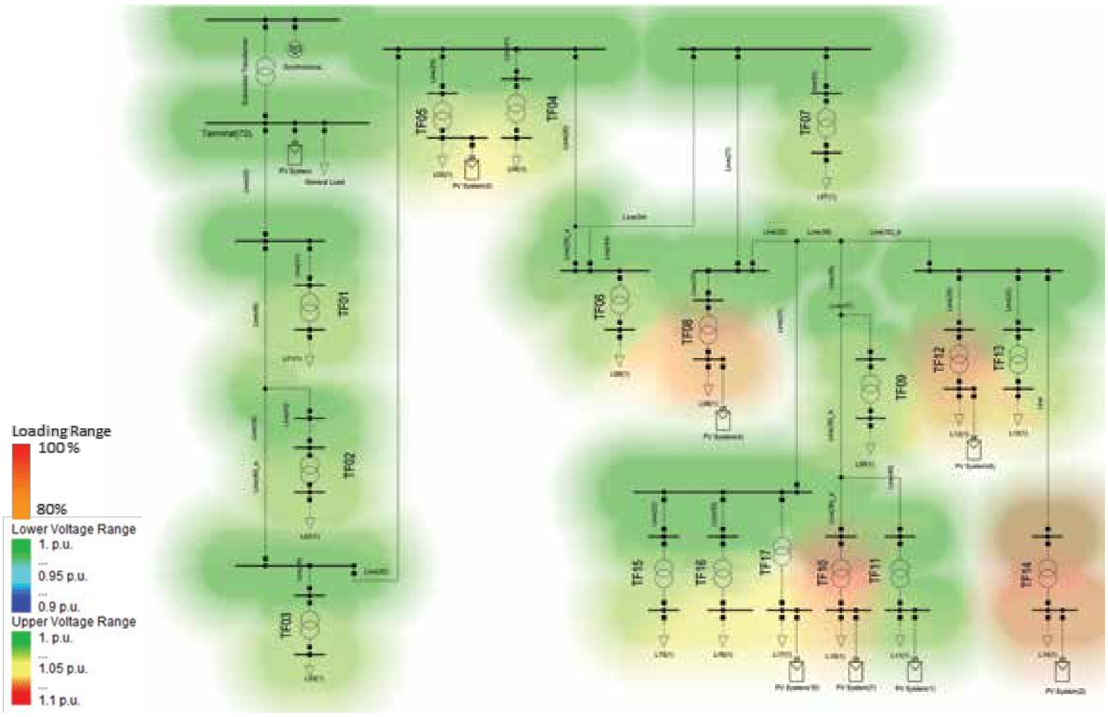
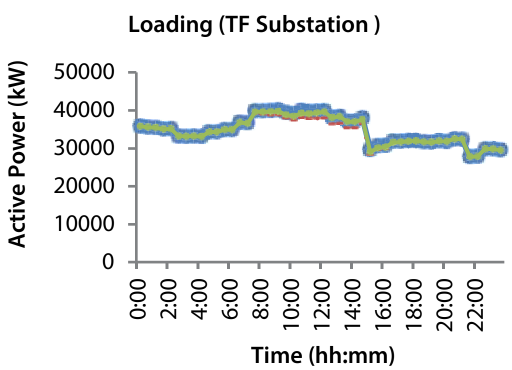
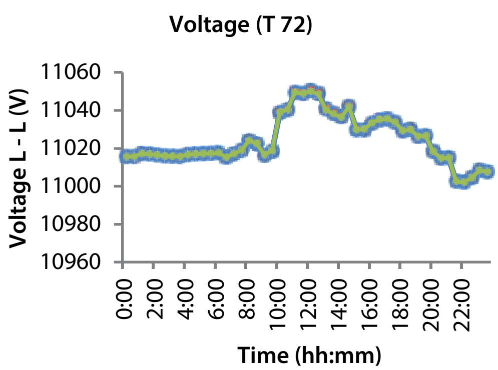
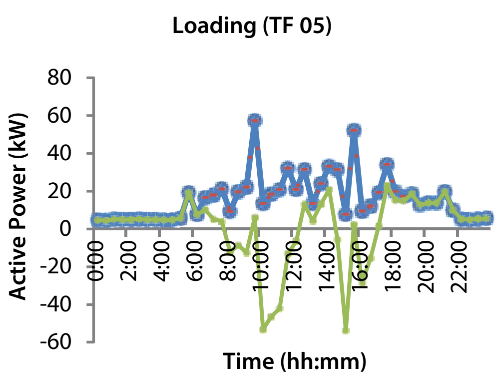
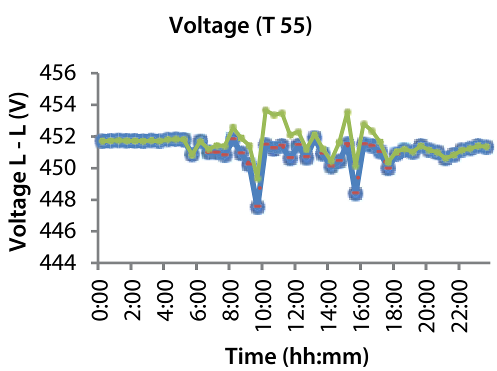


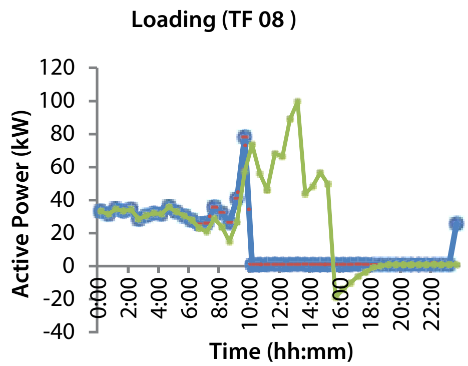
Figure D.7. Heat map of Network-1 with voltage and transformer-loading levels under 'photovoltaic minimum' scenario

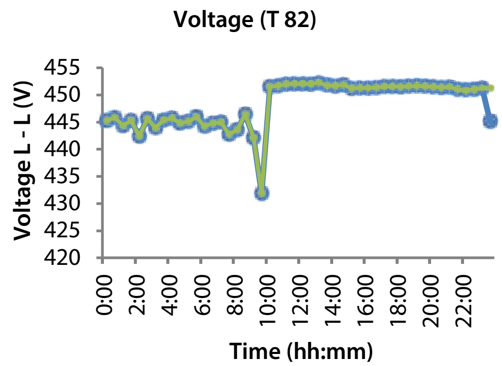


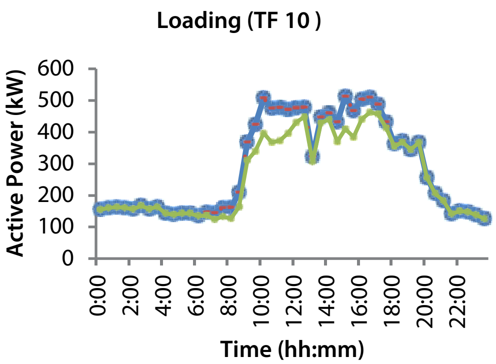


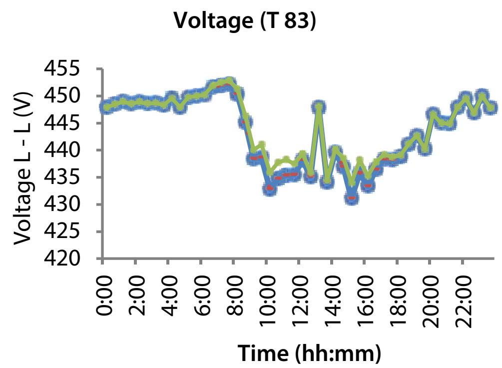


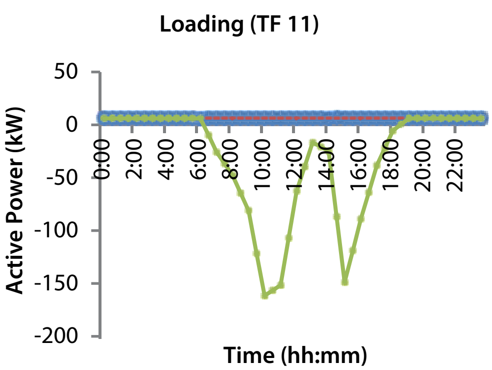


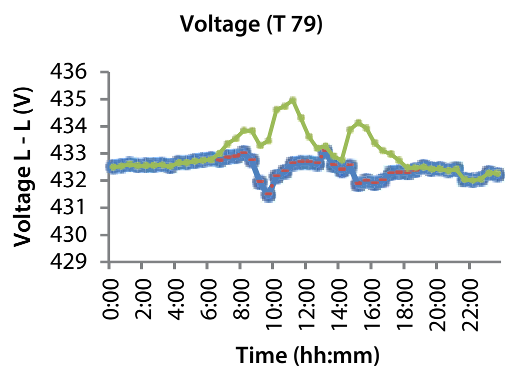

Loading (TF 08)
Active Power (kW)
120
100
80
60
40
20
0
-20
-40
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)

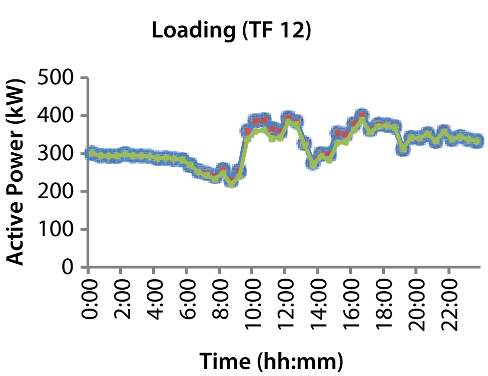

Voltage (T 82)
Voltage L - L (V)
455
450
445
440
435
430
425
420
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)

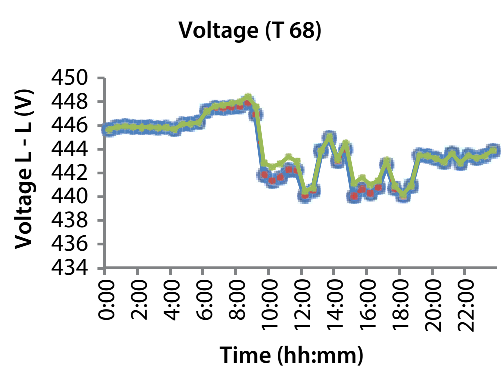

Loading (TF 10)
Active Power (kW)
600
500
400
300
200
100
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)


Voltage (T 83)
Voltage L - L (V)
455
450
445
440
435
430
425
420
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)


Loading (TF 11)
Active Power (kW)
50
0
-50
-100
-150
-200
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)


Voltage (T 79)
Voltage L - L (V)
436
435
434
433
432
431
430
429
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)


Loading (TF 12)
Active Power (kW)
500
400
300
200
100
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)


Voltage (T 68)
Voltage L - L (V)
450
448
446
444
442
440
438
436
434
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (hh:mm)

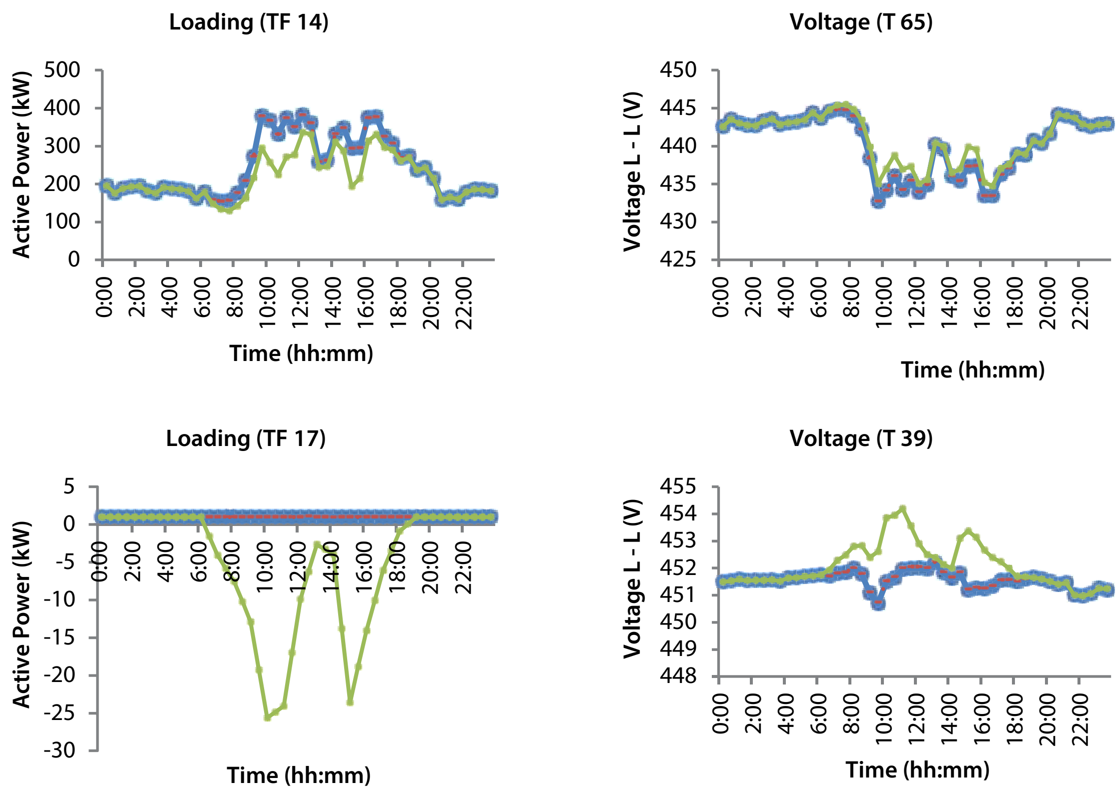


Figure D.8. Loading and voltage level of key distribution transformers in Network-1 under 'photovoltaic minimum' scenario

Distribution Losses

E.1 Amlipadar

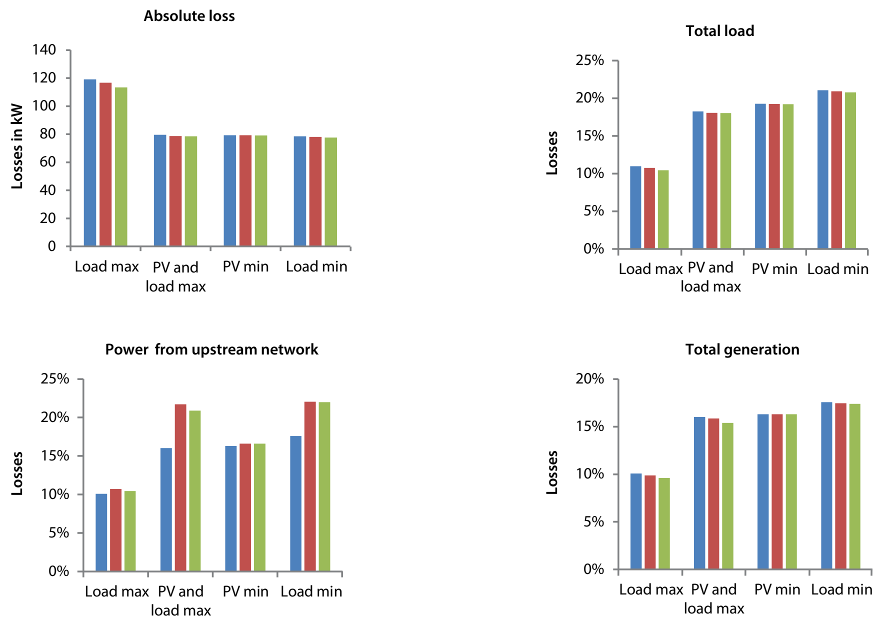


Figure E.1. Distribution losses in Amlipadar substation

E.2 Deobhog

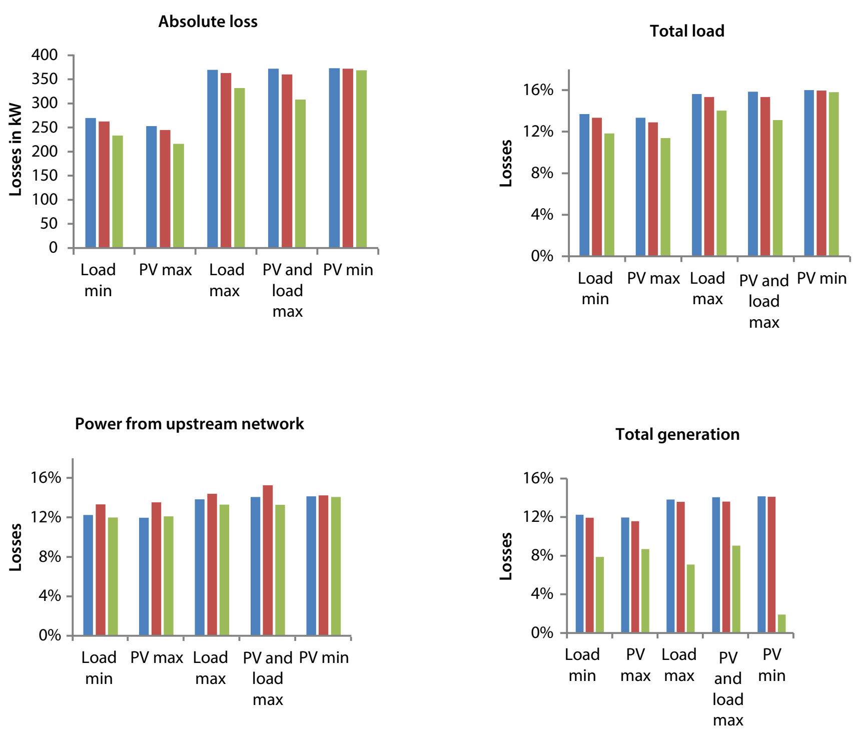


Figure E.2. Distribution losses in Deobhog substation

E.3 Jhakharpara

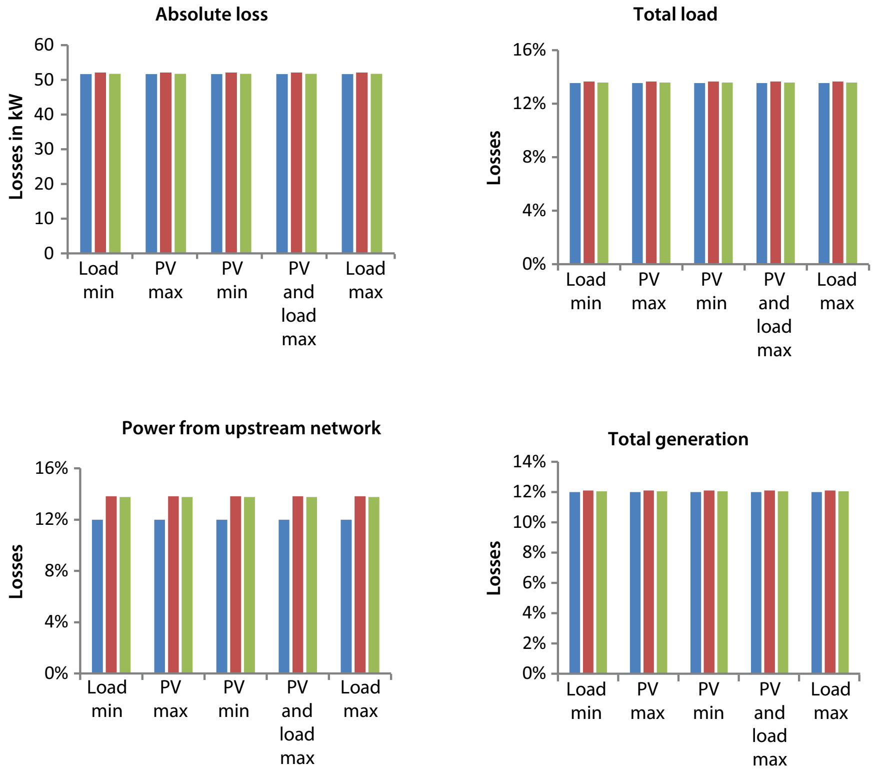


Figure E.3. Distribution losses in Jhakharpara substation

E.4 Gohrapadar

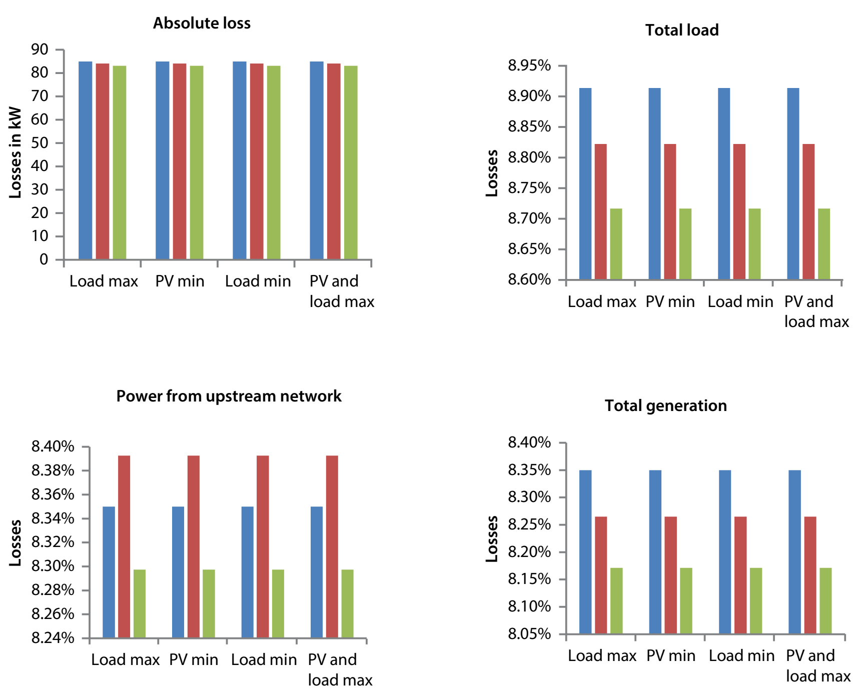


Figure E.4. Distribution losses in Gohrapadar substation

E.5 Network-1

Figure E.5. Distribution losses in Network-1 substation under 'photovoltaic and load maximum' scenario

Assumptions in Cost-benefit Analysis and Determination of Levelized Tariff

Table F.1. List of assumptions taken for cost-benefit analysis

S. No	Category		Description	Unit	Value
1	Power generation	Capacity	Deration, per annum after second year	%	0.50%
			Tariff period	Years	25
			Life of power plant	Years	25
2	Sources of funds	Debt:Equity	Debt	%	70%
			Equity	%	30%
		Funding options-1 (Domestic Loan Source-1)	Moratorium period	Years	0
			Repayment period (including moratorium)	Years	12
			Interest rate	%	12.76%
		Funding options-2 (Equity Finance)	Return on equity	% Per annum	16%
			Discount rate		10.78%
3	Financial assumptions	Depreciation	Depreciation rate (up to 12 years)	%	5.83%
			Depreciation rate (after 12 years)	%	1.54%
			Years for 5.83% SLM rate	Years	12.00
4	Working capital	For fixed charges	Operation and maintenance charges	Months	1.00
			Maintenance spares (% of O&M expense)		15%
			Receivables for debtors	Months	1.5
			Interest on working capital (%)		12.26%
5	Operation and maintenance expense Operation and maintenance expense escalation		Power plant	Rs lakh/ MW	7
			%	5.85%	

Table F.2. Determination of levelized tariff

Generation		Years -->																								
	Unit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Installed capacity	MW	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Net generation	lakh units	6.0	6.0	6.0	5.9	5.9	5.9	5.9	5.8	5.8	5.8	5.7	5.7	5.7	5.7	5.6	5.6	5.6	5.5	5.5	5.5	5.5	5.4	5.4	5.4	5.4
Fixed cost																										
	Unit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Operation and maintenance expense	Rs lakh	1.5	1.6	1.7	1.8	1.9	2.0	2.2	2.3	2.4	2.6	2.7	2.9	3.0	3.2	3.4	3.6	3.8	4.0	4.3	4.5	4.8	5.1	5.4	5.7	6.0
Depreciation	Rs lakh	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Interest on term loan	Rs lakh	13.1	12.0	10.8	9.7	8.6	7.4	6.3	5.1	4.0	2.9	1.7	0.6													
Interest on working capital	Rs lakh	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Return on equity	Rs lakh	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Total fixed cost	Rs lakh	31.5	30.4	29.3	28.3	27.2	26.2	25.2	24.1	23.1	22.1	21.1	20.1	13.0	13.2	13.4	13.6	13.8	14.1	14.3	14.6	14.9	15.1	15.5	15.8	16.1

Table F.2. Determination of levelized tariff

Levelized tariff corresponding to useful life																										
Per unit cost of generation	Unit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Operation and maintenance expense	Rs/kWh	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.1	1.1
Depreciation	Rs/kWh	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.6	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Interest on term loan	Rs/kWh	2.2	2.0	1.8	1.6	1.4	1.3	1.1	0.9	0.7	0.5	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Interest on working capital	Rs/kWh	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Return on equity	Rs/kWh	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4
Total cost of generation	Rs/kWh	5.2	5.1	4.9	4.8	4.6	4.4	4.3	4.1	4.0	3.8	3.7	3.5	2.3	2.3	2.4	2.4	2.5	2.5	2.6	2.7	2.7	2.8	2.9	2.9	3.0

Levelized tariff	4.11	Rs/unit

Stakeholder Consultations

Table A1: List of stakeholders

Organisation	Name	Designation	Contact
CSPDCL	Mr Shailendra Kumar Shukla	Chairman	0771-2574000
	Mr G. C. Mukharjee,	Director (Commercial and Regulatory)	0771-2576900 director.commercial@cspc.co.in
	Mr H. R. Narware	Director (Operation and Maintenance)	0771-2576800 hr.narware@cspc.co.in
BRPL	Mr Abhishek Ranjan	Head – Renewables and DSM, Power Planning and Scheduling and Energy Analytics	Abhishek.R.Ranjan@relianceada.com
	Mr Naveen Nagpal	General Manager (Renewables, BESS & Emobility)	naveen.nagpal@relianceada.com
	Ms Sugandhita Wadhera	Assistant Manager (Renewables)	Sugandhita.Wadhera@relianceada.com
	Mr Pankaj Kargeti	Manager	pankaj.kargeti@relianceada.com
SR Consultants	Ms Ritu S Jain	Director (SR Corporate Consultants Pvt Ltd)	8966002609/9109998039 srccl@srccl.in
	Mr Vipul Jain	Executive Assistant	8966002609/77 srccl@srccl.in
	Mr Ankur Shrivastava	Research Associate	7694967707 ankur11shri@gmail.com

Photos taken during interactions with CSPDCL officials

Photos taken during interactions with BRPL officials

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