Study on Urban Microgrids as an Enabler for Distribution Network

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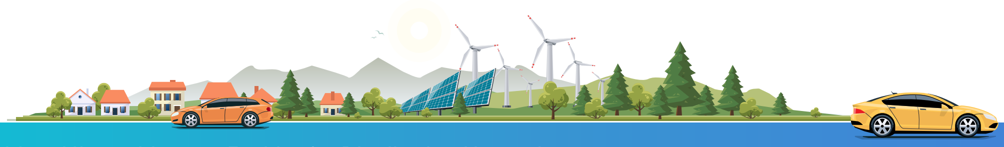


CONTENTS

EXECUTIVE SUMMARY

The renewable energy sources are the everlasting solution to the problems of depleting conventional energy sources, energy security, and increasing level of pollution in the environment though they alone cannot match the prevailing conventional sources available, such as coal, gas, among others. Renewable energy sources need to be coupled with balancing fleets including batteries and other forms of storage such as pumped hydro.

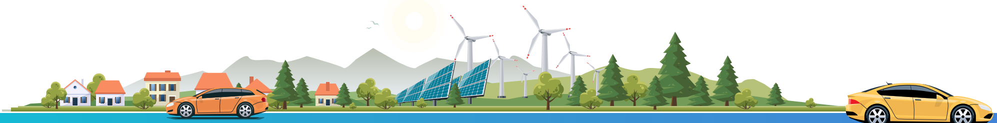
With the cost of generation from solar having fallen drastically, a similar trend is also seen in the prices of batteries. Further the fall in prices of battery could make renewables sustainable as renewable coupled with battery energy storage systems (BESS) have the ability to supply round the clock firm power. Other than providing firm power, renewable and storage can find multitude operational uses in power systems. One such application is microgrids, as it has got relevance in both urban and rural setup. In rural environment, microgrids can improve the accessibility of electricity and in urban setup, it can serve as a source of overload management.

In congested cities such as Kolkata and Delhi, this can be a beeline solution to defer distribution upgrades and right of way challenges. Moreover, the relevance of microgrids in cities such as Delhi is even more important due to dual peaks (afternoon and night) observed in loading pattern. The solar power could actually reduce the afternoon peak. Grid-connected urban microgrids can be utilized for several applications like improving the reliability and resilience, reducing the cost of electricity supplied, providing ancillary services and replacement of diesel gen-set operation. Besides this, microgrids can provide quality supply to localized sensitive loads (within the microgrids boundary) such as industrial drives, critical loads of hospital, and institutional laboratory's data centres as energy generated through microgrids can supply power with minimal harmonics. Moreover, microgrids is considered as a viable energy source for developing countries as it brings reliable power as it behaves as a localized power grid.

This study deals with the economic feasibility of urban microgrids in the licensee area of BRPL, New Delhi. Site selection and defining an operational use case were significant for the study. The rapid changes in ways of performing day-to-day activities and the kind of medical attention required (including putting people in isolation with oxygen supply) also impacted the power sector. The industrial and commercial load considerably decreased and domestic demand comparatively increased. The impact on distribution utilities also depends on the consumer mix, though the impact is more severe in cities such as Delhi, Mumbai owing to more number of Covid-19 cases reported here.

The Delhi government decided to use the Radha Soami Satsang Beas campus in south Delhi's Chhatarpur as the biggest Covid-19 temporary hospital in India with over 10,000 beds, roughly the size of 22 football fields, cooled by 18,000 tonne of air conditioners to combat the rapidly rising cases of the COVID-19 in the city. This was done within a month. This required lot of power distribution infrastructure in place and the load in a few days time increased to 100 times. The distribution equipment including three additional 11 kV feeders were set in place to supply the hospital. The economics of setting up urban microgrids at the site has been evaluated and the results show that it makes economic case to install microgrids to improve the utilization of distribution infrastructure laid down to supply temporary health facility.

BACKGROUND



Delhi, being one of the most populous urban cities in the country with high load density, has seen rapid growth in the per capita consumption of electricity in the last few decades. The per capita annual consumption of electricity stands at more than 1548 unit, which is higher than the national average of 1181 unit (FY 2018–19). The energy demand of the state has increased rapidly in the last decade which brought the total annual energy demand to 33,043 MUs (million units) in FY 2019–20 from 20,040 MUs in FY 2003–04, whereas the peak demand in the FY 2019–20 was 7409 MW. The electricity distribution in the city is managed by three privately owned distribution utilities: BSES Rajdhani Power Limited (BRPL), BSES Yamuna Power Limited (BYPL), and TATA Power Delhi Distribution Limited (TPDDL). Loadshedding has reduced considerably from a level of 4.9% to 0.055% which became possible after privatization of electricity distribution business in the state. In addition, the Power Department of Delhi Government intends to prepare islanding scheme to meet the essential and critical load in the case of grid collapse, and, consequently, Delhi will become the first state in the country to build such kind of resilient and reliable electricity distribution.

The current COVID-19 situation has largely disrupted the functioning and production processes of industrial and commercial segments. The impact of shutting down all non-essential industrial and commercial activities has adversely reflected in the electricity distribution business. Moreover, Delhi being the front runner in the reported COVID-19 cases has set many temporary shelter homes and health facilities. This required lot of power distribution infrastructure in place and the load in a few days' time increased to multiple times. The efforts put by Delhi's power distribution companies are commendable. One such distribution utility is BSES Rajdhani Power Limited (BRPL), which successfully contributed in setting up India's largest COVID-19 hospital – Radha Soami Covid hospital – with over 10,000 beds and 18,000 tonne of air conditioners.

BRPL, a major distribution utility in Delhi spread over 750 km^2 with customer density of 3100 per km^2, has been focussing towards feeding quality and un-interrupted power to the end consumers. The technical and commercial losses have been the major concern for utility in Delhi over a period of time, particularly before the privatization of electricity distribution infrastructure that took place in 2002. BRPL has been able to reduce the AT&C losses significantly from 63.1% in FY 2002 to 12.7% in FY 2017 by employing various technical as well as financial measures. However, the concerns for the utility in Delhi still exists in terms of network augmentation because the distribution network in the state is highly congested, and overloading of the distribution assets has been one of the main drivers for augmentation. Additionally, India has been pushing renewable energy quite aggressively which is evident from the ambitious target of attaining 175 GW of renewable energy-based installed capacity by 2022 that includes 100 GW from solar, 60 GW from wind, 10 GW from bio-mass, and 5 GW from small hydro. Out of the 100 GW targeted solar photovoltaic (PV) capacity, 60 GW is appointed for ground-mounted solar PV while 40 GW has been allocated for rooftop segment alone. The Government of NCT of Delhi has remained committed to declared national renewable energy targets and came up with its own state solar policy known as the 'Delhi Solar Energy Policy, 2016'. The policy assigns solar generation targets of 1 GW by 2020 (4.2% of energy consumed) and 2 GW by 2025 (6.6% of energy consumed), in line with the national target of 40 GW. With the given target of grid-connected rooftop PV, the power distribution operations may become challenging as high solar PV penetration at any particular part of distribution grid can cause various technical issues such as voltage and frequency rise, reverse power flow, and protection challenges in that segment of the network. Moreover, Delhi generally observes two peaks in a day, one during afternoon due to air conditioning loads and the second peak during the night. Since, the afternoon peak is observed to be lower than the evening peak, thus the localized solar generation coupled with BESS can contribute significantly in reducing the afternoon peak and some part of the evening peak (depending on the size of the battery). The controllable and balancing distributed power sources such as microgrids (coupled with BESS) in place are capable of balancing some proportion of localized solar generation for the benefit of power distribution utility.

Also, appropriate designing of the microgrids components and its control scheme could ease the issue of voltage and frequency fluctuations that occur due to supply and demand gap, and, to some extent, it could also provide power back-up to some critical consumers such as health facilities and have an indirect impact on the overall network operations as well.

The 'bad quality' or 'unavailable grid' supply has been the major driver of Indian microgrids markets. The last mile connectivity, complete household electrification supported by introduction of Saubhagya household electrification scheme, has shifted the spotlight on microgrids. Consequently, the Ministry of New and Renewable Energy of the Government of India took cognizance of the importance of microgrids and minigrids in achieving the objective of '24X7 power to all' with the proposed development of 10,000 renewable microgrids and minigrids with a generative capacity of 500 MW. However, the situation has changed dramatically now; India is currently going through unprecedented urbanization. Also, on the power generation front, India has become a power surplus country. The cost of solar-based generation has fallen drastically in the last decade followed by falling cost of battery storage technologies. Urban microgrids can make a big contribution to the decentralization and de-carbonization of India's power system. Delhi has been one of the few proactive states to acknowledge the scope of urban microgrids in better power management and its role in power distribution planning exercise.

Microgrids has changed the concept from how power is being supplied to how the power can be best utilized. Specifically, in urban setups where upgradation of distribution network is a tedious task and increases the grid discipline and rising obligations on DISCOMs, microgrids could find economically feasible operational use cases. In addition, microgrids are complex energy systems involving combination of various distributed energy resources, energy storage devices, planning, operation and control, and power flow management. The core component of the microgrids system is the distributed controllers which perform the control action for optimal operation of the system under different modes, such as grid-connected and islanded modes based on the pre-defined objective and monitoring of key electrical parameters. On the other hand, rural microgrids operating in islanded mode is generally beneficial for remote location where electricity access is not available round the clock or available only for a few hours. The urban microgrids can support utility in various ways by providing services even during grid-connected mode. Grid-connected urban microgrids can be utilized for several applications such as improving the reliability and resilience reducing the cost of electricity supplied, providing ancillary services, and replacing diesel gen-set operation. Increasing the reliability and resilience can include supplying power to critical loads, such as health facilities, military bases, institutional campuses, and industrial facilities along with some consumers who need un-interrupted power to their common loads (lifts, water pump, street light). Besides this, microgrids can provide quality supply to localized sensitive loads (within the microgrids boundary) such as industrial drives, critical loads of hospital, and institutional laboratory's data centres as energy generated through microgrids can be set to supply power with minimal harmonics.

Moreover, microgrids is considered to be a viable energy source for developing countries as it behaves as a localized power grid. India, in particular, started exploring this technology ever since the massive blackout in 2012 in the northern part of the country.

The broad-level applications of microgrids could be summarized as follows:

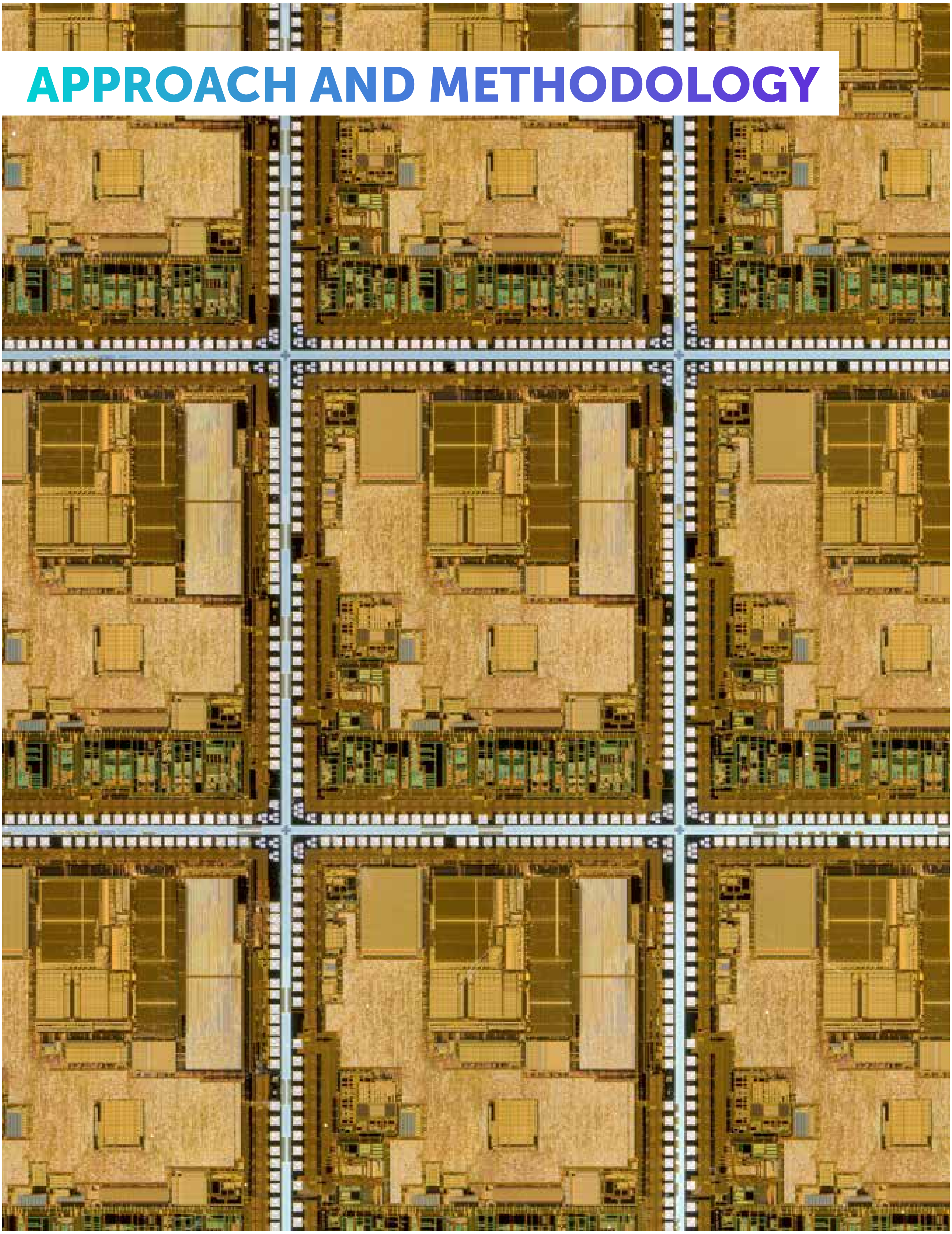
- Renewable energy integration: With solar PV-battery microgrids, the DISCOMs can efficiently integrate more renewable energy in their services areas to meet their renewable purchase obligation (RPO) targets and reduce the dependence on conventional plants.
- Deferred network upgradation: Land is a massive constraint in congested cities such as Delhi deterring the DISCOMs from upgrading the existing network to cater to the rising consumer demand in a particular area. Empowering consumers in such regions with microgrids will serve two purposes. First,

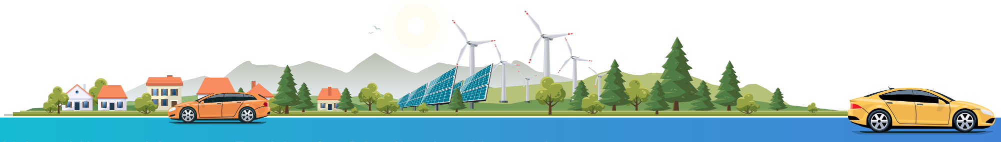
the grid dependence of these consumers would decrease due to improved utilization of solar electricity. Second, the stored electricity (surplus solar generation or off-peak grid electricity) can be utilized by DISCOMs at peak hours (energy arbitrage). As a result, the DISCOMs can accommodate peak demand without straining the network and construction of new components, thereby minimizing their expenses and improving resource utilization.

- Efficient demand-side management: The energy arbitrage offered by the microgrids can help DISCOMs in peak reduction and load levelling. DISCOMs put in significant efforts to maintain a uniform load curve to ensure reliable power supply. However, due to various reasons, such as consumer base or population density, the local demand could be considerably different from the overall load curve of DISCOMs. In such cases, battery integrated microgrids can support DISCOMs in load levelling by allowing flexible export of the stored electricity to the grid to meet the local or overall peak demand. Such flexible demand response would reduce the local peak and levelize the DISCOM demand.
- Savings under deviation settlement mechanism (DSM): A day-ahead demand forecast by DISCOMs is crucial for the smooth functioning of the electricity grid. The actual demand, however, could be influenced by many factors which are hard to anticipate in advance. To bring efficiencies in the process, the Central Electricity Regulatory Commission (CERC) has introduced DSM guidelines (Central Electricity Regulatory Commission 2019). Under this, the DISCOMs have to pay hefty penalties for any change in the scheduled despatch of electricity. In the event of unexpected demand, microgrids can supply the necessary support and help DISCOMs avoid loadshedding and penalties.
- Power backup during outages: The electricity network is interconnected. Any local disruption or imbalance can spread to broader areas affecting services. As microgrids can operate autonomously from the grid (islanding), they ensure safety and a continuous supply of electricity services to the connected consumers in the case of an outage in the main network.
- Miscellaneous benefits: In addition to the above-mentioned benefits, these urban microgrids can have a more profound impact on the DISCOM operations. First, the transmission and distribution losses would come down. Second, the availability of a firm renewable energy capacity would reduce their generation capacity procurement under the power purchase agreements (PPAs) and, in turn, the fixed charges. Lastly, they could also cut the power procured from the contracted capacity to reduce the variable cost.

Urban microgrids is an attractive value proposition to the consumers as well, as it can gain substantially from these systems in terms of reduced tariff and increased reliability of power supply.

APPROACH AND METHODOLOGY





In order to identify most feasible applications of the microgrids in an urban setup, various dimensions need to be considered including space availability, technical constraints, and existing operational issues. One of the important considerations has been the identification of the site for the feasibility assessment , and, in this regard, a few sites were shortlisted initially after discussing with BRPL, the distribution utility. Further, after various rounds of interaction with BRPL the most suitable site was selected based primarily on parameters such as space availability for solar PV deployment, consumer's type in the region, network operational challenges, and distributed energy resources already installed in that particular region. Defining the boundary of the urban microgrids was also essential, and, in this view, the suitable inter-connection point was identified alongside defining the region within which monitoring of the key grid parameters will be performed. Subsequently, the required data sets to perform the feasibility assessment was collected from utility, which included loading of the distribution transformers (DTs), feeders, and sub-station along with time-series generation of solar PV plant (it was already installed and operational in the region). Further, the sizing of the major components (solar PV and BESS) of microgrids system was estimated in such a way that the optimum balance between capital investment and benefit that will be earned from the system operation is obtained and no power is supplied back to the 66 kV grid. All the power generated is consumed locally within the 11 kV-power distribution network. The study was carried out in a sequential manner, as is shown in Figure 1.

Figure 1: Sub-divisions of the study

2.1 Site Selection

Site selection and defining an operational use case were significant for the study. The rapid changes in ways of performing day-to-day activities and the kind of medical attention required due to current pandemic situation (COVID-19) also impacted the power system operation. The industrial and commercial load considerably decreased and the domestic demand comparatively increased. The impact on distribution utilities also depend on the consumer mix. Moreover, the impact is more severe in the cities of Delhi and Mumbai due to more number of COVID-19 cases reported there.

The Delhi Government decided to use the campus of Radha Soami Satsang Beas in south Delhi's Chhatarpur to make the biggest COVID-19 temporary hospital in India with over 10,000 beds, roughly the size of 22 football fields, cooled by 18,000 tonne of air conditioners to combat the rapidly rising cases of COVID-19 in the city. Consequently, the distribution infrastructure was set up in 15–20 days, which required a lot of network re-configuration. Moreover, the load in a few days increased up to 100 times due to temporary health facilities that were set up at the site. The distribution equipment including three additional 11 kV feeders were put in place to supply the hospital. Once the situation normalizes, the electrical infrastructure set up to make temporary medical facility will become redundant. The feeders can be visualized from Figure 2. Additional three feeders were installed along with the feeder highlighted.

TERI, under facilitation support from BRPL, the distribution utility responsible for making such cumbersome arrangements in such a quick time, performed a broad-level analysis to assess the prefeasibility of an urban micro-grid. The basic reasons for selecting Radha Soami Satsang Beas are summarized in Figure 3.

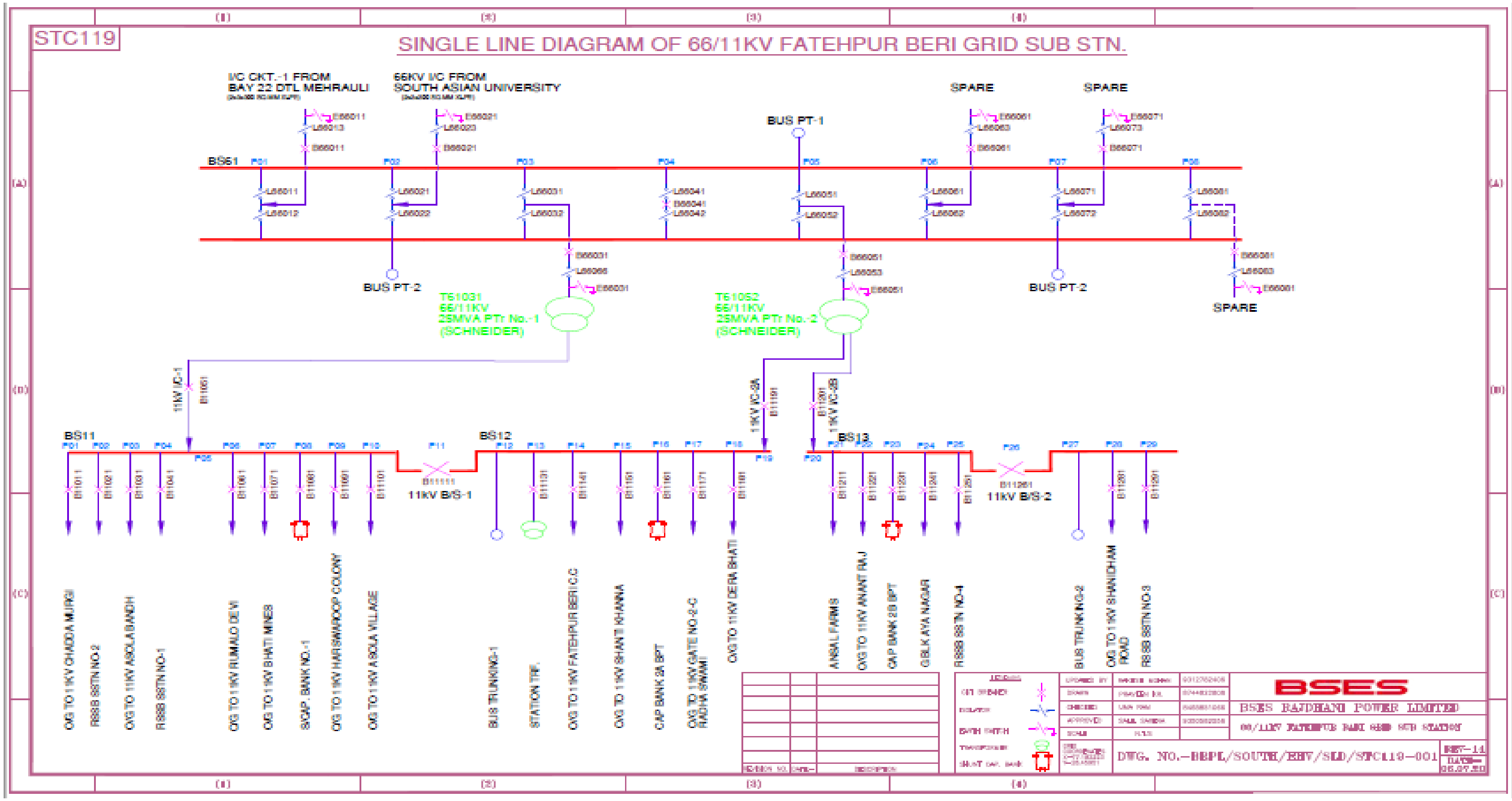
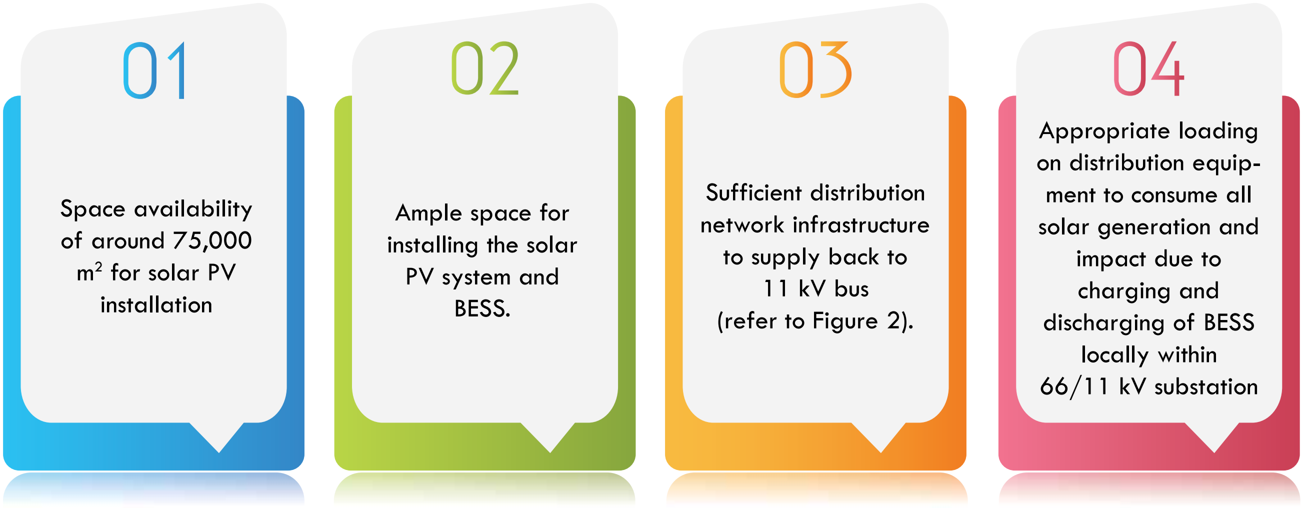


Figure 2: Single line diagram of 66/11 kV Fatehpur Beri grid sub-station



01

Space availability of around 75,000 m^2 for solar PV installation

02

Ample space for installing the solar PV system and BESS.

03

Sufficient distribution network infrastructure to supply back to 11 kV bus (refer to Figure 2).

04

Appropriate loading on distribution equipment to consume all solar generation and impact due to charging and discharging of BESS locally within 66/11 kV substation

Figure 3: Site selection rational

2.2 Data Collection

The following data sets were collected from the BRPL in order to carry out feasibility assessment and design the appropriate control scheme for identified application:

- Distribution transformer time-series loading (of 7 DTs placed in the region as indicated in Figure 4) were obtained from DT meters installed at secondary terminal of transformer (having 3-F, 4-wire, 415 V L-L connection) which recorded parameters at an interval of 30 minute for FY 2018–20.
- Time-series energy import/export data was collected from BRPL which was obtained from the meter installed at High Tension (HT)/11 kV line as shown in single line diagram in Figure 4 (SLD). This particular bi-directional energy meter records the electricity consumption/excess generation of PV plant (if any) of the consumers who have opted for HT connection. The data was recorded at an interval of 30 minute from August, 2019 to June, 2020.
- The time-series loading of 11 kV feeder emanates from nearby sub-station to feed supply to the consumers who are connected to this network, as indicated in the form of SLD as shown in Figure 4. The HT meters at 11 kV feeders are usually installed by the utility to record the network parameters such as power flow, voltage, and current on each phase. The data received from BRPL for this feeder had recording interval of 15 minute for a period of 2 years (July, 2018–July, 2020).
- Solar PV plant (of capacity 200 kW) generation data from July, 19 to July, 20 at interval of 30 minute.
- Time-series loading of two 66/11 kV power transformers which have power rating of 25 MVA each. The values were recorded at an interval of 15 minutes and the data was obtained for some months to capture seasonality for FY 2019–20.
- SLDs were collected for sub-station and one of the 11 kV feeders wherein microgrids inter-connection is being proposed.
- Despatch schedule for FY 2019–20 was collected for selected days for each month considering seasonality and days of maximum and minimum demand.
- Variable cost of electricity of all generating plants was also collected to understand the peak and off-peak prices for each month.
- Time-series loading data of BRPL for the last five financial years at 15-minute interval.

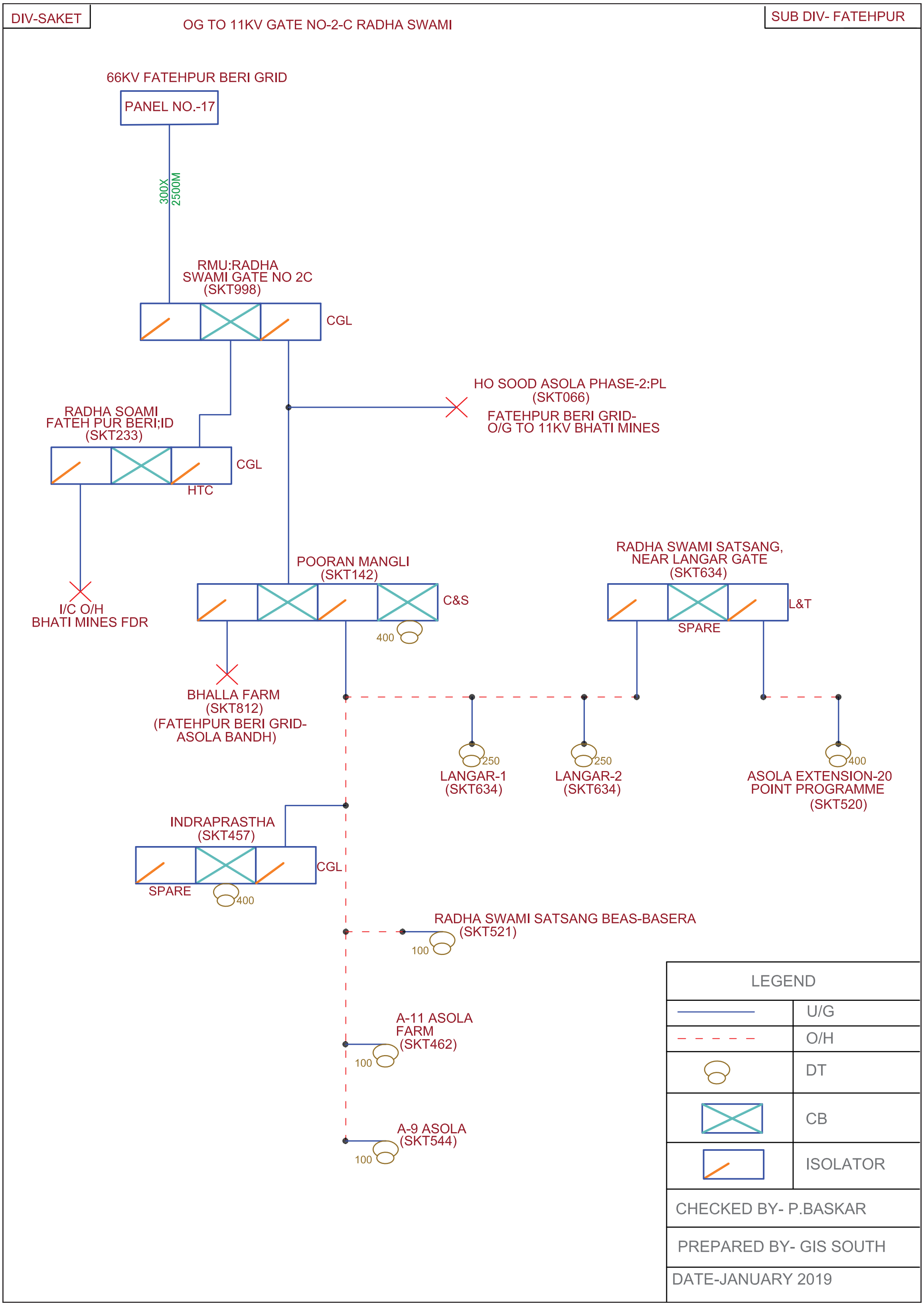
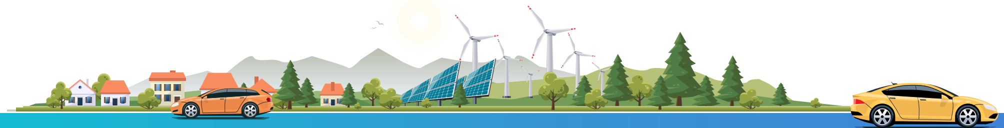


Figure 4: SLD of 11 kV Radha Soami feeder



2.3. Load Research and Identification of Application

The loading of a particular 11 kV feeder and two power transformers (25 MVA each) were assessed in order to analyse the peak loading and average demand on the respective feeder and substation. It was found from the analysis that the loading on sub-station and a selected 11 kV feeder (wherein microgrids integration is proposed) are approximately in the range of 50 to 60% of the rated capacity. The loadings of 66/11 kV sub-station and a particular 11 kV Radha Soami feeder for a selected day under different months are depicted in Figures 6 and 7, respectively.

In addition, the system-level loading of BRPL for the last 5 years (FY 2015–2020) was also assessed in order to find out an optimal way to operate the microgrids so as to provide maximum benefit to the end consumer in terms of tariff reduction or enhancing reliability and quality of power supply. Accordingly, the annualized load curve and peak demand were estimated at an interval of 15 minutes for 5 years (from 2015 to 2020), as depicted in Figures 8 and 9. Furthermore, to understand the distribution of peak demand and the corresponding durations for FY 2019–2020 were analysed along with monthly average loading patterns (refer to Table 1). The purpose of monthly average loading assessment was to examine energy arbitrage opportunity through controlled operation of microgrids.

Table 1: Annualized load curve assessment for FY 2019–20

Range of Load				
MW	MW	Cumilative instances	Duration (h)	% of Time
0	500	0		-
501	1,000	5,494	1,374	15.64%
1,001	1,500	16,587	2,773	31.57%
1,501	2,000	26,464	2,469	28.11%
2,001	2,500	33,134	1,668	18.98%
2,501	3,000	35,086	488	5.56%
3,001	3,501	35,136	13	0.14%

The power purchase portfolio and despatch schedule of utility were analysed, and substantial difference in cost of electricity was found between off-peak and peak durations. The same can be referred to from Figure 5. On average, there exists an energy arbitrage opportunity of INR 3.097 on each unit (excluding roundtrip efficiency losses of BESS).

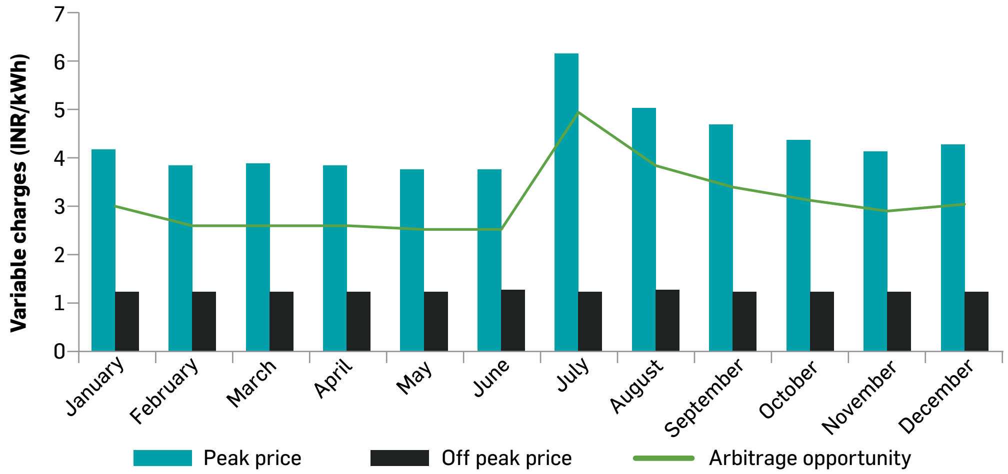


Figure 5: Month-wise utility's power purchase cost

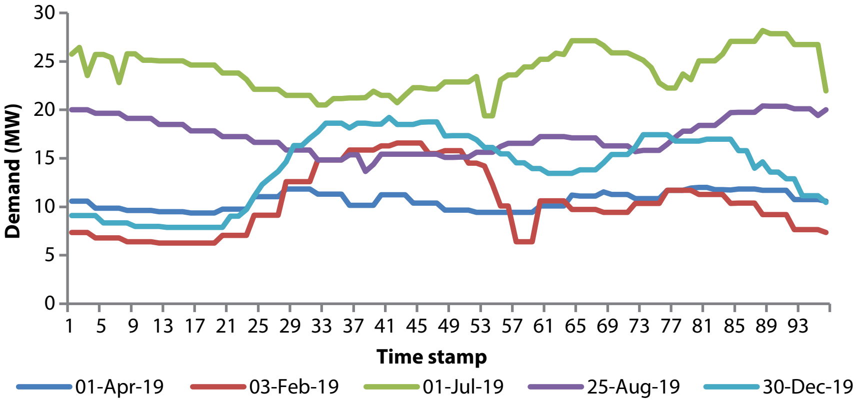


Figure 6: Load variation at sub-station level with time

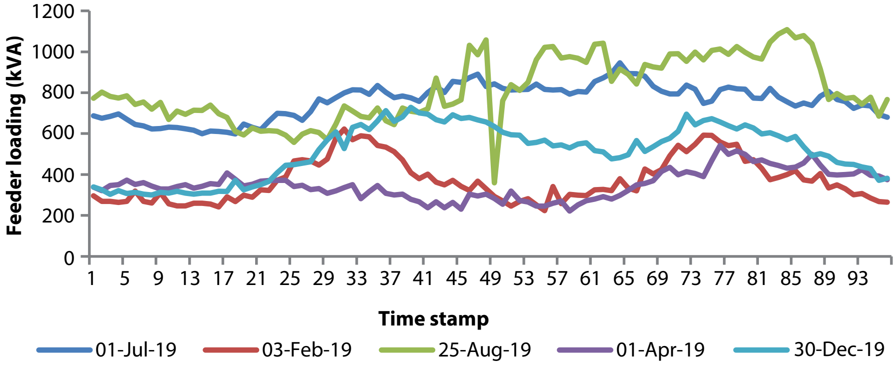


Figure 7: Load variation of 11 kV Radha Soami feeder with time

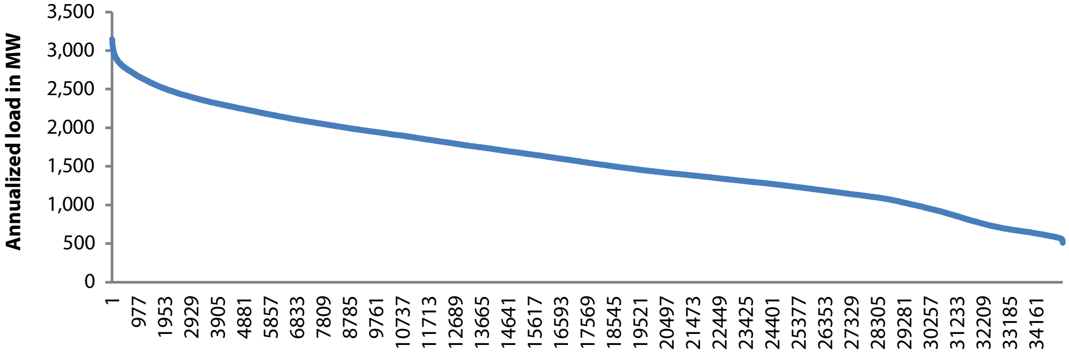


Figure 8: Annualized load curve for FY 2019-20

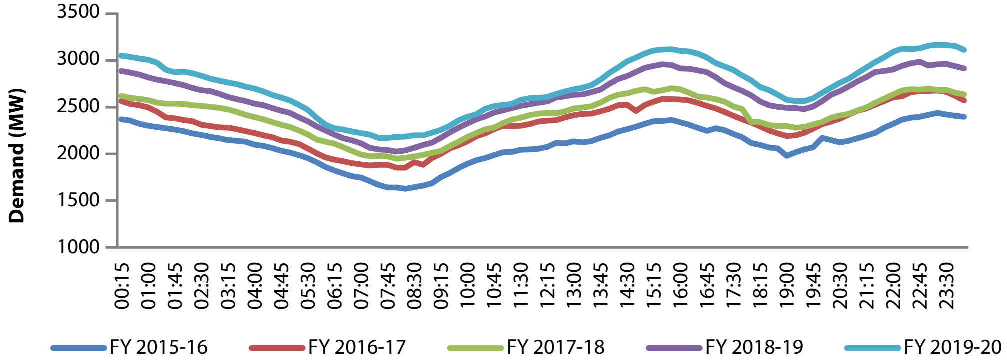


Figure 9: Year-wise utility's annual peak demand

2.4. RE-generation Estimation

The Radha Soami society, where the microgrids installation is proposed, has already installed 200 kWp rooftop PV plant, which is functional since 2019. Further, 8 MW of solar PV potential was found in the society as per the initial survey conducted by BRPL as it has lot of empty space for ground-mounted deployment. Subsequently, the potential was assessed using Helioscope (as shown in Figure 10), and the results were validated with earlier estimation that was done by BRPL. In order to estimate the time-series generation of solar PV (estimated capacity) in the premises of aforesaid society, the hourly generation of installed plant was retrieved. In addition, the yearly energy generation pattern is obtained as an outcome of simulation study that was carried out in the Helioscope. The available space for PV deployment alongside snapshot of single line diagram (SLD) of plant is shown in Figures 10 and 11. The monthly average production of 8 MW plant (for one year) is also indicated in Figure 11, and it can be seen that energy generation can reach up to 40,000 kWh in the month of April. The annual energy generation from the PV plant is estimated to be 12.26 GWh with performance ratio of 80.6%. The detail outcomes of the simulation study are illustrated in Annexure 1.

Figure 10: Site map and detailed layout obtained from Helioscope

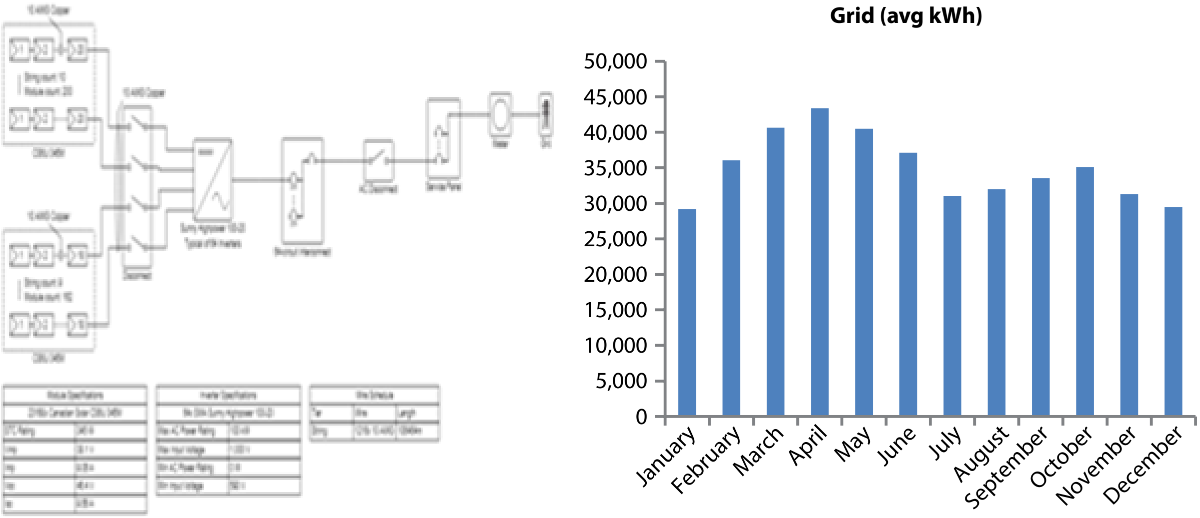


Figure 11: SLD for inter-connection of PV plants with grid and monthly average energy generation

2.5. Application and Plausible Revenue Streams of the Microgrids System

The applications and revenue streams discussed in this section are as shown in Figure 12.

Applications	Revenue Streams
• Power back-ups to some critical consumers on the Radha Soami, II kV feeder • Energy arbitrage	• Savings in peak power purchase by charging during off-peak periods and discharging during peak periods • Meeting RPO targets • Energy arbitrage by charging during off-peak periods and discharging during peak periods and discharging during peak periods of BRPL • Savings in terms of T&D losses • Revenue savings in terms of avoided unplanned outages

Figure 12: Mapping of applications and revenue streams

Energy arbitrage: After carrying out the preliminary analysis, it was decided that the microgrids be operated for tapping energy arbitrage opportunity to reduce the power purchase cost by offsetting the variable charges of most expensive plants of the season. The month-wise mapping of expensive and least cost-generating plants in terms of variable cost of energy can be referred to from Figure 13.

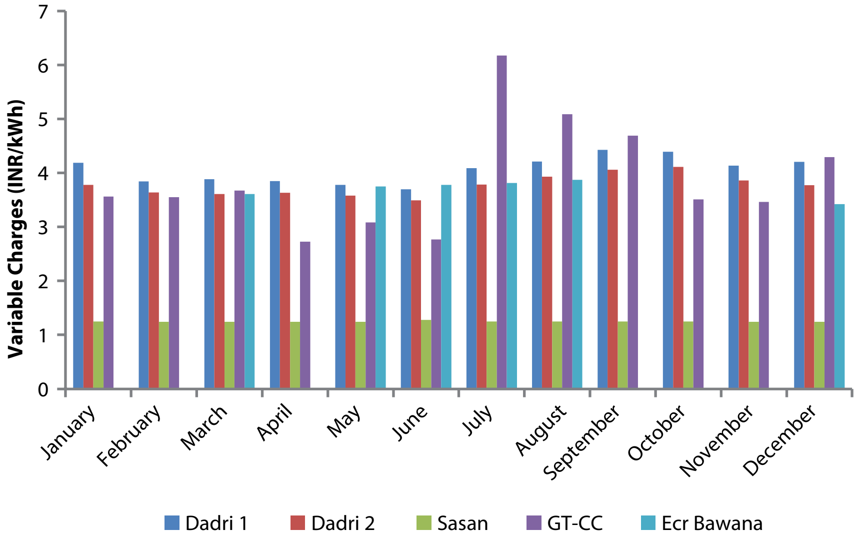


Figure 13: Month-wise variable energy charges of different generating plants

The least cost plant in operation has been Sasan and Dadri-I and GT-CC are among the expensive plants of all the seasons. The energy arbitrage is calculated based on offsetting the most expensive power plant and taking more power from the cheapest power plant. The technical minimum of generating power plants is not impacted due to BESS operations as the size of the battery (4 MWh) is significantly less in comparison to other contracted capacity from these generating power plants. Though, this was tested for some days in a year but not for all days in a year. The brief simulation exercise is recommended to validate the same.

Power back-up: The power outages in the selected 11 kV feeder due to unforeseen events (such as frequent tripping, load shedding) were reported to be 25 hours in 2019 with 2 hours of maximum continuous outage, whereas the planned outages were observed for 4 hours (in total) in the same year. It is, therefore, decided to supply power to selected portion of the 11 kV feeder through urban microgrids, thereby providing back up for 2–5 hours depending upon the demand on the respective feeder. The average loading of critical consumers (identified to receive uninterrupted power supply) on the feeder was 200 kW. Avoided loss in revenue was calculated based on the difference of the billing rate of critical consumers to the average cost of supply (ACOS) for BRPL.

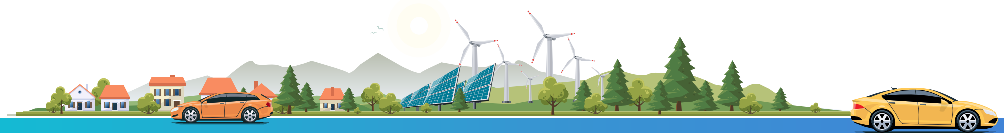
Other revenue streams: BRPL was unable to completely meet its RPO targets and thus had to pay hefty penalties. Assuming INR 1 per unit of Renewable Energy Certificate (REC) purchase cost to BRPL, if RPO targets are not met, benefits were estimated for the size of 8 MW solar microgrids coupled with 4 MWh of BESS.

- Following a thumb rule that for consumption of 100 units of electricity, In general a distribution utility actually buys 120 units of it from generators due to transmission and distribution losses, benefits from localized consumption of locally generated solar power were estimated.
- Black start in power distribution system basically means restoring a generating unit with its auxiliaries present at distribution downstream which is supplied by DG set or battery and extending the power supply to loads after dead bus charging and energizing a distribution line to seek loads. This is the first step in system restoration post a partial or total black out in any part of an electrical power grid. In view of the growing complexity in power systems with addition of new renewable energy generation, the need for a well-tested plan for system restoration has gained currency across system operators round the globe. Going forward, with gradual development of a mature power market in India the black start facility of existing and upcoming generating stations can be commoditized and possibly traded as an ancillary service to the power system users for which each black start capable generator would be required to get its black start capability validated and certified on a regular basis. In such a scenario, microgrids can provide ancillary services to support black start, if the network or customer grid goes down, energy storage can stand at the ready to start critical generators. Micrgrid equipped with solar PV and BESS can provide black start support to the regional electricity grid by supplying active/reactive power to the network in order to maintain the voltage and frequency within the specified limit, which will essentially help to initiate the system restoration and load recovery from a partial blackout or total blackout situation. The critical challenges arising in system restoration using conventional blackout unit (such as wind, hydro, and gas power station) includes reactive power balance, switching transient voltage, inrush current caused by no-load transformers, and generator self-excitation. Also, these units have low regulating capacity due to the slow response while solar PV+BESS has fast response time in the range of milliseconds and is capable of addressing the aforesaid issues.
- **Renewable energy-based electric vehicle charging:** Since a large amount of energy which is generated from solar PV plant will be supplied back to the main 11 kV common bus due to low demand at a particular 11 kV Radha Soami feeder (wherein microgrids inter-connecion is proposed), and sufficient space availability for public EV chargers installation, the renewable energy-based electric vehicle charging can also be seen as a plausible application. The charging of electric vehicles during daytime can be performed through solar PV-generated power while overnight charging can be done through BESS by utilizing two cycles of charge and discharge per day (one cycle for energy arbitrage and another for electric vehicle charging). The proposed approach of clean energy-based electric vehicle charging may also reduce the technical losses in the line especially when charging occurs through solar PV because the net amount of power flow in the 11 kV feeder will be reduced signifinacntly in case multiple electric vehicle charging takes place at the same time.

Despite these many merits, as PV is an intermittent source that lacks the consistency in producing the output power, the charging during daytime can get hampered. Therefore, a battery energy storage unit coupled with solar can optimize sources, when the electric vehicle charging is in operation. The appropriate control strategy and power flow management schemes for electric vehicle charging have not been elaborated in detail in this particular study.

2.6. BESS Sizing and Operational Control Methodology

In order to provide flexibility to microgrids operation, the viability of stationary battery energy storage system (BESS) was also explored. An optimal storage size was selected for this particular study in such a way that the balance between capital investment and revenue earned from BESS operation is obtained, and the space constraint was also taken into consideration as BESS installation of this scale requires ample space. The technical aspects considered while appropriately sizing of BESS was to ensure that the charging and discharging operations of BESS did not result into supplying power back to 66 kV grid and the full potential of solar can be utilized. The generation of solar coupled with BESS is consumed locally in 11 kV distribution network. Accordingly, 4 MWh of BESS was found to be optimum which will be a kind of AC coupled system, integrated with grid at point of connection where power evacuation for solar PV is provided. As the application of microgrids has been described in the previous section, it becomes imperative to design the appropriate control scheme for BESS operation, which is also the only controllable source within the microgrids architecture. In grid-connected mode, the discharge trigger will be given to primary controller of BESS (i.e. Energy Management System) when the variable cost of electricity is maximum in a day while the charging will take place when the cost of supply is minimal, thereby maximizing the benefit in terms of power purchase cost saving to utility. However, the charge and discharge duration alongside rate of charge/discharge will essentially be determined from the cost of supply in different time block which is generally being predicted on a day-ahead basis by utility. Hence, the duration and rate at which charge/discharge operation is performed will be decided beforehand (one day before) in practical scenario when BESS will be deployed on site. Furthermore, the charge/discharge limitation will also be considered while designing the control topology as the life of battery pack largely depends upon the rate at which charge/discharge is performed. In order to showcase the fundamental operation of BESS, the performance of the system has been shown on a monthly basis since the peak and off-peak time slots generally remain same for a month. Thus the threshold of charge/discharge operation has been maintained constant for a period of one month. Moreover, the average monthly load curve (based on average of each time slots of a day) was calculated as described in the preceding section, which is the representation of peak and off-peak time for each months of a year. Further, a fixed charge and discharge threshold have been evaluated for each month, and, consequently, the variable rate of discharge and charge has been proposed in order to ensure the optimal operation of BESS in such a way that the highest discharge rate is defined when the peak load is observed. Similarly, the charge rate will be higher when the system level load is minimal. The control methodologies for BESS operation under different conditions are depicted in the form of flow chart as shown in Figure 14.



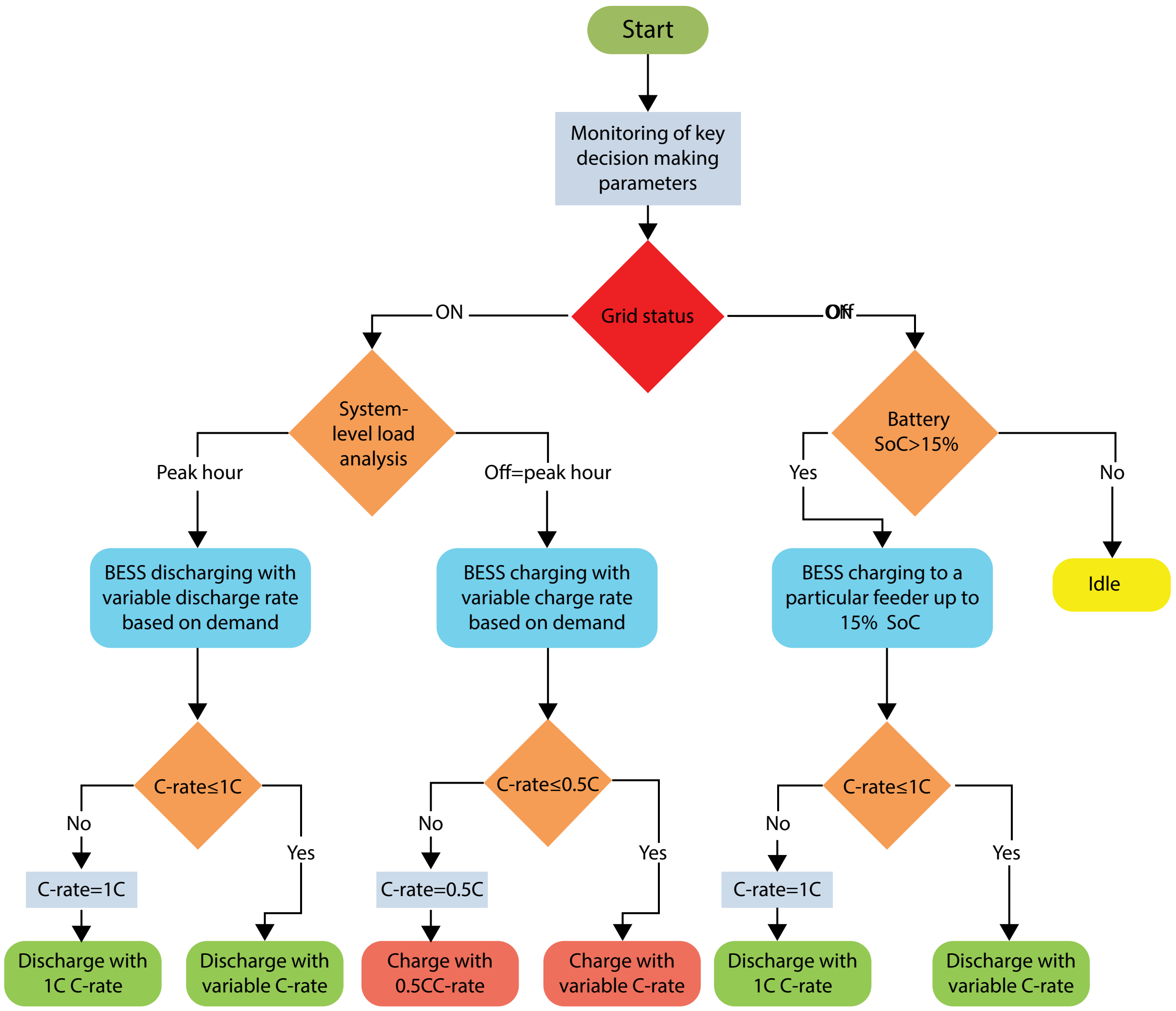


Figure 14: Basic control methodology for BESS operation

Additionally, as the battery converter in the proposed application is required to operate in both the grid-connected and the islanded mode, thus the controller which provides binary signals to converter's switches need to be accordingly designed, and smooth transition from one mode to another mode (grid-connected to islanded or vice versa) has to be ensured.

RESULTS AND DISCUSSION

The urban microgrids has got relevance in the case of urban setup in terms of responding to dynamics of distribution grid operation with increasing renewable energy penetration and deferring distribution upgrades in congested cities such as Delhi, Kolkata, among others. The overload was not the case for this particular study as maximum load on distribution equipment was found to be 40%–50% of the rated capacity. In fact, the minimal loading of the 11 kV feeder provided an opportunity to supply power back to 11 kV bus and share the solar power generated among the 14 feeders emanating from the 11 kV bus (refer to Figure 2) in site selection section.

a. **Operating hours of BESS**: BESS control logic was designed to operate as per peak and off-peak hours of BRPL. Time-series loading data at system level was assessed for last five financial years. BESS was designed to charge during off-peak hours where there is a possibility to consume more from cheap power plants and discharge during peak durations whenever there is a possibility of curtailing power purchase from expensive power plant to its technical minimum. Figure v indicates the month-wise charging durations estimated based upon power purchase portfolio assessment for specific days, load curve analysis for last five years, and technical minimum for specific power plants. The hours of charge and discharge operation are shown in Annexure 2.

b. **Benefit assessment (stacking the different value stream)**: As per the applications discussed in the previous section, the revenue streams were stacked together to calculate the true value of microgrids vis à vis a total cost of the system. The results are shown in Figures 15 and 16 for Capex mode of financing.

Assuming total investment cost of Rs 44 crore, of which Rs 32 crore for 8 MW of solar capacity and Rs 12 crore for 4 MWh of BESS (LFP technology), the total undiscounted payback is between four and five years. Table 2 presents the non-discounted payback period with change in price of battery.

Table 2: BESS cost versus payback period

BESS Cost in $/kWh	450	400	350	300	250	200
Non-discounted PBP in years	4.96	4.79	4.63	4.47	4.3	4.14

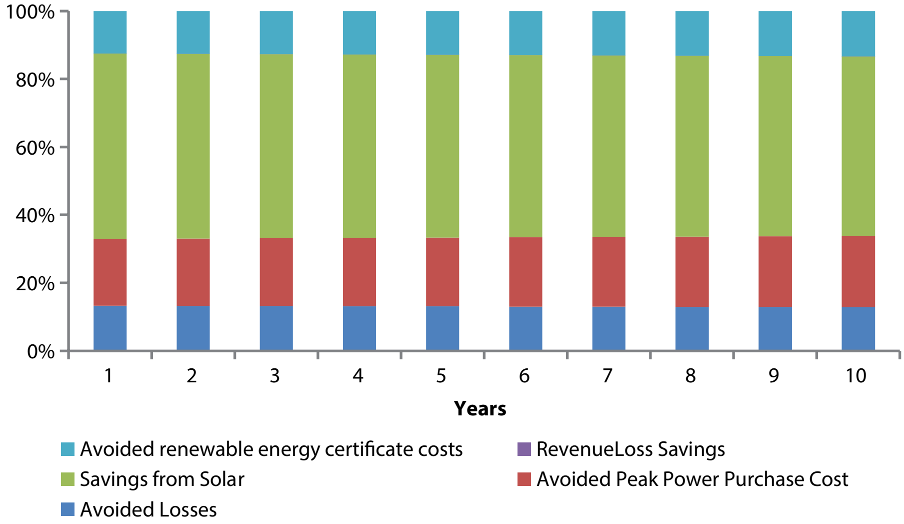


Figure 15: Share of revenue streams in total benefit in %

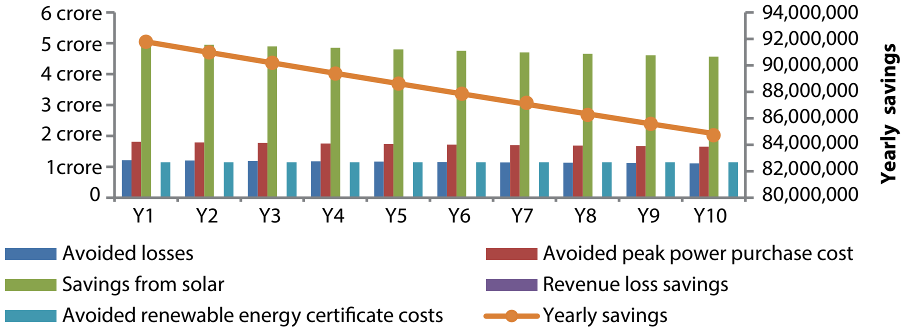


Figure 16: Share of revenue streams in total benefit in Millions

The other major assumptions are as follows:

1. Cycle of BESS per day: 1 cycle
2. Battery efficiency assumed: 90%
3. Usable BESS capacity: 4000 kWh with efficiency losses
4. Annual system degradation: 1%
5. Annual hours of outage on the 11 kV Feeder: 20 hours
6. REC cost: INR 1000 per MWh
7. Solar system cost: Rs 4 crore per MW

c. **Impact on feeder and sub-station loading:** The battery was sized to fully utilize the estimated solar potential. The impact of solar generation and BESS operations was assessed on the loading of the distribution equipment which included power transformers (25 MVA each) and 11 kV Radha Soami feeder. The exercise was done on typical days of the year considering data availability and duration of the study (refer to Figures 17 and 18).

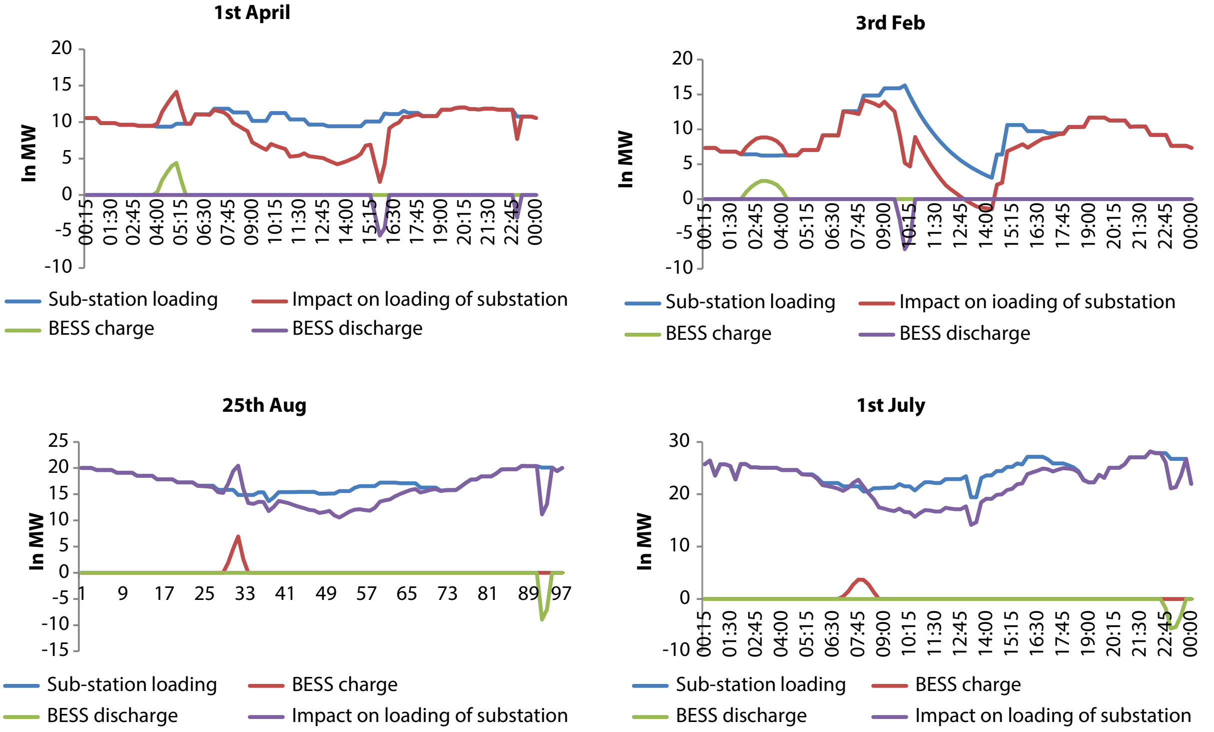
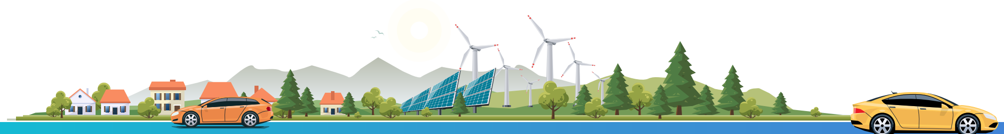


Figure 17: Impact on substation-level loading as a result of operations of microgrids



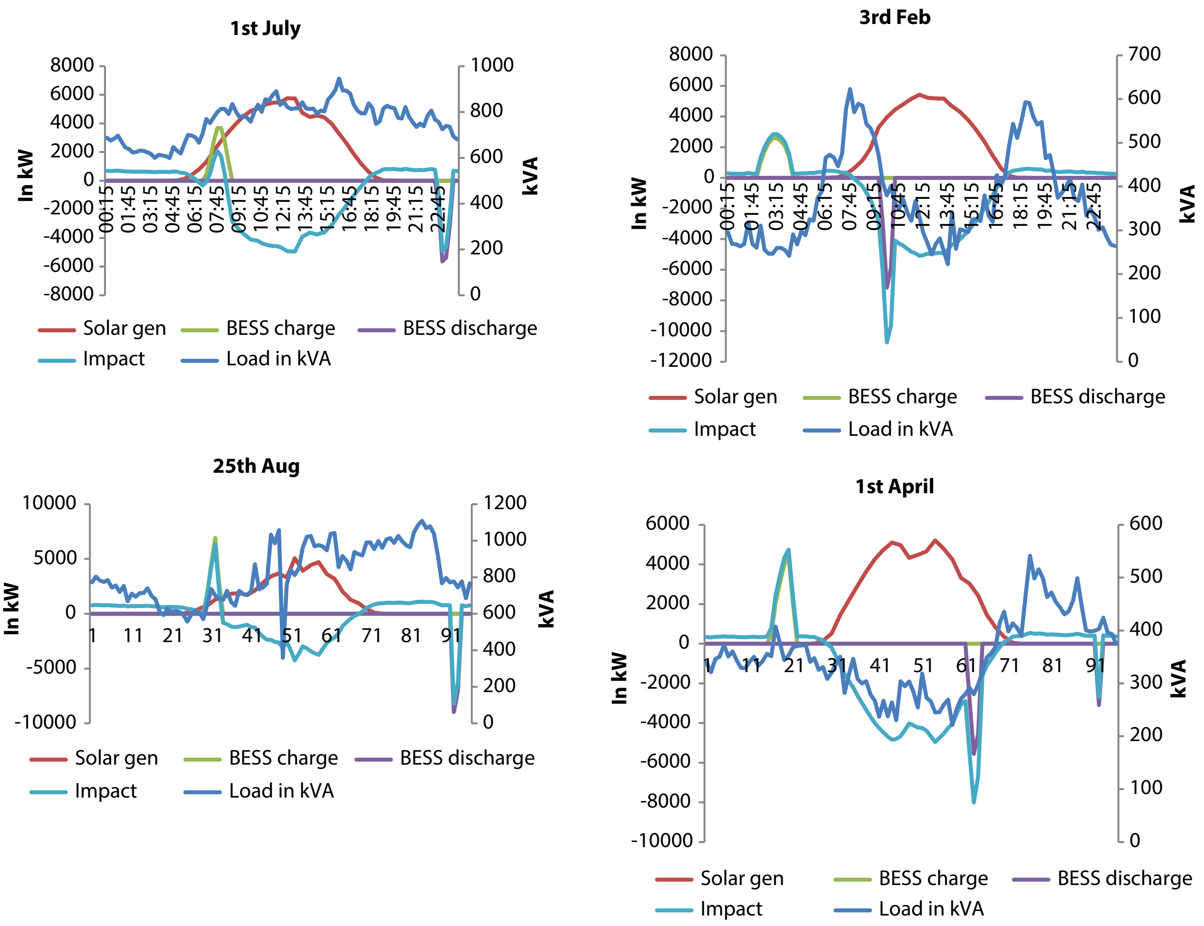


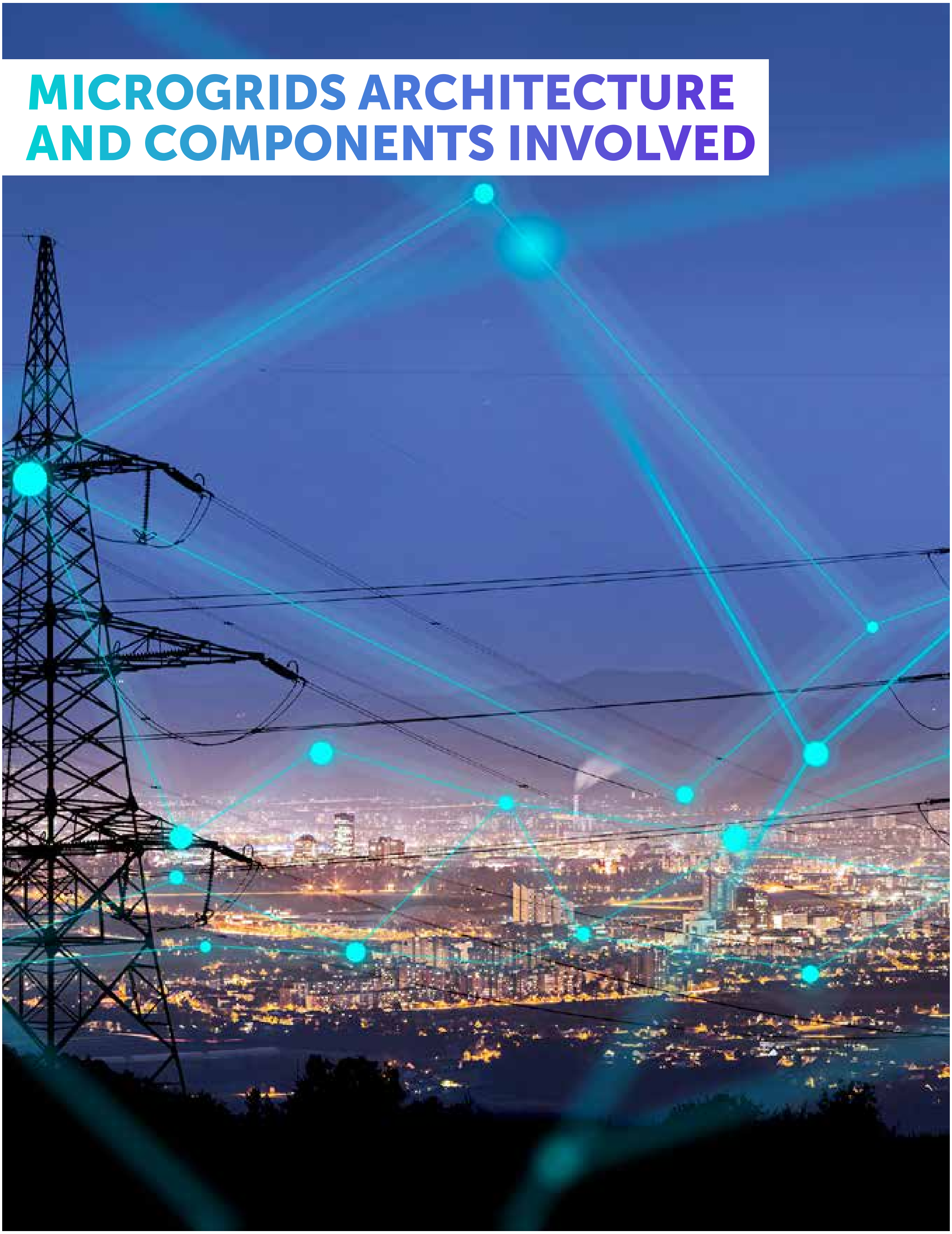
Figure18: Impact on feeder-level loading as a result of operations of microgrids

As can be referred to from Figure 17 depicting sub-station loading impact on 3 February, the BESS operations ensured that power is not supplied back to 66 kV grid. Also, the maximum power supplied back to 11 kV bus is around 6 MW, which lies within the rated capacity of four feeders built to supply power to temporary health facility – Radha Soami Covid hospital.

Future scenario: For meeting its RPO targets, BRPL has already tied up 1.2 GW of renewable energy capacity which is expected to be operational by FY 2021–2022. This included both solar and wind power generators (refer to Annexure 3).

Thus, to assess the impact of such a renewable energy capacity, wind profiles, and solar profiles for these power plants were generated through simulation. The load profile of BRPL was also estimated for FY 2021–22 using last five financial years' data. The exercise was done simply by calculating CAGR based on higher weights to most recent data. Then, net load curve was assessed by reducing the estimated load curve by the renewable energy capacity due to their must run status to assess microgrids operations in such a case. The hours of operation of BESS were accordingly defined as per the net-load curve of FY 2021–22. There has been not much significant change in hours of operations (refer to Annexure 2).

MICROGRIDS ARCHITECTURE AND COMPONENTS INVOLVED



As it has been already described earlier, the microgrids system for this particular study comprises 8 MW solar along with 4 MWh of BESS, and the system will be a kind of AC coupled wherein the AC output of the solar and battery inverter will be inter-connected at common point in the11 kV feeder. However, the exact power evacuation point for integration may be explored later during the project execution stage, if the pilot demonstration of the proposed concept is carried out. The existing 11 kV feeder has limited power handling capability, and integration of microgrids system (solar PV and BESS) will further increase the stress on the line, thus a separate 11 kV feeder parallel to existing feeder needs to be laid down which will essentially be allocated to cater to the power flow to/from the microgrids. The schematic of the microgrids components and the power evacuation point for its inter-connection with the grid are represented in Figure 19.

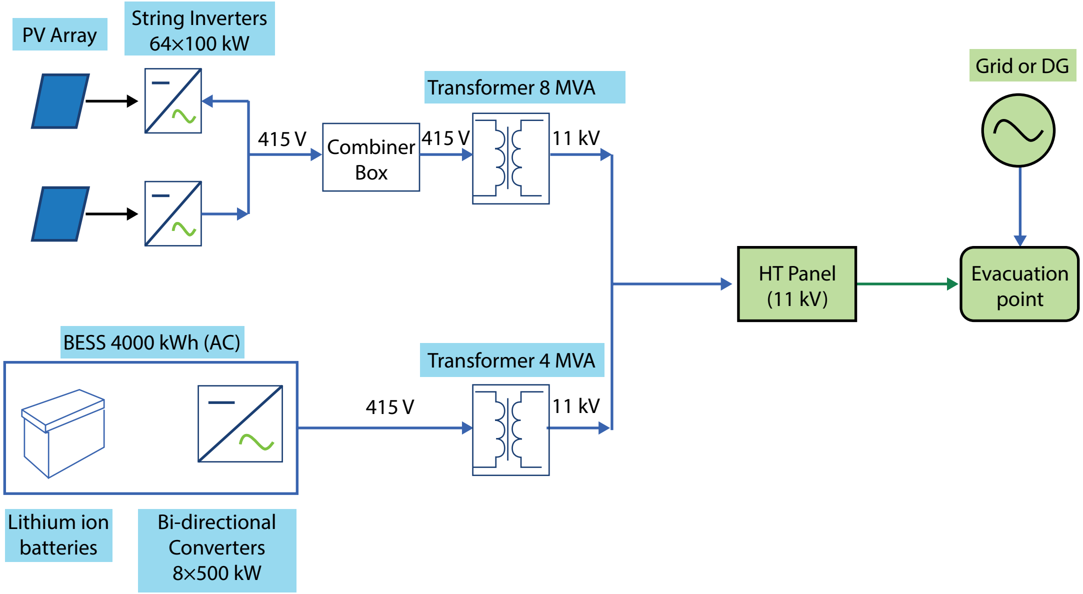


Figure 19: Components of microgrids

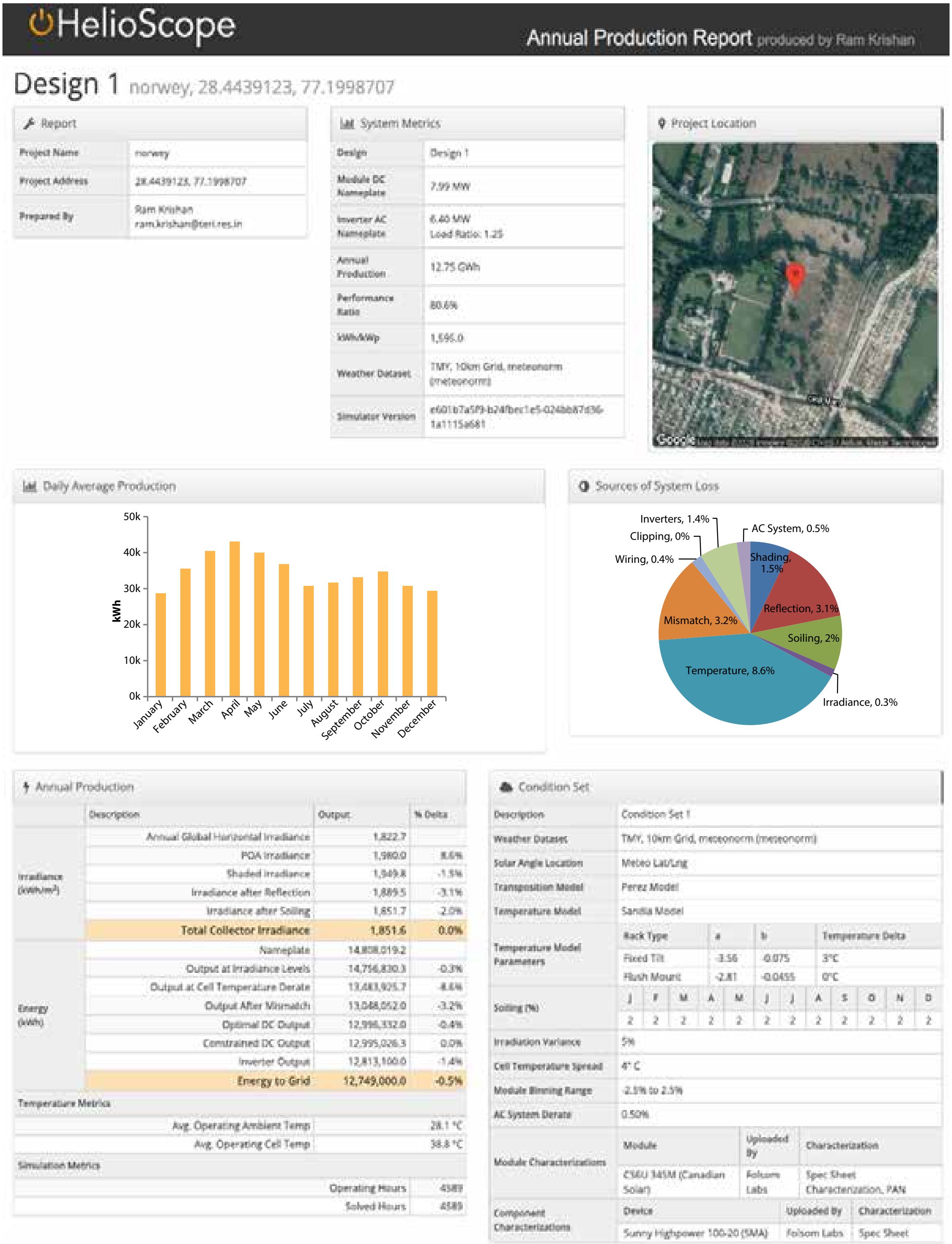
Furthermore, the components details that are involved in the microgrids system are given in Table 3.

Table 3: Quantity-wise components in urban microgrids

Components	Power rating	Quantity
Solar PV modules	345 W	23,168
String inverters	100 kW	64
Battery PCUs	500 kW	08
Isolation transformer for solar PV	8 MVA	01
Isolation transformer for BESS	4 MVA	01

ANNEXURES

Annexure 1: Detailed outcome of simulation study



HelioScope

Annual Production Report produced by Ram Krishan

Design 1 norwey, 28.4439123, 77.1998707

Report

Project Name	norwey
Project Address	28.4439123, 77.1998707
Prepared By	Ram Krishan ram.krishan@teri.res.in

System Metrics

Design	Design 1
Module DC Nameplate	7.99 MW
Inverter AC Nameplate	6.40 MW Load Ratio: 1.25
Annual Production	12.75 GWh
Performance Ratio	80.6%
kWh/kWp	1,595.0
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Simulator Version	e601b7a5f9-b24fbec1e5-024bb87d36-1a1115a681

Project Location

Daily Average Production

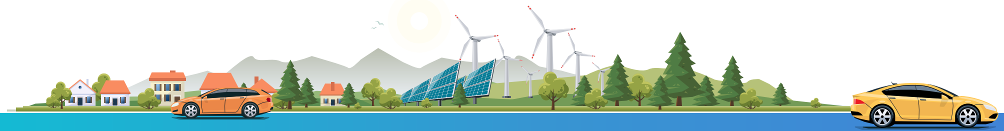
Sources of System Loss

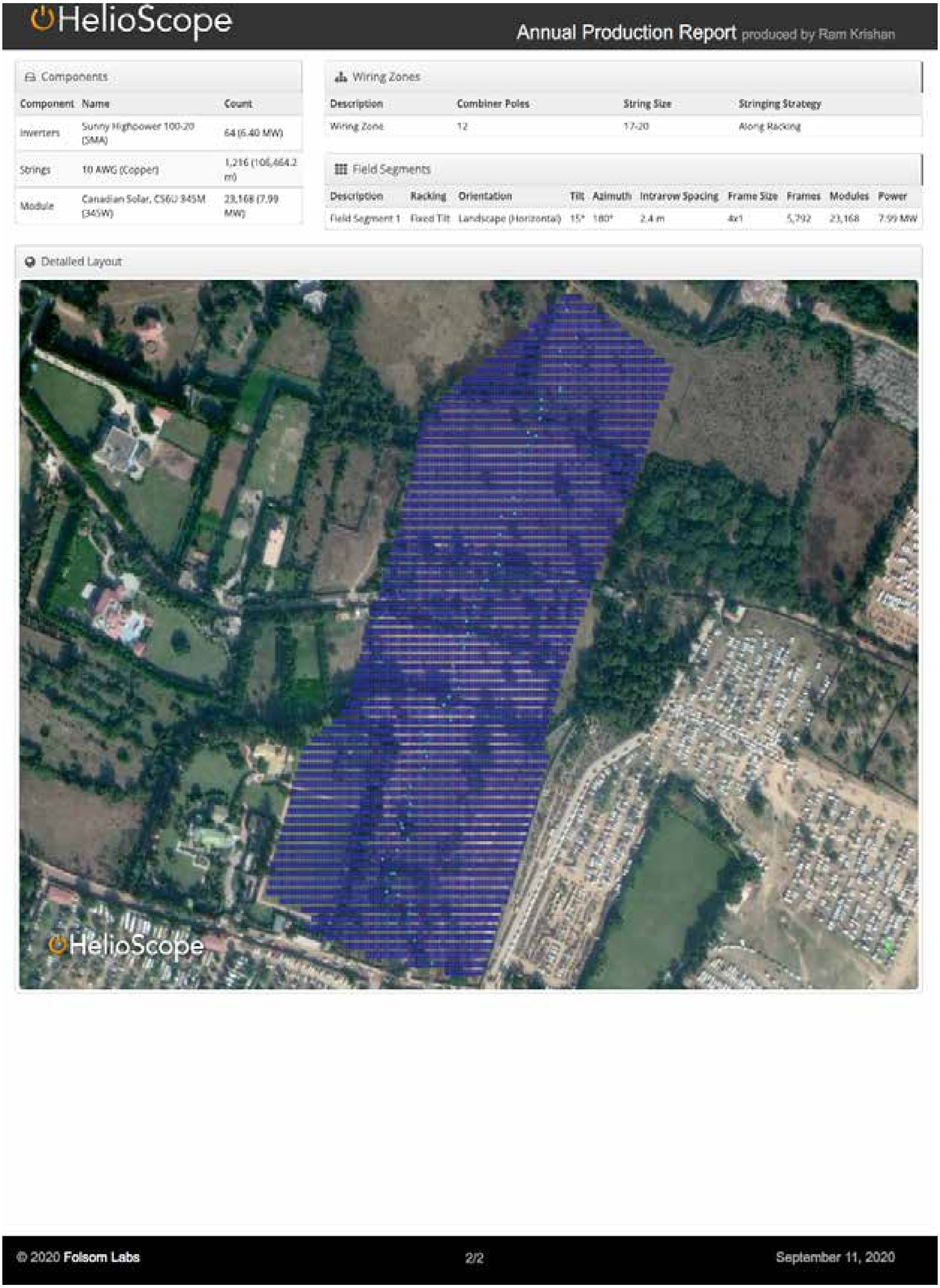
Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	1,822.7	
	POA Irradiance	1,980.0	8.6%
	Shaded Irradiance	1,949.8	-1.5%
	Irradiance after Reflection	1,889.5	-3.1%
	Irradiance after Soiling	1,851.7	-2.0%
	Total Collector Irradiance	**1,851.6**	**0.0%**
Energy (kWh)	Nameplate	14,808,019.2	
	Output at Irradiance Levels	14,756,830.3	-0.3%
	Output at Cell Temperature Derate	13,483,925.7	-8.6%
	Output After Mismatch	13,048,052.0	-3.2%
	Optimal DC Output	12,996,332.0	-0.4%
	Constrained DC Output	12,995,026.3	0.0%
	Inverter Output	12,813,100.0	-1.4%
	Energy to Grid	**12,749,000.0**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		28.1 °C
	Avg. Operating Cell Temp		38.8 °C
Simulation Metrics			
		Operating Hours	4589
		Solved Hours	4589

Condition Set

Description	Condition Set 1											
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)											
Solar Angle Location	Meteo Lat/Lng											
Transposition Model	Perez Model											
Temperature Model	Sandia Model											
Temperature Model Parameters	Rack Type	a	b	Temperature Delta								
	Fixed Tilt	-3.56	-0.075	3°C								
	Flush Mount	-2.81	-0.0455	0°C								
Soiling (%)	J	F	M	A	M	J	J	A	S	O	N	D
	2	2	2	2	2	2	2	2	2	2	2	2
Irradiation Variance	5%											
Cell Temperature Spread	4° C											
Module Binning Range	-2.5% to 2.5%											
AC System Derate	0.50%											
Module Characterizations	Module	Uploaded By	Characterization									
	CS6U 345M (Canadian Solar)	Folsom Labs	Spec Sheet Characterization, PAN									
Component Characterizations	Device	Uploaded By	Characterization									
	Sunny Highpower 100-20 (SMA)	Folsom Labs	Spec Sheet									





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Components

Component	Name	Count
Inverters	Sunny Highpower 100-20 (SMA)	64 (6.40 MW)
Strings	10 AWG (Copper)	1,216 (106,464.2 m)
Module	Canadian Solar, CS6U 345M (345W)	23,168 (7.99 MW)

Wiring Zones

Description	Combiner Poles	String Size	Stringing Strategy
Wiring Zone	12	17-20	Along Racking

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Landscape (Horizontal)	15°	180°	2.4 m	4x1	5,792	23,168	7.99 MW

Detailed Layout

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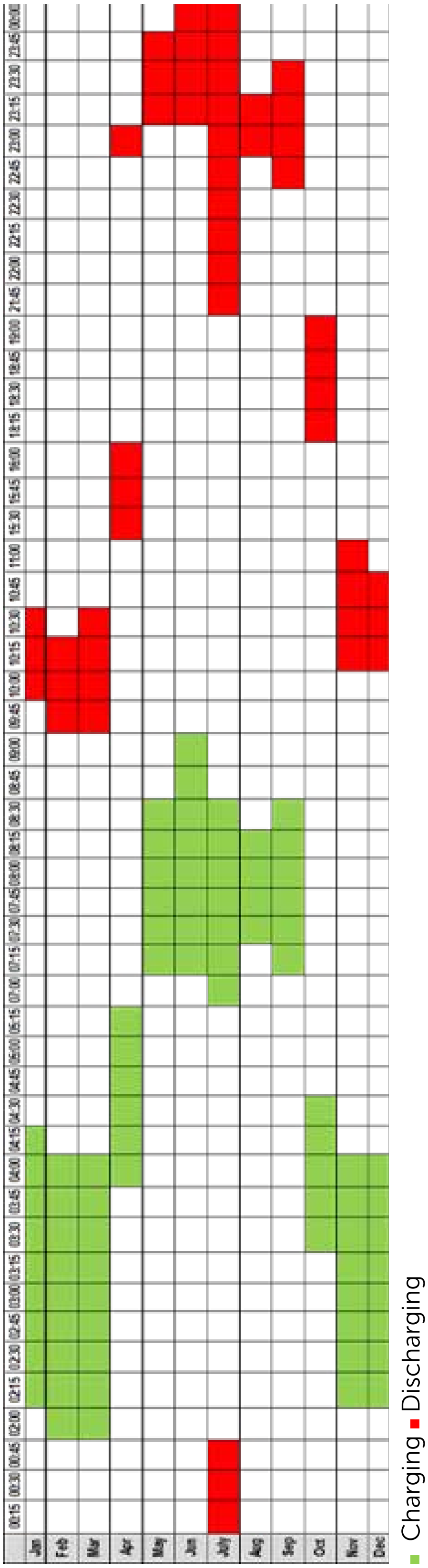
2/2

September 11, 2020

Annexure 2: RE Portfolios of BRPL



Annexure 3: RE Portfolios of BRPL

S. No.	Description	Capacity (MW)	Estimated Energy supply (MUs)	Remarks
1.1	SECI Solar Rajasthan	20	39.7	Operational
1.2	Thyagraj	1	0.98	
1.3	SECI (Solar)	400	841	SCOD 24th Dec '21
1.4	SECI (Solar)	350	735.8	SCOD April-June '21
2	**NON-SOLAR**			
2.1	TOWMCL	8	59.6	Operational
2.2	MSW Bawana	10	52.2	
2.3	PTC wind- Green infra	50	142.8	
2.4	PTC wind - Inox	50	148.9	Revised SCOD- Jun'19
2.5	SECI (Wind)	150	446.8	70 operational 80 in Sept' 20
2.6	SECI (Wind)	100	297.8	April 21
2.7	SDMC WTE (Tekhand)	10	50.8	SCOD Sep'20
2.8	SECI (Wind)	50	148.9	June 21

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We believe that resource efficiency and waste management are the keys to smart, sustainable and inclusive development. Our work across sectors is focused on

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2. Increasing access and uptake of sustainable inputs and practices

3. Reducing the impact on environment and climate

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