ISGF India Smart Grid Forum

India SMART UTILITY Week 2025

INDIA SMART GRID FORUM

175 YEARS OF IIT ROORKEE Estd. 1847

11th Edition of India Smart Utility Week (ISUW 2025) International Conference and Exhibition on Smart Energy and Smart Mobility

A keynote address on

Capacity Building in Utilities and Industry for Energy Transition

Presented by:
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Blackout Experience and Learning in India (2012)

700 million people affected

400 kV Bina-Gwalior-Agra 2nd line shutdown → **Large amount of unscheduled import of power by NR from WR and ER** → **Forced Outage of some Thermal and Gas power plants in NR** → **400kV and 200kV lines were tripped from WR to NR**

- Failure in load management and planning
- Lack of observation and coordination on TTC
- Irregular maintenance and lack of monitoring
- Weak inter-regional corridors due to multiple outages

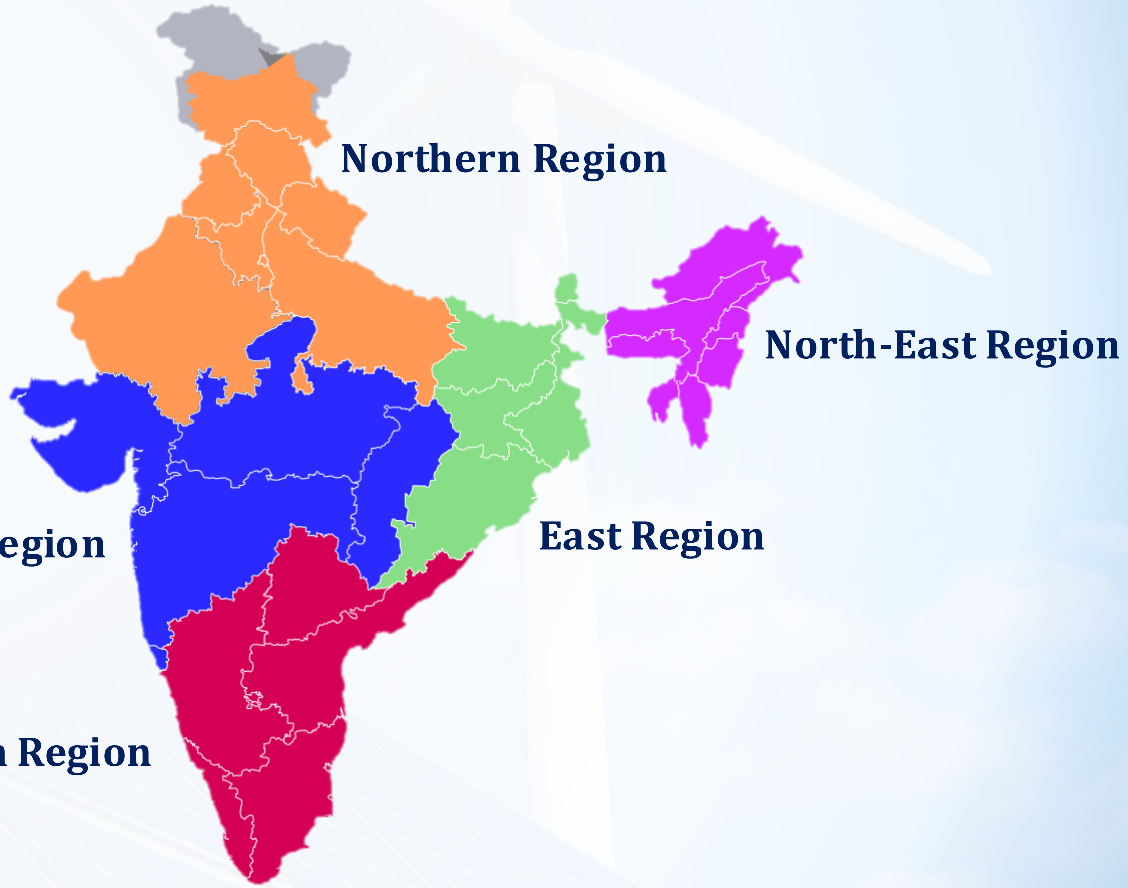
Area affected on 30th and 31st July 2012

Area affected only on 31st July 2012

During the 2012 post-blackout era, the drive to work on Smart Energy Grids and Energy Storage was sparked.

Indian Grid....One of World's Largest

1 National Synchronous Grid



India's Energy Sector: Global Ranking and Achievements

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Indian Grid....One of World's Largest

1 National Synchronous Grid

3 Electricity Generation (1700 BU)
Installed Capacity (454 GW)
Transmission System (490306 km)

4 Solar Generation (92 GW)
Wind Generation (47 GW)

5 Hydro Generation (47 GW)

10 Nuclear Capacity (8.18 GW)
Pumped Storage Installed Capacity (4.7 GW)

*IEA WORLD ENERGY OUTLOOK & IHA HYDRO STATUS REPORT

India's Energy Transition Roadmap

Resource	Mar-24	Mar-30	Mar-47 (tentative)
Hydro	47	54	100
Small Hydro	5	5.3	
Solar PV	82	293	**1200**
Wind	46	100	**450**
Biomass	11	15	23
Nuclear	8	15	55
Coal + Lignite	218	252	235
Gas	25	25	11
Total	442	777	**2075**
BESS (5 hrs)	–	42	**300**
Pumped Storage	4.7	19	115

*All capacities in GW (Operational Capacity 3.3 GW)

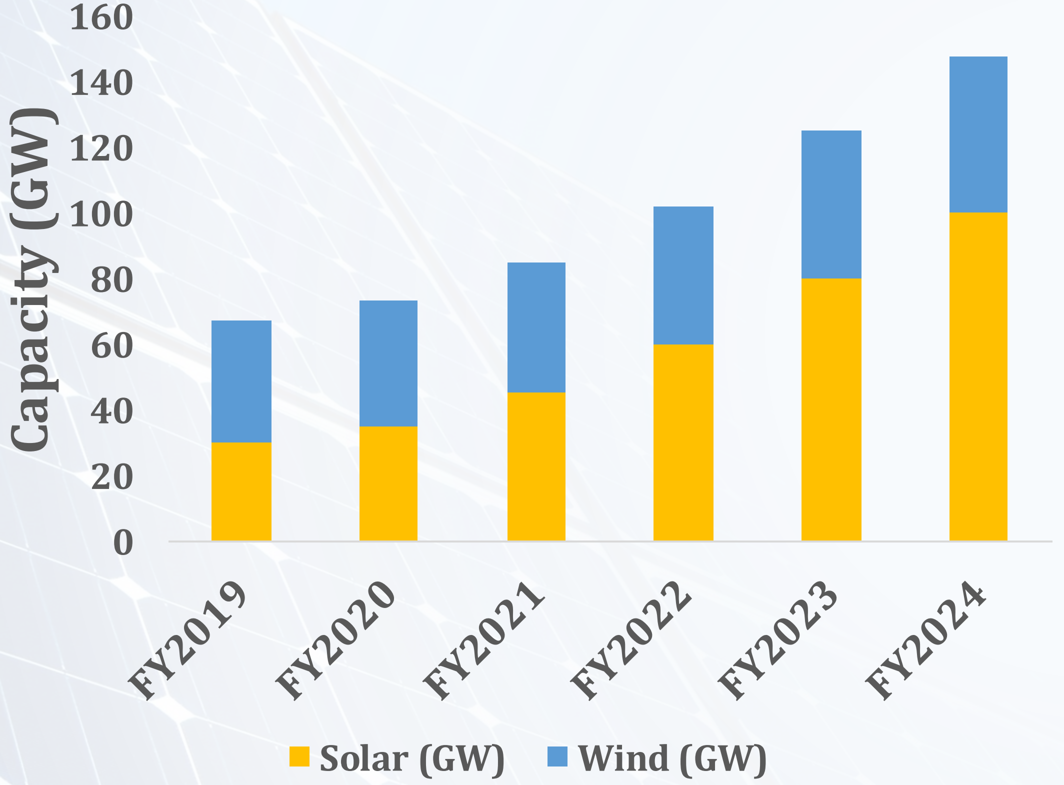
	2024	2030	2047*
Maximum Demand Met (GW)	~250#	334^	~700
Electricity Consumption for preceding FY (BU)	~1620#	1949^	4620
Total Generation Installed Capacity (GW)	442	777	**2052**
Non-fossil Fuel Based Generation Installed Capacity (GW)	210	500	1828
Wind & Solar Installed Capacity (GW)	138	393	**1650**

Operational Data of Grid-India
* As on Sep 2024 from CEA installed Capacity Report
^ 20th EPS survey by CEA

*CEA REPORT ON OPTIMAL GENERATION CAPACITY MIX 2029-30 (VER 2.0) AND OTHER DATA AS PER CEA'S LTPS STRATEGY

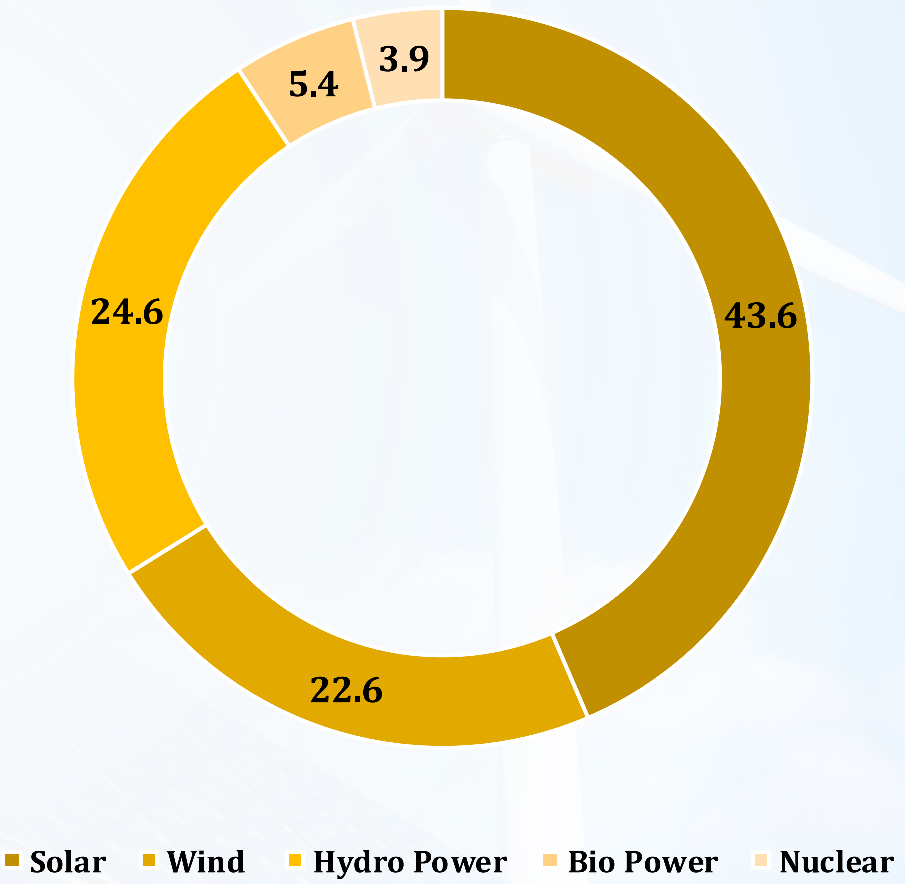
Renewable Energy Installation Trends in India (2024)

Annual Installations in INDIA
as of Sep 2024



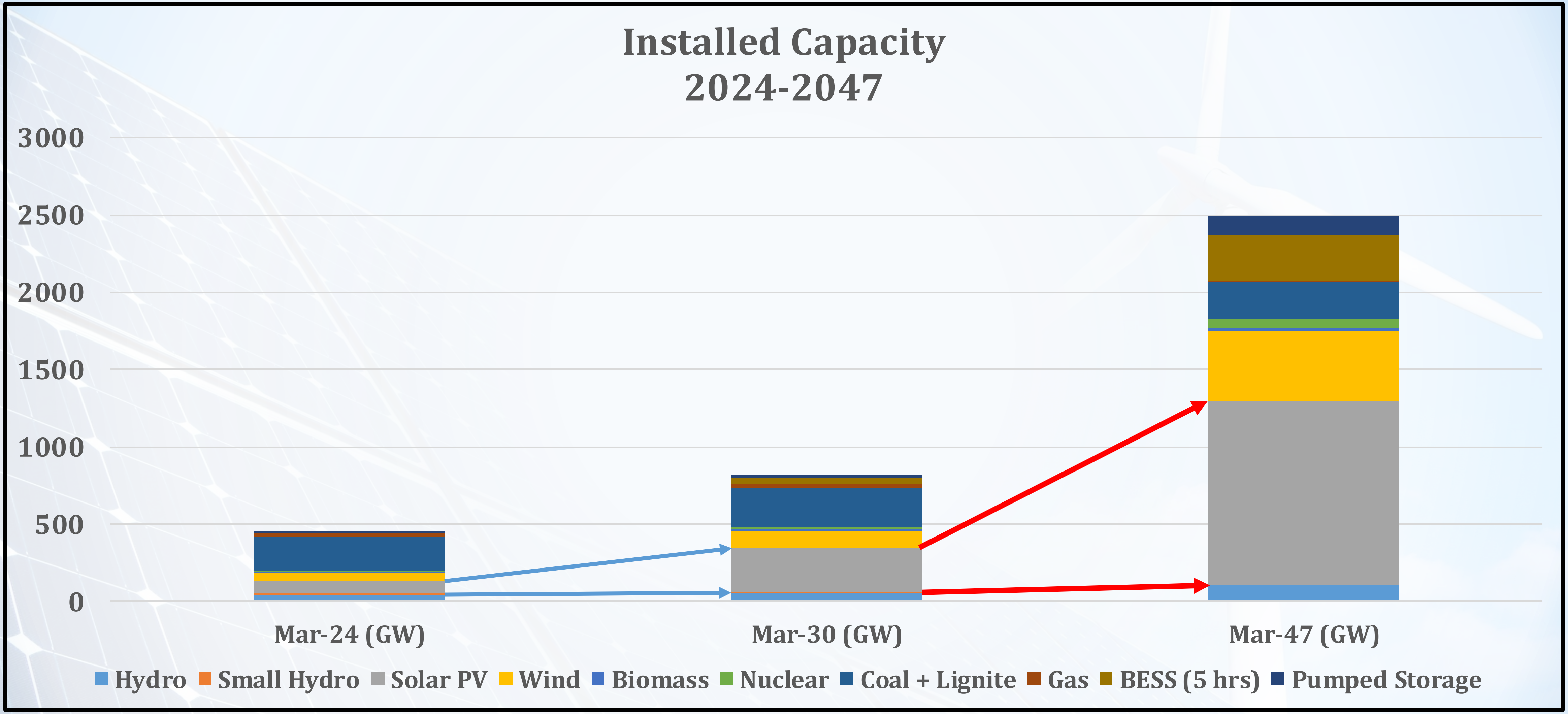
Highest Instantaneous RE penetration of ~33% recorded - 6th July 2024

Non Fossil Power Capacity (%)
as of 31st Oct 2024



*GOVERNMENT OF INDIA, MINISTRY OF POWER, CENTRAL ELECTRICITY AUTHORITY

Long Term Installation Planning in India



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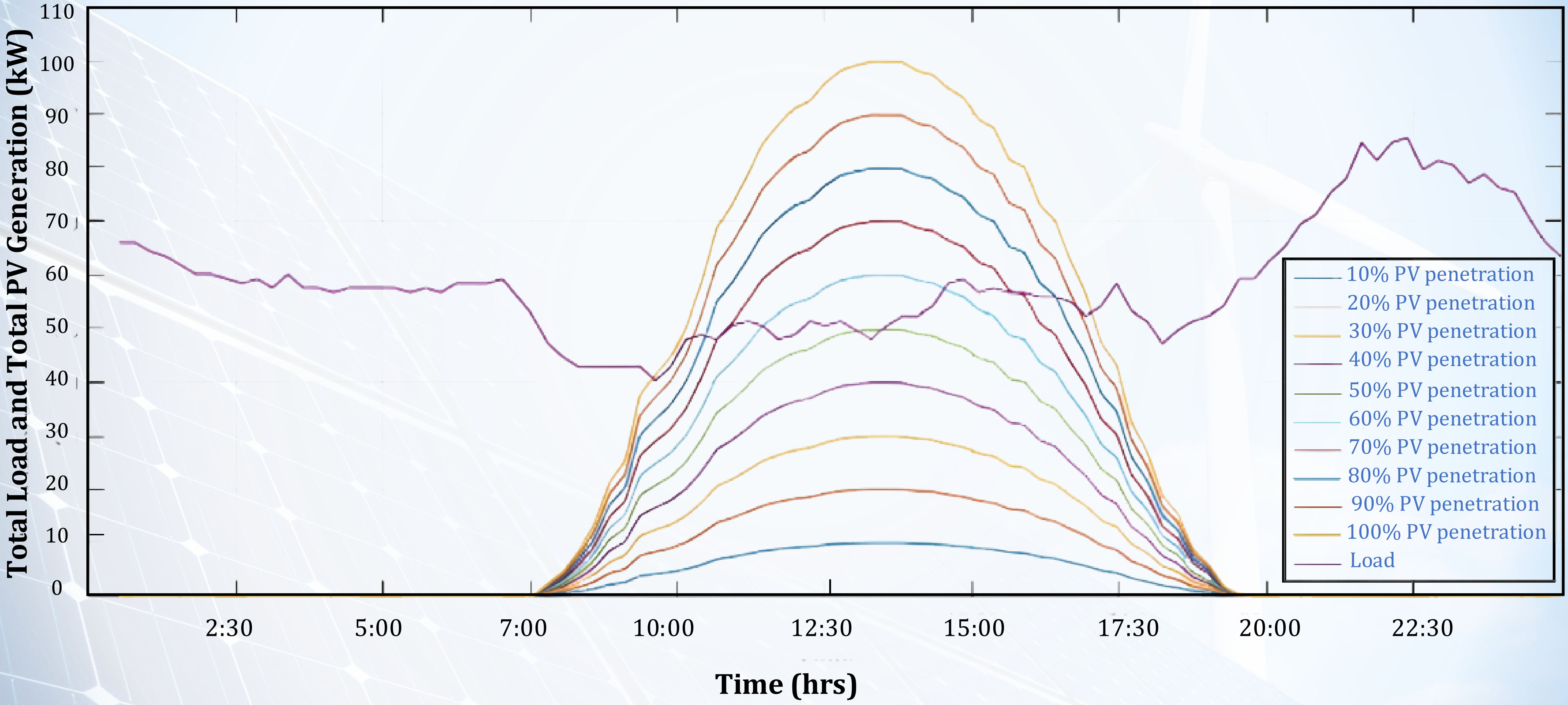
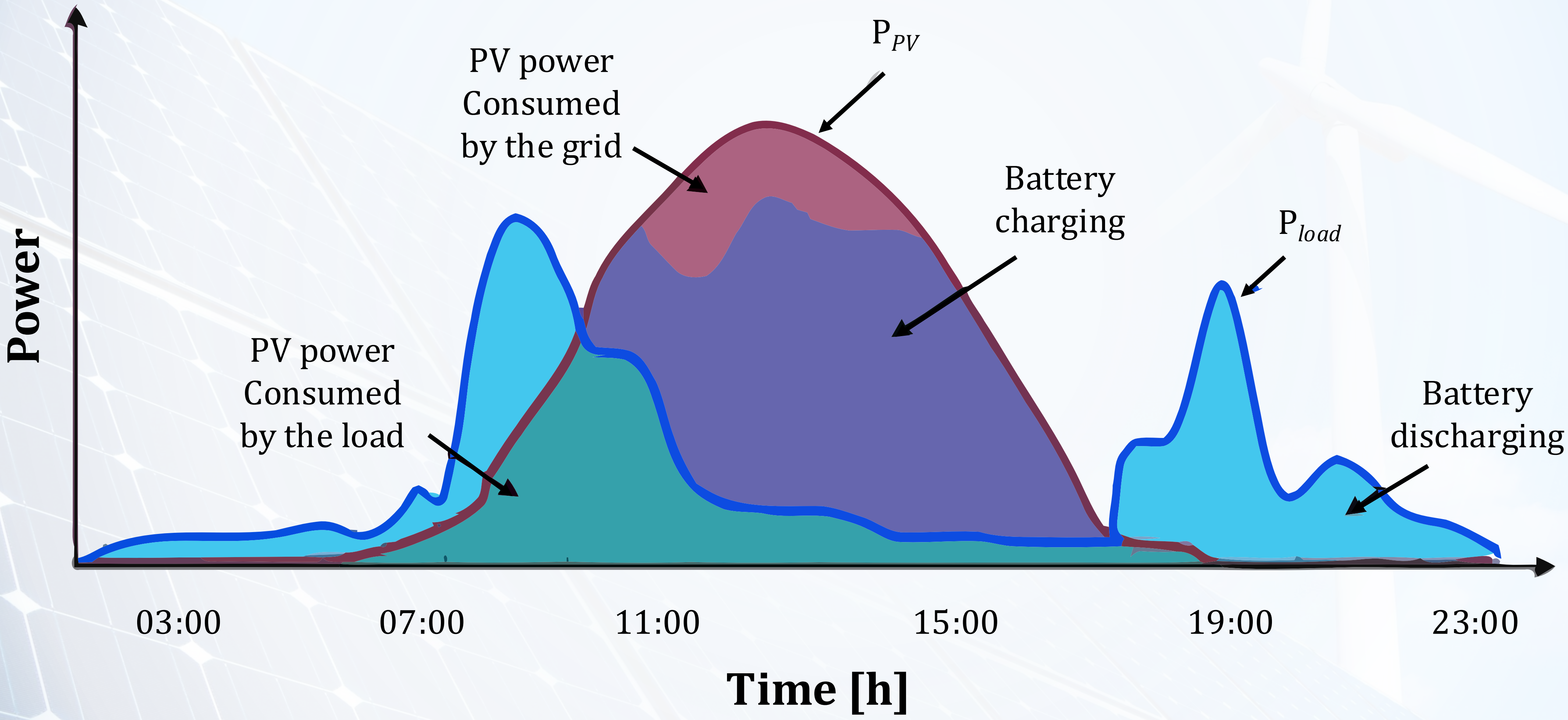
Daily Load Curve and the Total PV Power Generation



Daily Profile of the PV Power Generation and Load Demand and Battery



Motivation

Reduction of global warming and peak energy deficit with renewable sources

Key renewable sources in India are wind and solar contributing 54% and 26% to the overall renewable generation respectively

Solar rooftop is a prime option in India to meet local demand at low voltage distribution system.

India targets to install 300GW of solar by 2030 and Mission Innovation aims towards 100% renewable generation

Solar rooftop systems are rapidly getting integrated in low voltage distribution network.

Issues in Solar Rooftop Integration

- **EXISTING SCENARIO**

Over-voltage fluctuations

- Low X/R ratio results in over voltage at the feeder ends due to higher penetration of solar-photovoltaic generation in LV network.

Unable to operate in islanded mode

- Most of solar rooftop systems operate in grid-feeding mode.
- It demands a strong utility support or potential voltage source to synchronize the inverter.

Unintended trip

- Switching of heavy loads creates an instantaneous voltage overshoot in weak LV distribution system.
- This triggers an unintended tripping of the inverter which resets and reboots itself.

Issue with Large Scale Deployment of Solar Rooftop

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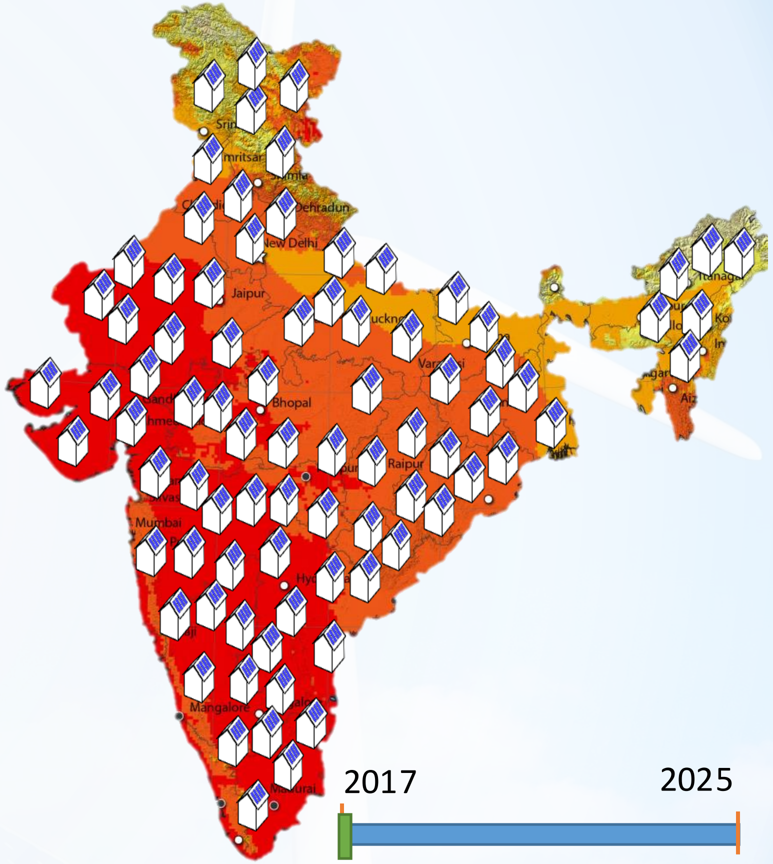
System Instability

- Large scale solar integration creates a deficit in the rotational inertia of the system.
- The system will be vulnerable to sudden load changes and impacts the frequency stability of the system which leads to frequent blackouts.

Power Imbalance

- Conflicting nature of solar and load profile will create a serious peak energy deficit.
- Abrupt fall in solar generation creates power imbalance.

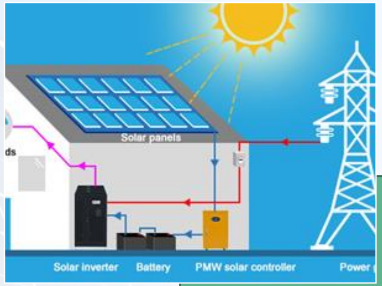


2025

Objectives

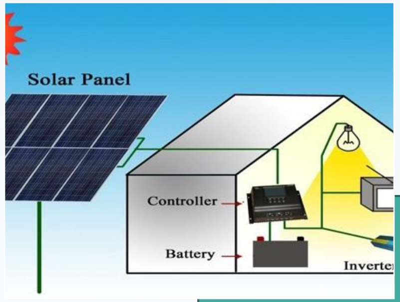
- Reducing the voltage fluctuations at point of common coupling in distribution network caused by large penetration of PV.
- Harvesting maximum energy from PV through integration of DES
- Increasing the reliability of power supply in weak distribution system.
- Enhancing ancillary services to the conventional grid.
- Transforming the passive low voltage distribution network into active and controllable smart distribution grid.

Distributed Energy Storage Features



Grid Connected Mode

- Active power balance during grid peak and off-peak hours
- LVRT capabilities
- Network voltage support
- Power quality improvement in terms of good voltage profile and less power interruptions
- Improves the reliability index of the network



Islanded Mode

- Active power balance with PV to meet the local load demand
- Acts as main power to critical loads present in the network in the absence of PV during islanded mode of operation
- Provides support to the network during faults (safeguard from the risk of voltage collapse)
- Acts as critical source during network maintenance and restoration
- Aids inertia to the system during abrupt load changes

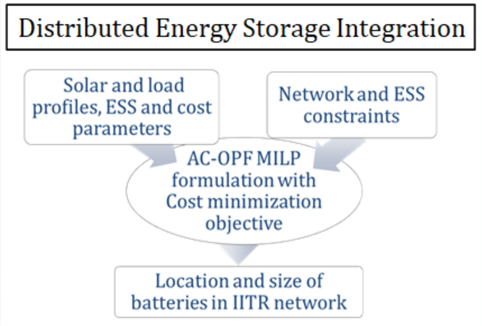
Progress Plan

01
Problem Formulation

System Modelling and Analysis

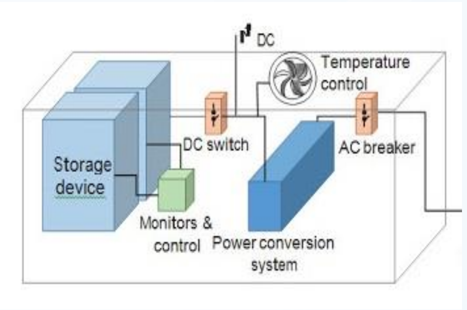
02
Solution Methodology

Optimization of Energy Storage Systems



03
Control and design of Solution obtained

Storage dispatch/operation. Test control algorithms with a laboratory setup



04
Field Deployment

Battery, BMS, PCS, EMS complete setup deployment

2025

Challenges in Storage Integration

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Challenges

- DISCOMs doesn't encourage practical testing and deployment of DES to address the issues related to PV penetration in low voltage distribution network (LVDN).
- Real time simulation in the laboratory may not replicate the MW scale practical scenarios.
- High capital cost of battery energy storage systems and the capacity degradation over time and use. Lack of degradation models.
- High-capacity cost of solar rooftop integration to low voltage distribution networks.

Solution

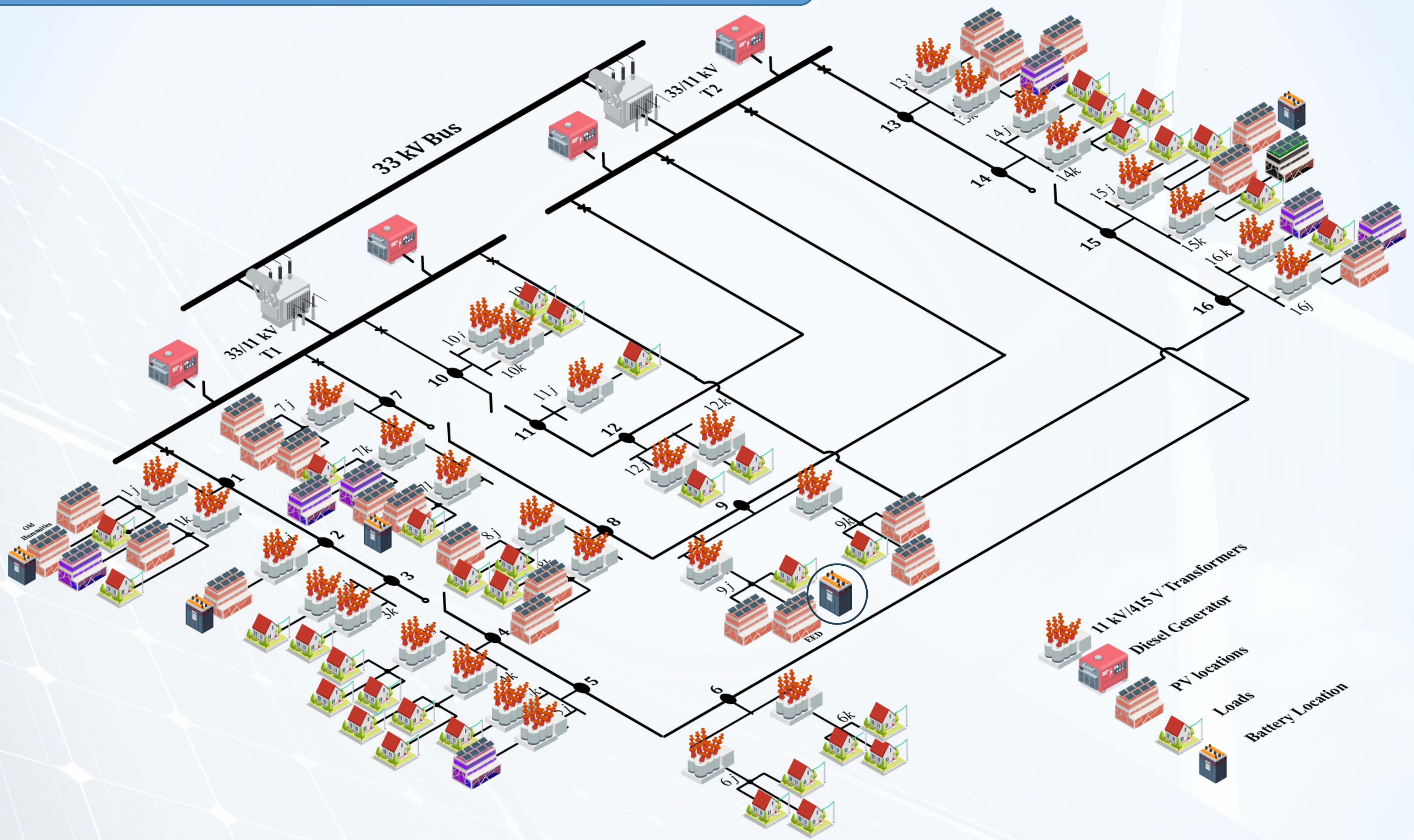
Utilising Government Institution Distribution Networks

- Availability of advanced simulation platforms.
- Practical testing facilities upto kW range.
- No capital investment required for developing LVDN.
- Highly qualified and experienced research personnel.

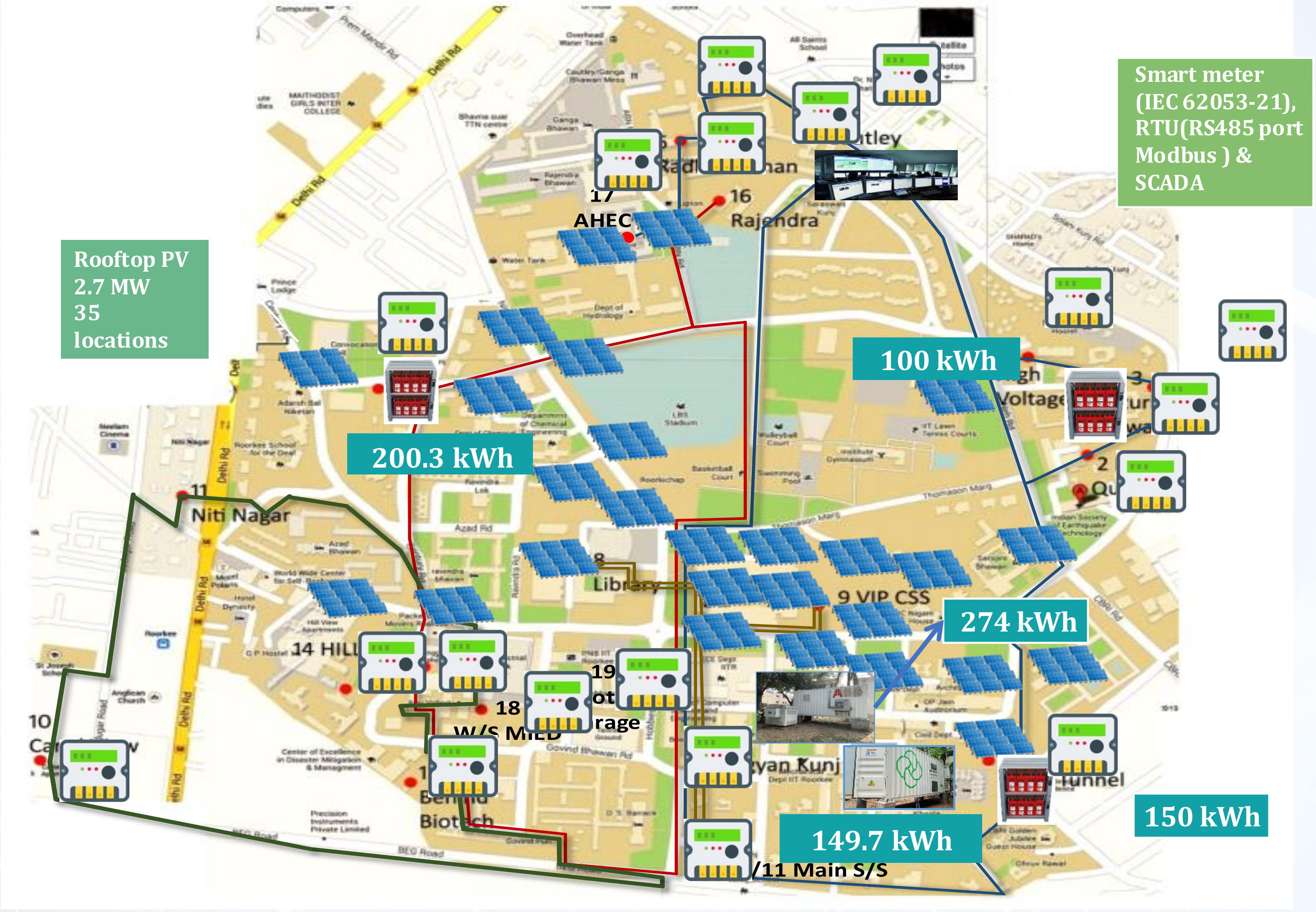
IIT Roorkee

- Number of Substations: 21
- Load Demand: Peak-8 MW, Minimum-3 MW.
- Installed PV capacity: 2.7 MW at 35 Locations.
- Distribution System is mostly underground.
- RTUs installed in each substation and the total system is now under SCADA.
- Frequent tripping of solar system due to over-voltages.
- Unique research facilities such as RTDS, linear power amplifier, kW range microgrid testbed.

Case Study: IITR Distribution Network

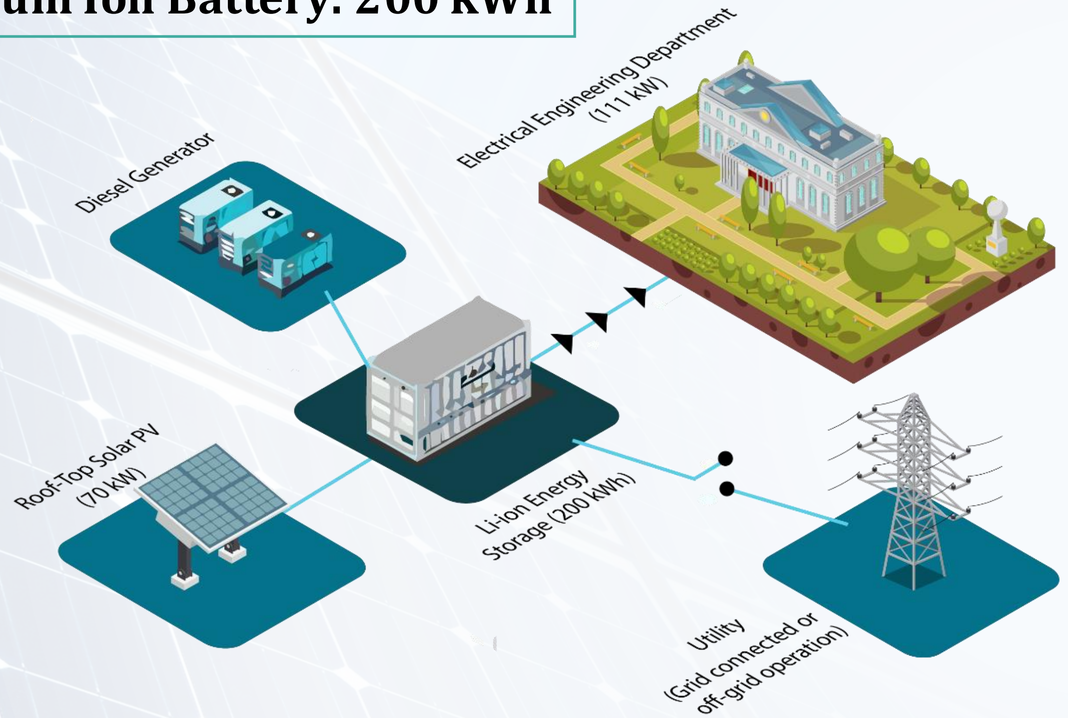


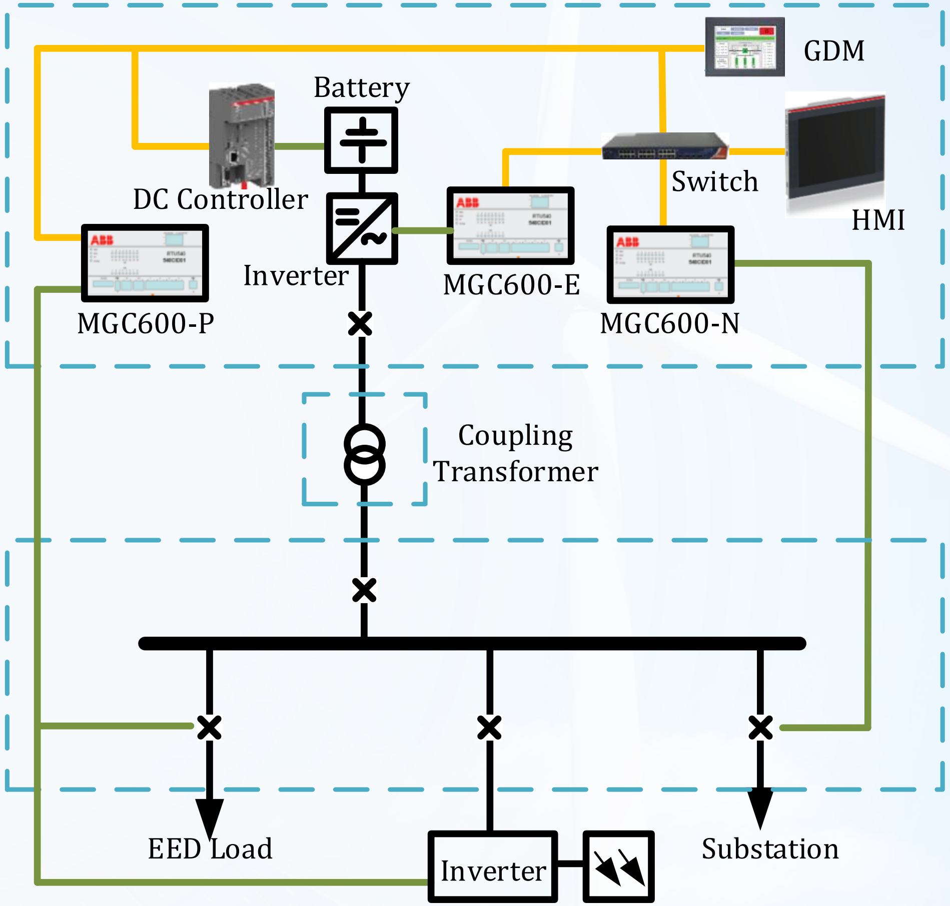
Integration of DES in IITR Distribution Network



Electrical Engineering Department Microgrid Architecture

Total Load: 111 kW
Rooftop solar PV: 70 kW
Lithium Ion Battery: 200 kWh





- Battery control panel and control cabinet
- Controller for Network/grid, load and, solar PV with Sync. facility
- Islanding Relay

- System Ethernet Switch and Router
- HMI touch screen
- 400/415V, YNd11

Details of BESS at Electrical Engineering Department

- 300 kVA inverter modules
- 200 kWh-200 kW Lithium-Ion batteries
- Exhaust/HVAC systems for Lithium-Ion battery
- Battery control panel and control cabinet
- Controller for network/grid, load and, solar PV with sync. facility
- Islanding relay
- System ethernet switch and router
- HMI touch screen
- Coupling transformer, 250kVA, oil type, two winding transformer, outdoor type, oil type, 400/415V, YNd11

200 kWh Lithium-Ion batteries being deployed at EED

Real Time Analysis of Distribution Network with Solar Integration

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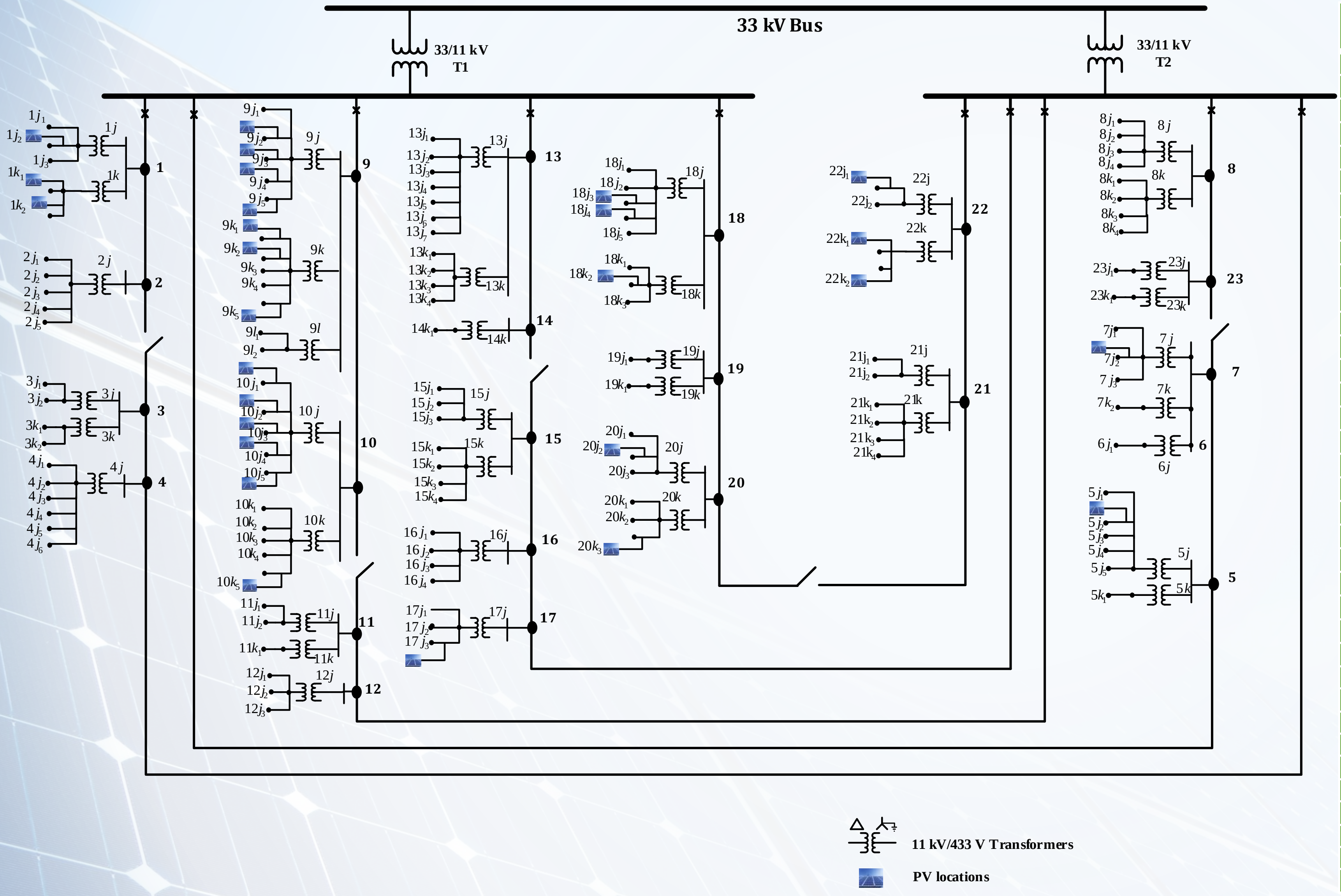

S. No.	Site (Departments / Centers)	Peak Power O/P (kWp)
1	Alternate Hydro Energy Centre	42
2	Dept of Architecture & Planning	66
3	Geomatics Engg.	60
4	Dept of Civil Engineering	200
5	Department of Chemistry	61
6	Dept of Chemical Engg	119
7	Dept of Management Studies	40
8	Dept of Earthquake Engg	66
9	Dept of Earth Science	50
10	Institute Computer Centre	32
11	Water Resource Development &Mgnt	43
12	Dept of Electronics and Computer Engg	114
13	Dept of Electrical Engg	170
14	Dept of Humanities and Sciences	35
15	Dept of Hydrology	26
16	Dept of Maths & Physics	60
17	Dept of Metallurgy	159
18	MCA block	15
19	Institute Instrumentation Centre	22
20	Dept of Mechanical Engineering	100
21	Mahatma Gandhi Central Library	42
22	Lecture Hall-1,2	30
23	Lecture Hall Complex	84
24	Hafiz Mohd Ibrahim Building	61
25	Industrial Block	48
26	OP Jain Auditorium	21
27	RS wing	46
28	Jawahar Bhawan	178.2
29	Govind Bhawan	129.36
30	Ravindra Bhawan	136.29
31	Rajendra Bhawan	137.28
32	Azad Bhawan	67.32
33	Cautley Bhawan	92.4
34	Ganga Bhawan	59.4
35	IIT R Hospital	66
	Total	2678.25

Monitored Load Profile

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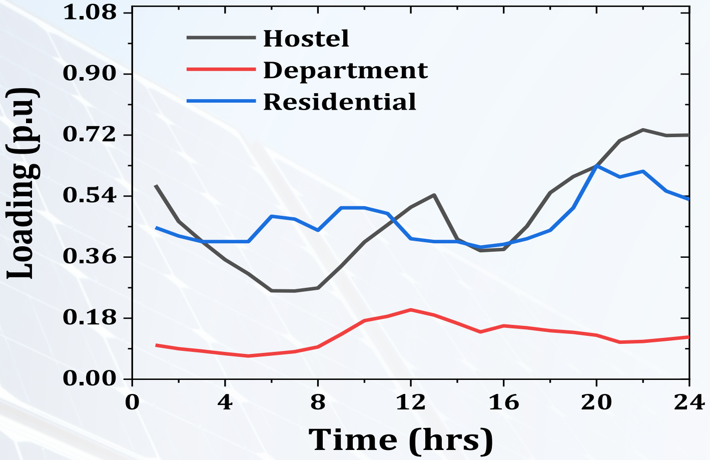
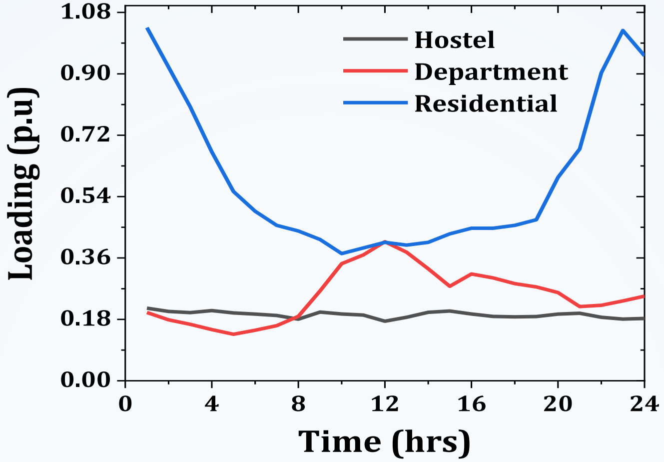
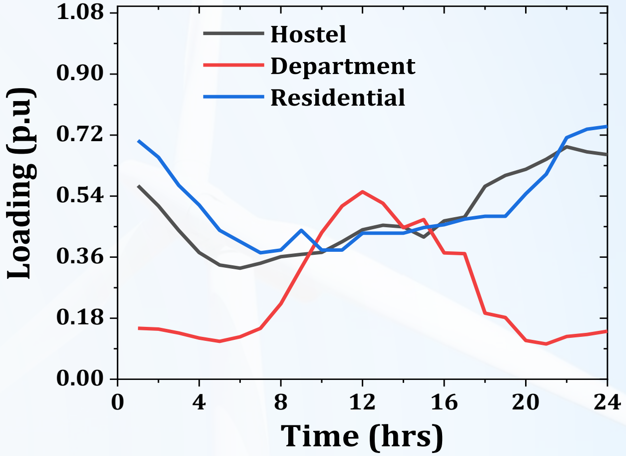
Spring season load



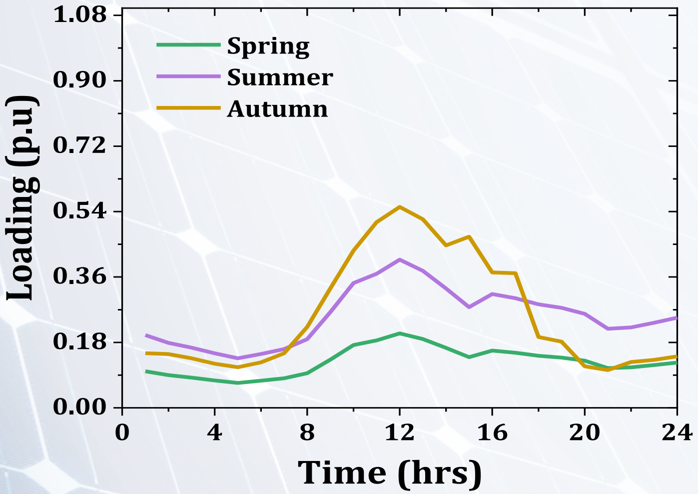
Summer season load



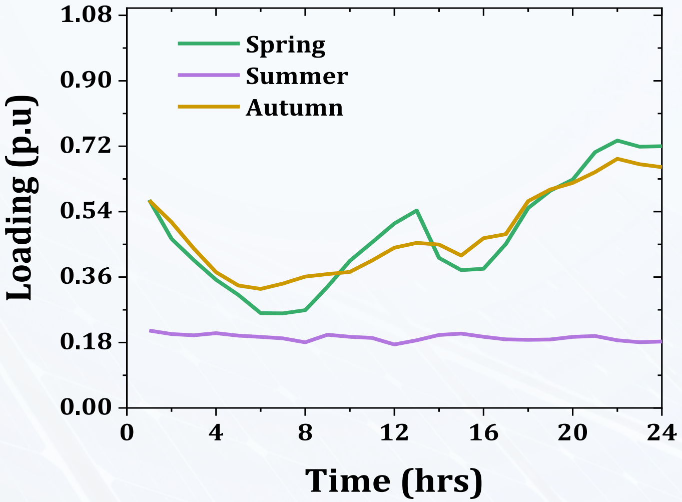
Autumn season load



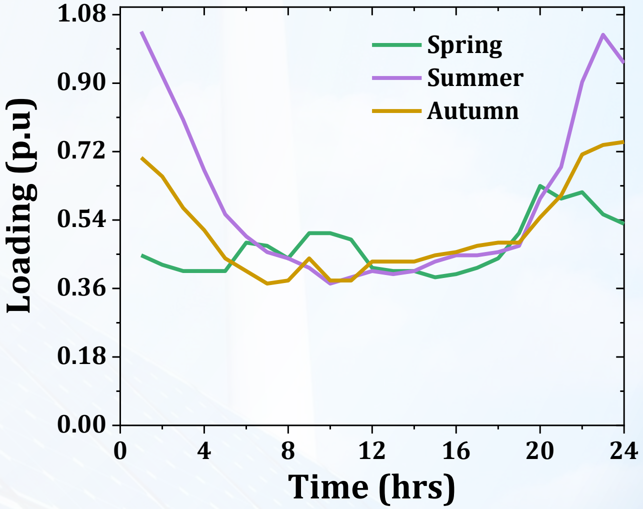
Departmental load



Hostel load



Residential load



Real Time Voltage Variations with PV Integration

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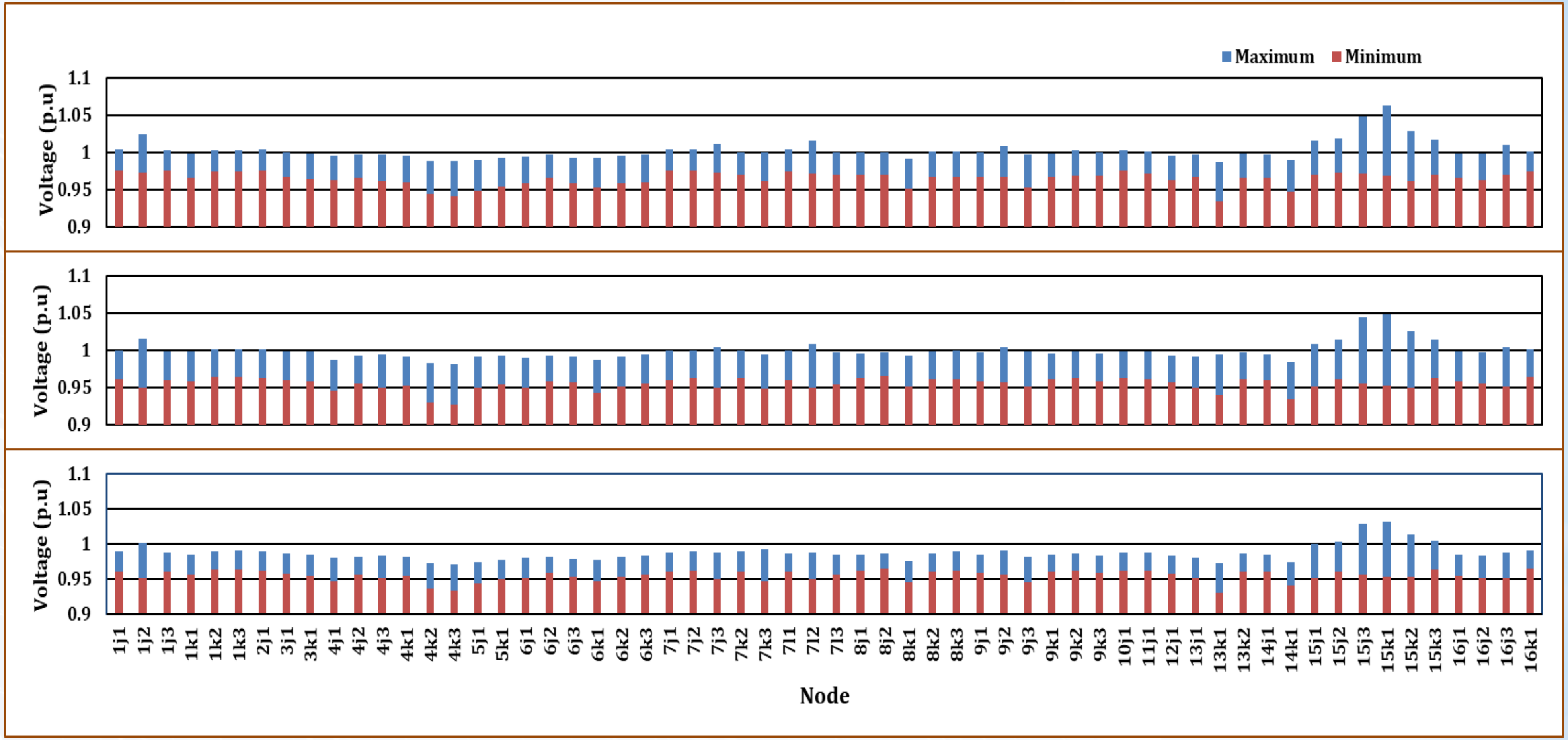
Conclusion

- Overvoltage signifies high PV penetration with lightly loaded condition.
- Absence of PV and high loading condition lead to low voltages at some of the locations.
- For efficient utilization of available surplus PV power, deployment of BESS can be helpful.



Maximum and Minimum voltage (p.u.) at various buses in (a) spring (b) summer (c) autumn season

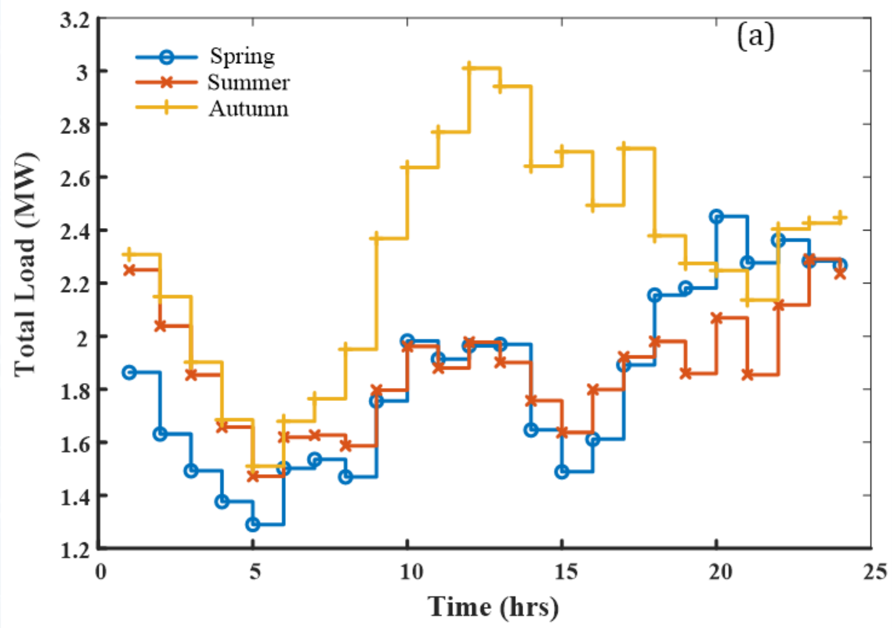
Optimal Allocation of BESS

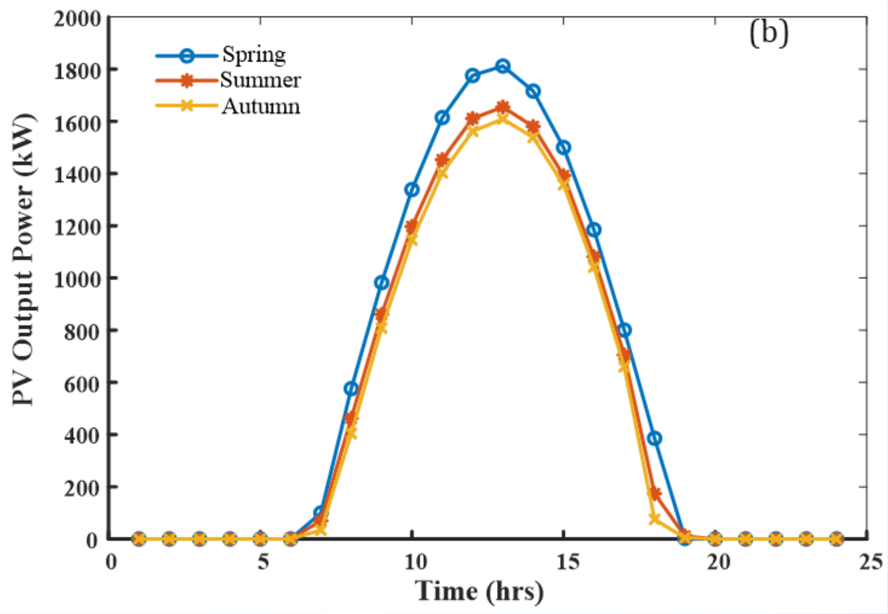
Objective: Sitting and sizing of BESS in a solar penetrated network to reduce investment and operation cost of the battery.

Contributions:

- Distributed BESS planning with uncertainty of PV and loads, battery's operating lifecycle.
- A linearized AC-OPF based MILP model.

Parameters	Values
Investment Cost of Li-ion battery (Ref. NREL)	370 $/kWh 370*4 $/kW
Fixed O&M Cost	2% of $/kW
Lifetime	10 years
Capital Recovery Factor (r=7% and lifetime=10 yrs)	0.1424
Discharging/ Charging period	4 Hrs.
DoD Limits	20% to 80%





(a) Total load variation of IITR network for three seasons (b) Total solar generation

Ref. W. Cole and A. W. Frazier, "Cost projections for utility-scale battery storage: 2020 update," 2020.

Optimal Allocation of BESS

Objective Function: Min. Sum (Power rating cost+ Energy rating cost+ Fixed Operation and maintenance cost of Li-ion battery+ Grid input

$$f = \sum_t MP_t P_{grid} + C_E \sum_{es} E_{rated} + C_p \sum_{es} P_{rated}$$

Set of network constraints: Nodal power balance, Voltage limit at each node, linearized power flow equations, etc.

Nodal Power balance $P_{grid} + P_{PV} + P_{dch} = P_D + \sum_{i,j}^{N} P_{ij} + P_{ch}$

Voltage limits at each bus $V_{min} \leq V_i \leq V_{max}$

Linearized power flow $P_{ij} = V_{nom}\left(\Delta V_i - \Delta V_j\right) G_{ij} - V_{nom}^2 B_{ij} \theta_{ij}$

Set of energy storage constraints: State of energy, charging and discharging power limits, state of charge limits, total energy storage capacity, same energy at the start and end of the day, etc.

Energy stored at time t: $E_i(t+1) = E_i(t) - \Delta t(\frac{P_{dch,i}}{\eta} - P_{ch,i}\eta \quad)$

Avoiding simultaneous charging and discharging: $U_{dch,i} + U_{ch,i} \leq 1$

Status of initial and final energy over a period of 24 hrs : $E_i(1,1) = E_i(t,1) = 50\%\ of\ E_{rated,i}$

PHIL Simulation

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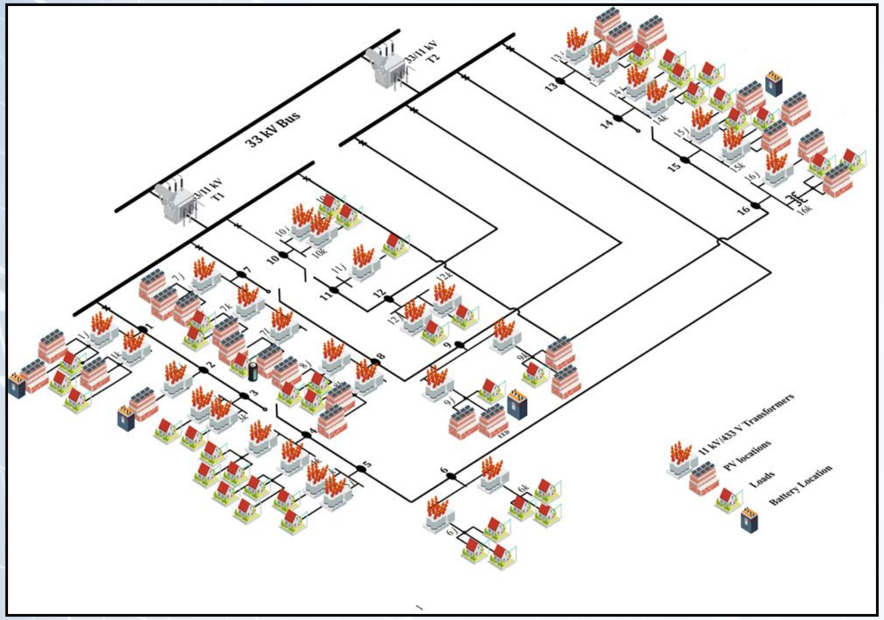

IITR DISTRIBUTION NETWORK

Integrated with distributed energy storage system

MTU

6- Racks Real Time Digital Simulator

GTAO

GTAI

Control signal to Power amplifier

Monitored V&I signals

POWER AMPLIFIER

DISTRIBUTED ENERGY STORAGE

Communication signals

Power signals

BESS Installation at Old Humanities Building

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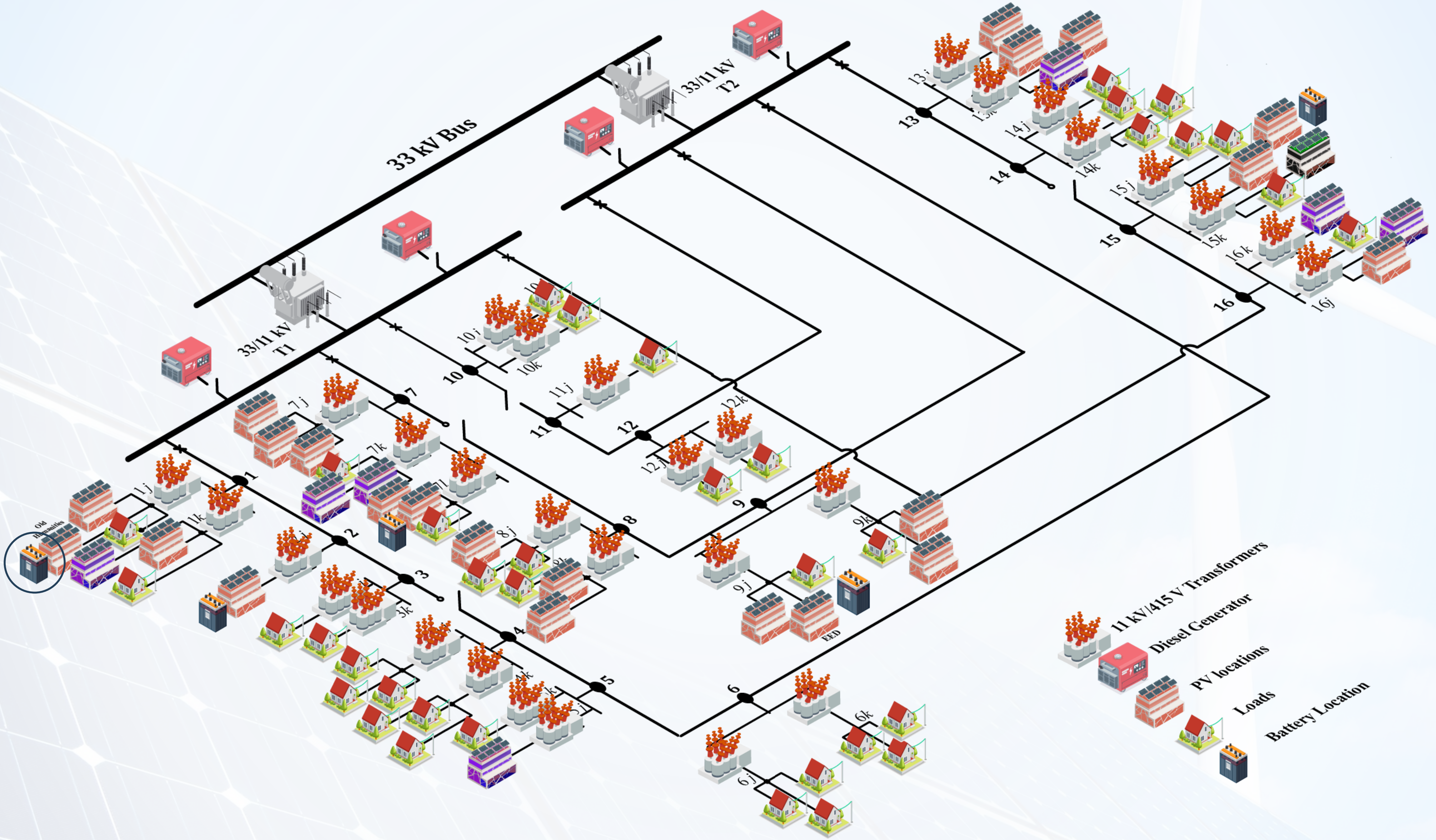
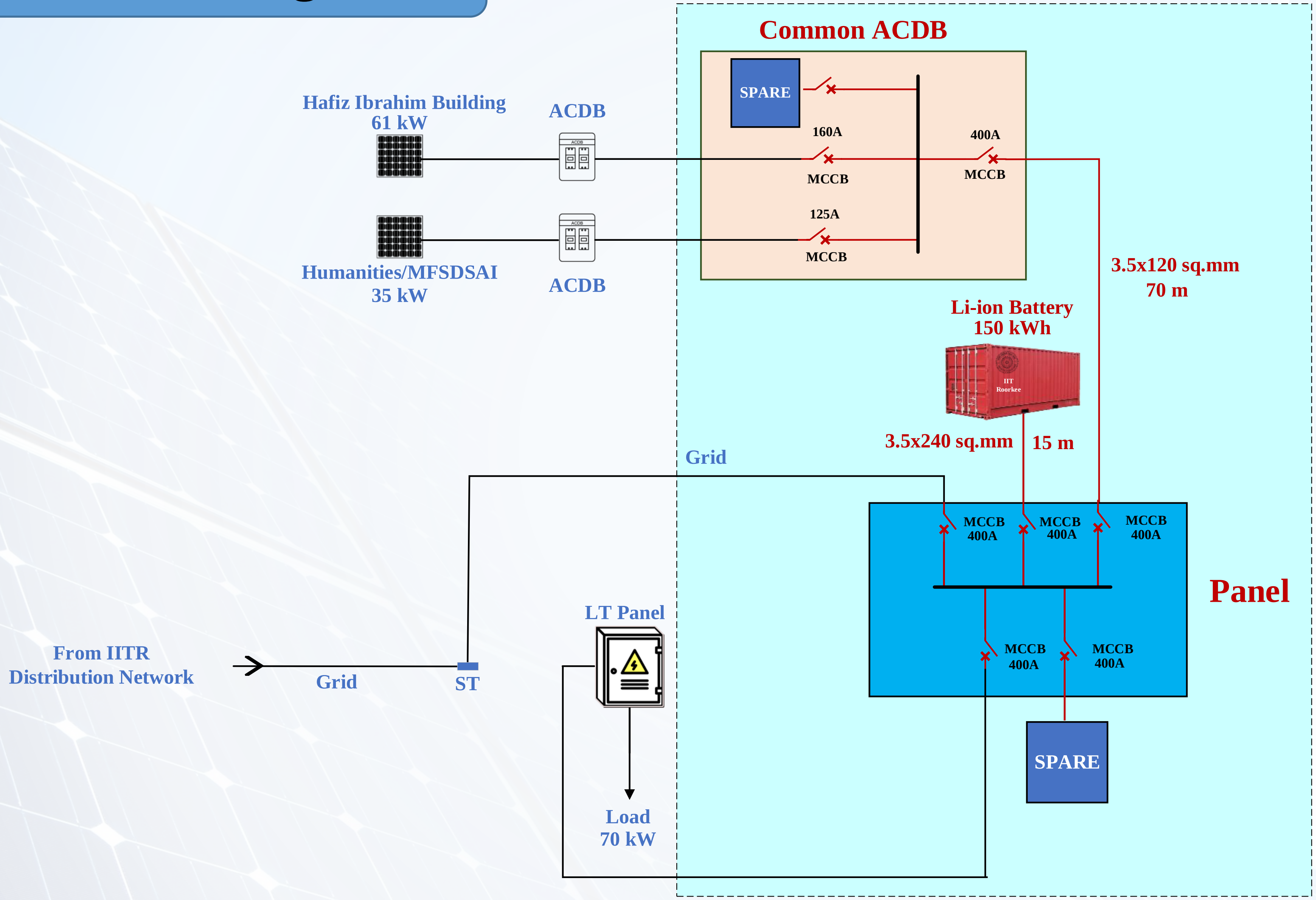
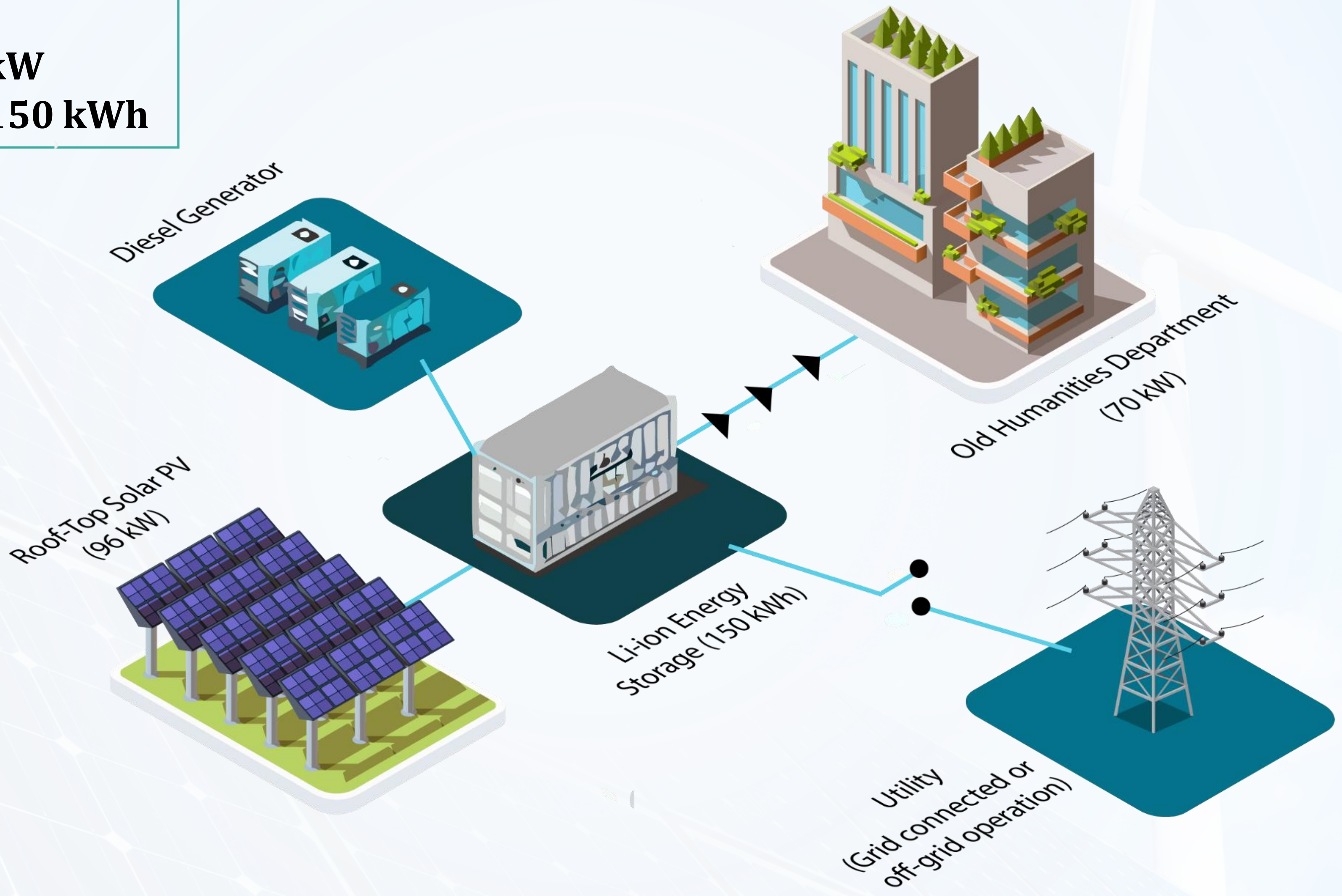


Single Line Diagram



Old Humanities Department Microgrid Architecture

Total Load: 70 kW
Rooftop solar PV: 96 kW
Lithium Ion Battery: 150 kWh



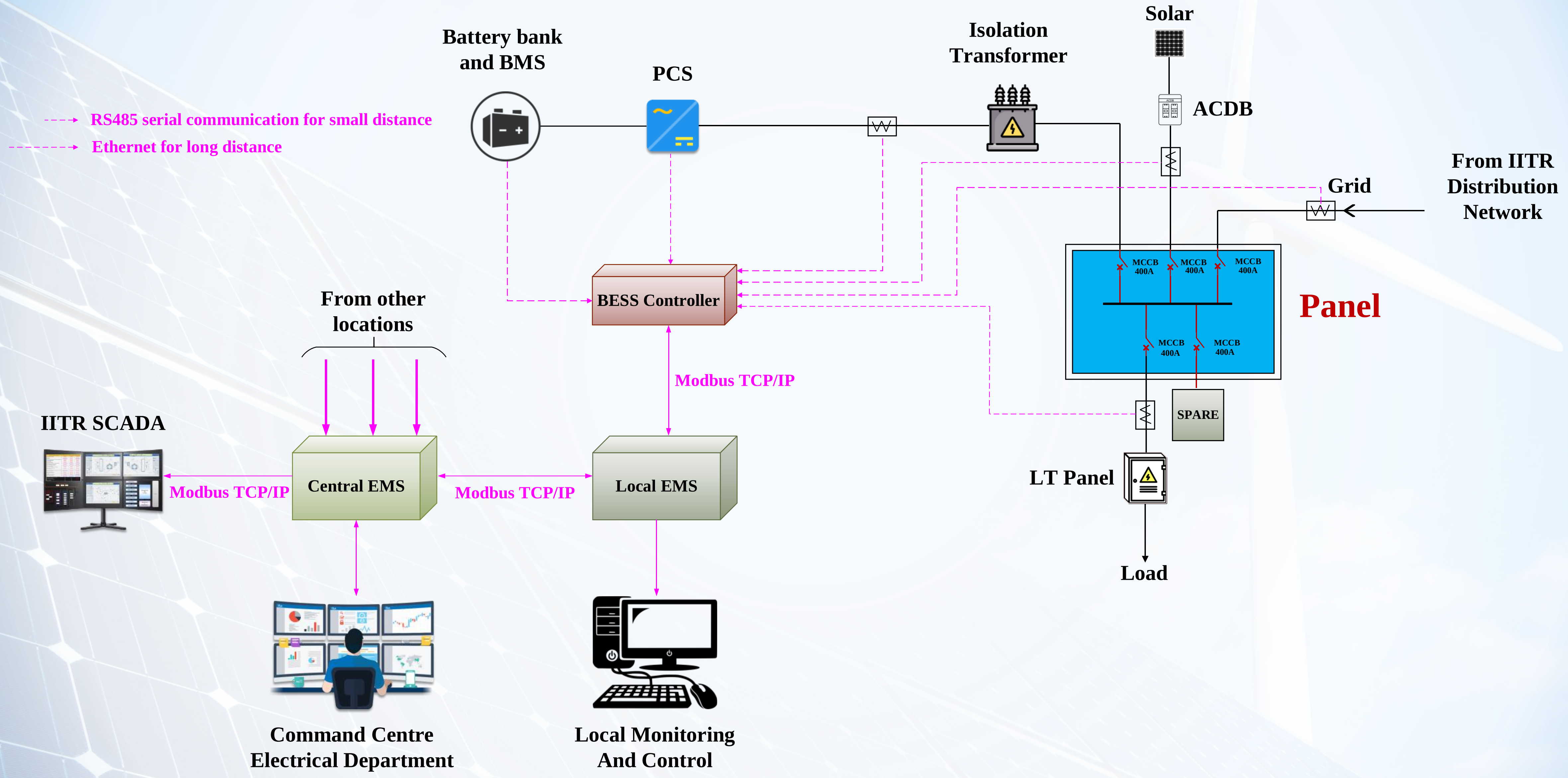
BESS container and components

Fig: The installed BESS Container

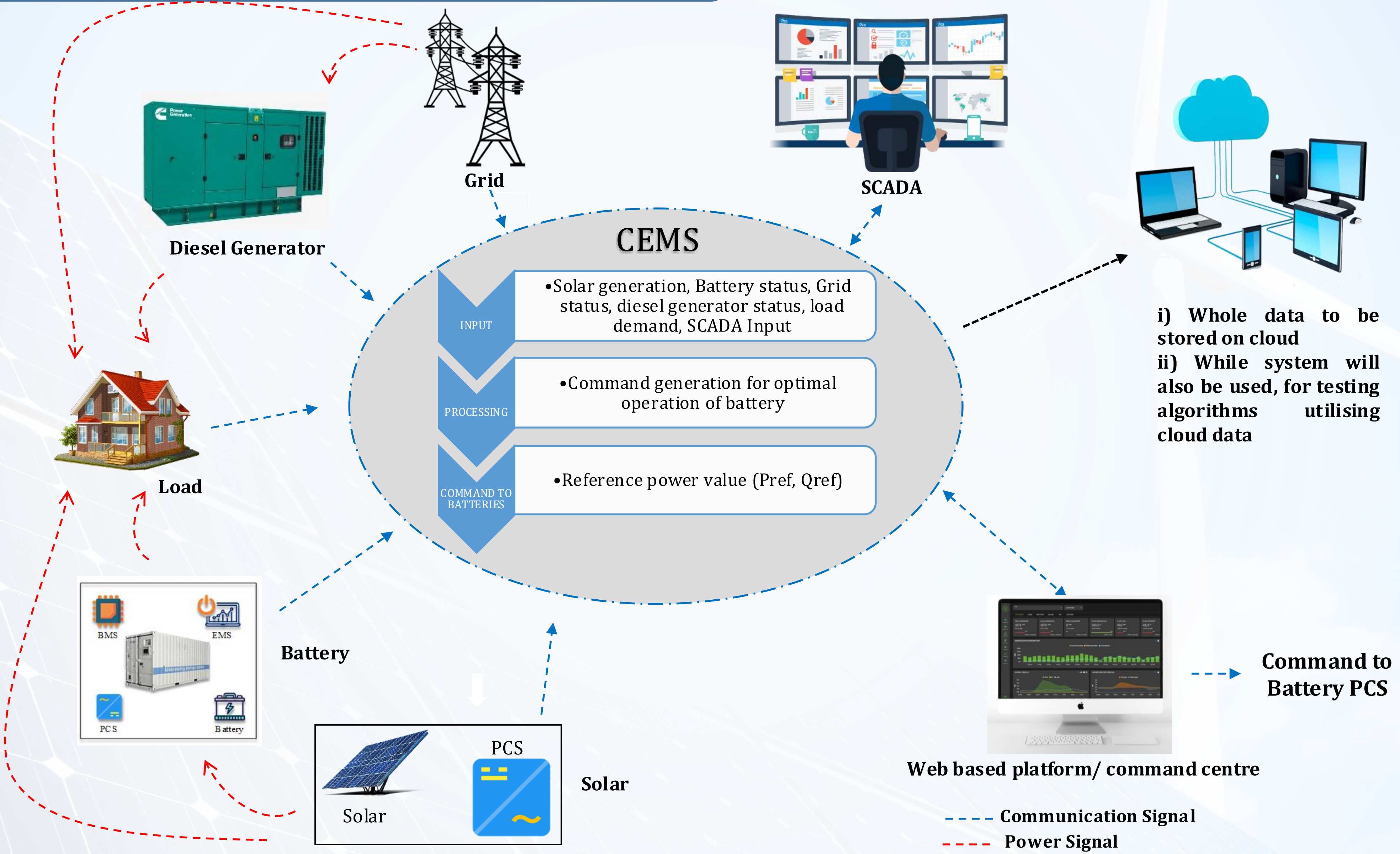
Fig: Battery Bank and BMS

Fig: EMS and PCS

Old Humanities Department Communication Setup



Framework of Central EMS (CEMS)



Central Energy Management System

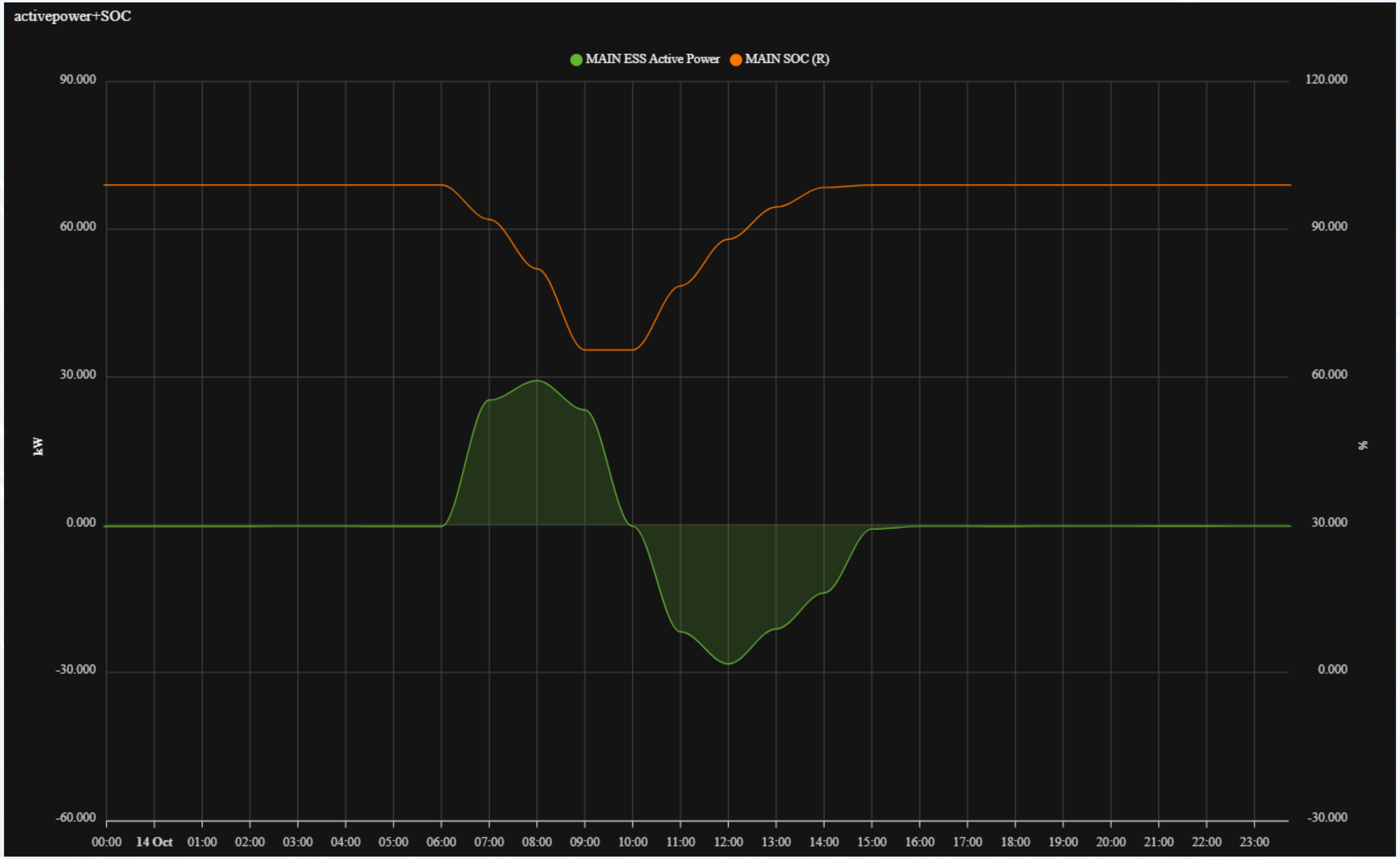
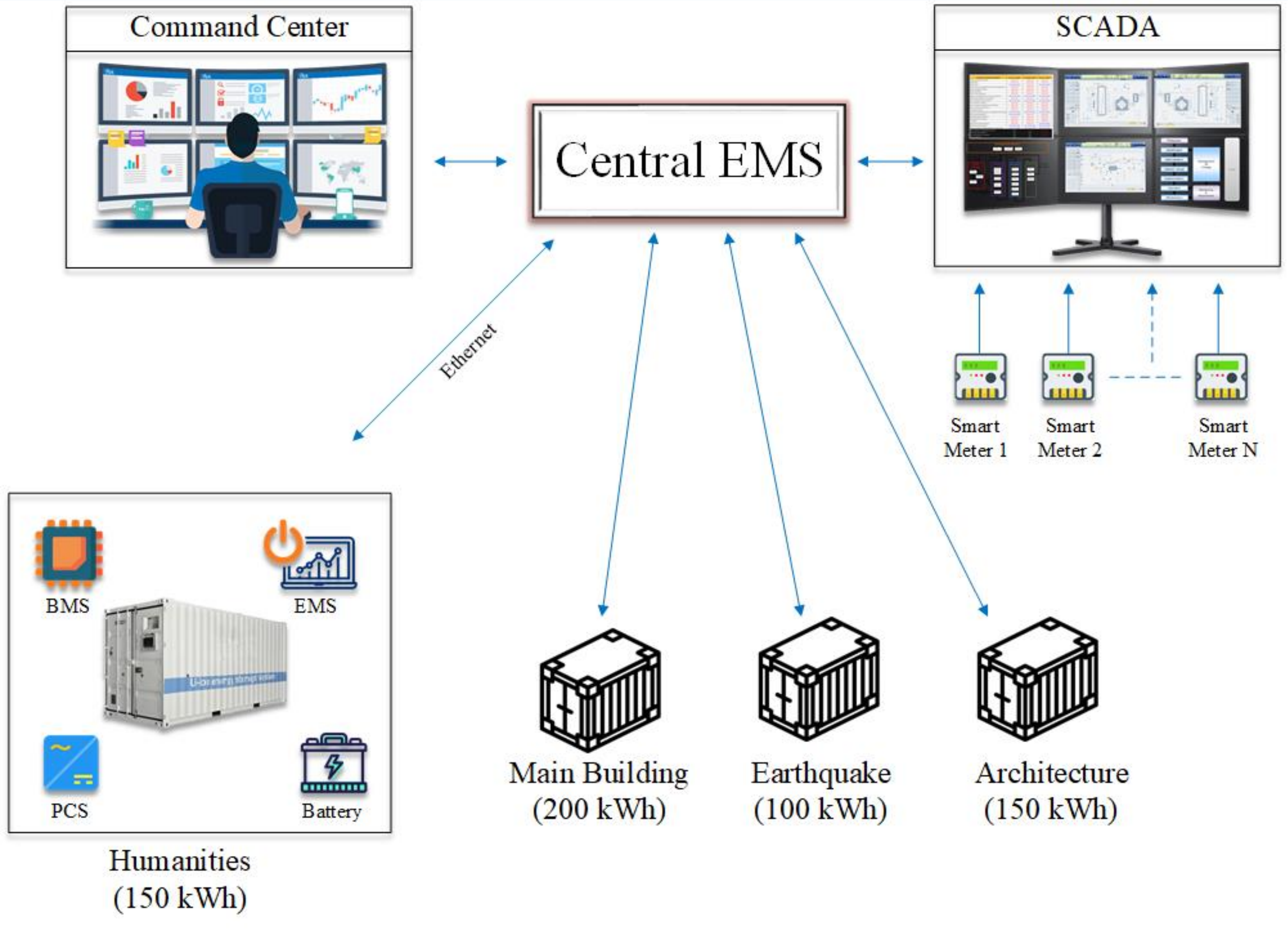


Fig: Active power and SOC of BESS during charging/discharging (online)

Integration of DES with SCADA and CEMS



Outcomes

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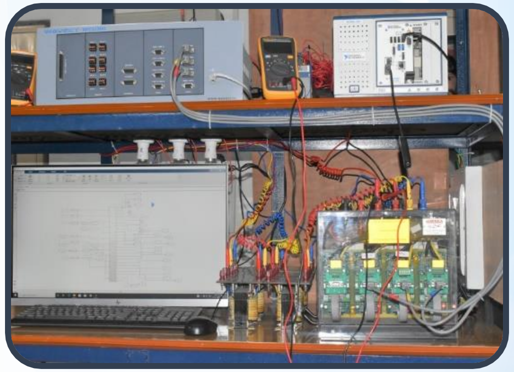
Outcomes

Applicable to low voltage distribution network with rooftop PV installations.

Interoperability of microgrids in the distribution system improves the reliability of supply to the local consumers.



Use of battery energy storage system (BESS) as back up and development of technologies to maintain uninterrupted power supply.

Energy storage deployment will play a crucial role in achieving India's target of 280 GW PV installation by 2030, necessitating a demand for flexibility in power system.

Multi Microgrid Structure (Future Scope)

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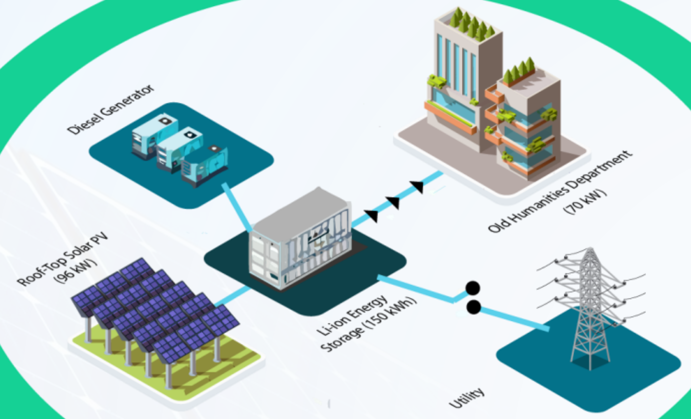
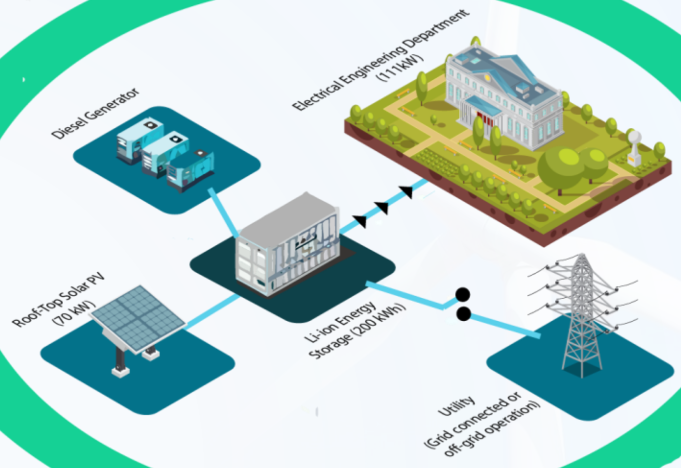
Old Humanities Department





Electrical Engineering Department

Main Building

Architecture Department

Earthquake Department

Future Scope

- Data Analysis and model-based scheduling of distribution grid.
- Economic scheduling of multi-microgrids for efficient operation.
- The future distribution network will have several connected microgrids which are required to be operated as fully independent and controllable entities as per the grid regulations.
- The low voltage distribution networks are reconfigurable and after storage integration, a reliability analysis can be carried out.

THANK YOU!