



CMET

CENTRE FOR MISSION ON ENERGY TRANSITION

Where Clean Energy Meets Innovation



<https://cmet.manit.ac.in/>

MANIT Bhopal

Preparing the Grid for Renewables. Preparing Renewables for the Grid.

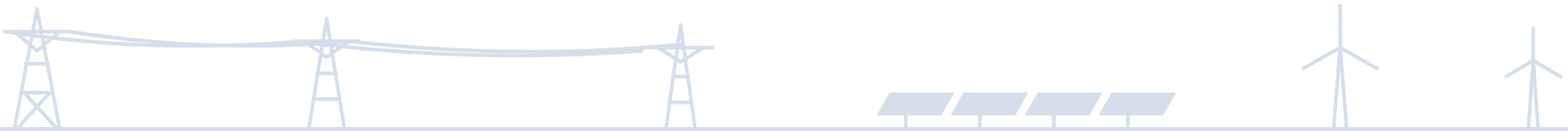
Advancing Power-System Planning, Grid
Innovation and Renewable Energy Integration

RESEARCH

INNOVATION

IMPLEMENTATION

POLICY



About CMET

At CMET, the objective is not simply to enable more renewable energy, but to ensure that every addition contributes to a stronger, more flexible and future-ready electricity grid.



Established at Maulana Azad National Institute of Technology (MANIT), Bhopal



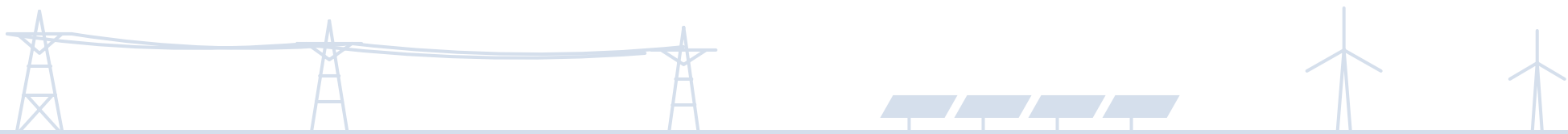
In collaboration with the New and Renewable Energy Department, Government of Madhya Pradesh

India's energy transition is entering a phase where the challenge is no longer limited to how much renewable energy can be installed, but increasingly where it should be developed, how much the grid can accommodate, and how renewable energy and storage can be planned and operated to strengthen the power system.

The Centre for Mission on Energy Transition (CMET), established at Maulana Azad National Institute of Technology (MANIT), Bhopal, in collaboration with the New and Renewable Energy Department, Government of Madhya Pradesh, is working to address these questions through a unique combination of advanced power-system research, technology development, field demonstrations and policy engagement.

From identifying grid-ready locations for renewable energy and assessing transmission and distribution network capabilities, to optimising solar-storage systems and unlocking grid-support services from existing renewable assets, CMET focuses on making the energy transition technically feasible, economically efficient and practically implementable.

What sets CMET apart is its ability to move beyond theoretical analysis. Working closely with utilities, government agencies, regulators and research partners, the Centre uses real network data to develop planning tools, validate technologies on operating power systems and translate research findings into actionable planning methodologies, procurement frameworks and regulatory interventions.



Our Core Research and Innovation Areas



Renewable Energy Siting and Transmission Readiness

Identifying grid-ready locations for renewable energy and storage through transmission headroom assessment, network constraint analysis and infrastructure planning. Initiatives such as RIPE and Trans-IRP aim to align renewable energy deployment with transmission capability and future grid requirements.



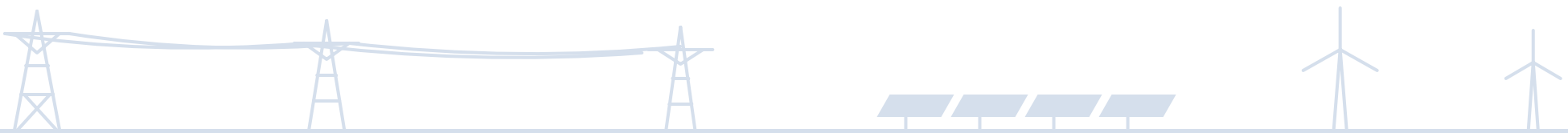
Integrated Resource Planning (IRP)

Developing state-level planning frameworks that integrate renewable generation, energy storage, resource adequacy, transmission requirements and system economics to support informed, cost-effective and reliable long-term power-sector investments.



Distribution Grid Readiness and Hosting Capacity

Assessing and enhancing the capacity of distribution networks to accommodate decentralised renewable generation. Through GridLens, CMET examines feeder constraints, changing demand conditions and smart inverter capabilities to enable greater renewable integration.



Our Core Research and Innovation Areas



Inverter-Based Grid Support and Reactive Power Management

Unlocking the potential of distributed solar inverters for voltage regulation and reactive power support. CMET's field demonstrations at Raipura, Sandla and MANIT have contributed to technical innovations, procurement provisions and regulatory developments in Madhya Pradesh.



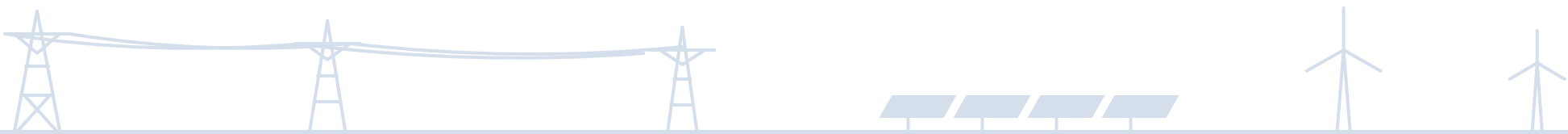
Energy Storage and Hybrid Renewable Systems

Advancing the planning, sizing and operation of battery storage and solar-storage systems. Research on AC-DC coupling and capacity optimisation addresses system architecture, grid-support capabilities, dispatch strategies, metering and techno-economic performance.



Planning Tools, Procurement and Regulatory Innovation

Translating power-system research into practical decision-support tools, procurement frameworks, technical standards and regulatory interventions, enabling utilities and policymakers to move from analysis to implementation.



CENTRE FOR MISSION ON
ENERGY TRANSITION

CMET

MANIT BHOPAL

DYNAMIC VOLTAGE CONTROL FROM SOLAR INVERTERS

Grid support,
decentralised,
reliable and
cost-effective

REGULATES BOTH
UNDERVOLTAGE
AND OVERVOLTAGE

AVOIDS OR DEFERS
CAPEX ON CAPACITOR
BANKS

DECENTRALISED
GRID MANAGEMENT
AT THE LOCAL LEVEL

USES EXISTING
INVERTER AND PPC
INFRASTRUCTURE

A CMET flagship program
to demonstrate and enable
solar inverters as active
grid-support assets.

1 Why utilities need it

- 1 Long rural feeders face high voltage variation, affecting supply quality and consumer experience.
- 2 High solar penetration can cause voltage rise during light load and voltage drop during peak load.
- 3 Conventional capacitor banks provide fixed, stepwise support, can only inject and are not location-specific.
- 4 Solar inverters can provide fast, continuous and location-specific voltage control, both injection and absorption, without additional hardware at the substation.

2 Inverters can control both undervoltage and overvoltage

Undervoltage ($V < 0.97$ pu)

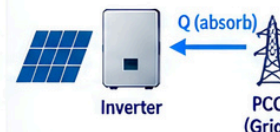
Inverter injects (supplies) reactive power to raise the voltage (capacitive operation).



Helps increase voltage
at the PCC

Overvoltage ($V > 1.03$ pu)

Inverter absorbs (consumes) reactive power to reduce the voltage (inductive operation).



Helps reduce voltage
at the PCC

3 From capacitor banks to dynamic voltage control

Conventional capacitor banks	Inverter-based dynamic voltage control
Fixed, stepwise compensation	Dynamic, continuous control
Limited to specific locations	Available at multiple locations (rooftop, feeder, utility scale)
Can only inject (no absorption)	Supports both undervoltage and overvoltage
Designed for localised/typical support	Fast, automatic and location-specific response
Additional infrastructure and maintenance	Uses existing inverter and plant infrastructure
Not effective for overvoltage	Controls both voltage rise and voltage drop
Cannot address future hosting capacity needs	Avoids or defers CAPEX on additional capacitor banks and other voltage-control assets

4 Field pilots in Madhya Pradesh: Technical validation of dynamic voltage control

MANIT Rooftop | 230 kW



- Institutional rooftop demonstration of dynamic voltage control.
- PCC-based control (Volt-VAR and time-based modes).
- Improved voltage profile and reduction in harmonic distortion (THD).

Shamshabad | 2 MW



- Demonstrated PPC-based dynamic voltage control.
- Automatic control with remote monitoring.
- @QNight / night-time voltage support demonstrated.
- Stable operation and improved voltage profile.
- Feeder-level deployment on rural 11 kV network.

Sandla | 2 MW



- Dynamic voltage control with remote PCC measurement.
- PPC-enabled supervision and control.
- Improved feeder voltage management.
- Demonstrated scalability for wider deployment.

5 Metering and implementation using existing infrastructure



- PCC-level measurement using existing ABT meters with direction-aware accounting.
- No additional hardware in most cases — uses existing inverter and plant controller infrastructure.
- MDAS and billing systems can record and process voltage-support data similar to energy accounting.
- Enables operational deployment with minimal incremental cost and clear, measurable performance.

6 MPERC: A measurable grid service

MPERC has approved a regulatory framework for decentralised solar voltage-support service from grid-connected solar projects.

PCC voltage at ABT	Applicable provision
$V < 0.97$ pu	Reactive power injection (capacitive) rewarded; absorption penalised.
$V > 1.03$ pu	Reactive power absorption (inductive) rewarded; injection penalised.
0.97 – 1.03 pu	No incentive or penalty.

Settlement rate:
₹0.05/kVArh
(incentive or penalty)

MPERC Order
15 July 2026
Petition 12/2026

7 Value for DISCOMs

- Improved voltage profile across rural and urban feeders.
- Control of both undervoltage and overvoltage.
- Stronger local grid management at feeder level.
- Better renewable integration and higher solar hosting capacity.
- Avoids or defers CAPEX on capacitor banks and other voltage-control assets.
- Better renewable integration and reduced dependence on upstream reactive supply.
- Scalable deployment across solar projects.

From distributed solar generation to decentralised voltage management — a scalable, cost-effective solution for stronger distribution networks.

GridLens

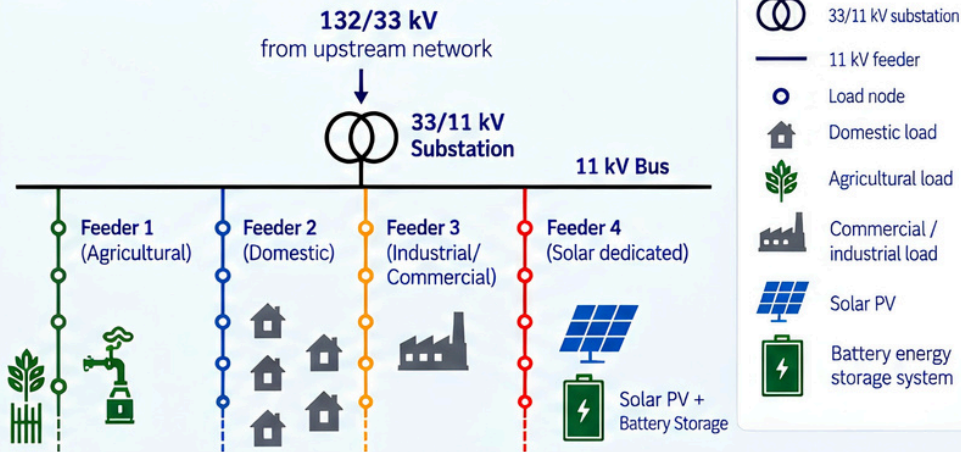
Distribution System Intelligence

Turn feeder data into planning-ready decisions for solar, storage and grid strengthening.

GridLens helps DISCOMs use network data to understand feeder constraints, assess hosting capacity, evaluate smart inverter control, and identify appropriate solar, storage and grid interventions — enabling confident, cost-effective investment decisions.

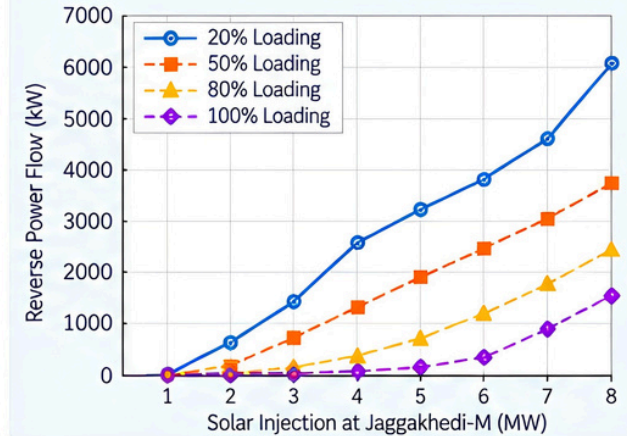
Illustrative Distribution Feeder

From a 33/11 kV substation with multiple 11 kV feeders



Illustrative Reverse Power Flow Result

Reverse power flow at a 33/11 kV substation for varying solar injection and feeder loading.



Why DISCOMs Need GridLens

- 1** Rising solar penetration can create voltage issues, reverse power flow and local network stress.
- 2** Feeder conditions vary significantly across agricultural, domestic and mixed-load networks.
- 3** Investment decisions need feeder-specific technical evidence, not generic assumptions.
- 4** Utilities need to know where interventions will create the highest network value.

What GridLens Offers

- 1 Hosting capacity assessment**
Estimates additional solar that can be integrated on each feeder without violating network limits.
- 2 Solar + storage planning, sizing and placement**
Identifies suitable feeder locations and optimal sizes for solar PV and battery storage systems.
- 3 Smart inverter control assessment (Volt-VAR / Volt-Watt)**
Assesses and configures smart inverter control strategies for voltage support and higher hosting capacity.
- 4 Intervention planning for network strengthening**
Evaluates and compares intervention options such as smart inverter control, storage and network augmentation, to address constraints and improve network performance.
- 5 Planning-ready outputs for investment decisions**
Provides clear technical recommendations, and prioritised actions for investment-ready reports.

Key Outputs for DISCOMs

- 1 Feeder-wise constraint identification**
Locations with potential voltage issues, high loading or reverse power flow.
- 2 Feeder-wise hosting capacity**
Additional solar that can be integrated for different scenarios.
- 3 Indicative solar + storage sizing and placement**
Suitable locations and optimal sizes to maximise network benefits.
- 4 Recommendations on smart inverter control and supporting interventions**
Actionable guidance for network strengthening.

From Network Data to Investment Decisions

- 1 Analyse network conditions**
Feeder topology, load profiles, DERs and equipment parameters.
- 2 Assess opportunities and constraints**
Hosting capacity, reverse power flow and network limitations.
- 3 Plan and evaluate interventions**
Solar, storage, smart inverter control and network augmentation.
- 4 Support investment decisions**
Prioritised actions for phased implementation.

Cleaner Energy
Smarter Networks
Stronger DISCOMs

Trans-IRP

Transmission-Informed
Integrated Resource
Planning

**Plan renewable
growth where
the grid can
deliver it.**

Trans-IRP connects resource adequacy and transmission planning in one framework. It helps planners assess how generation, storage and transmission need to evolve together for a reliable, cost-effective and grid-feasible energy transition.

A collaborative initiative with
UC Santa Barbara, WRI India
and Prayas Energy Group.

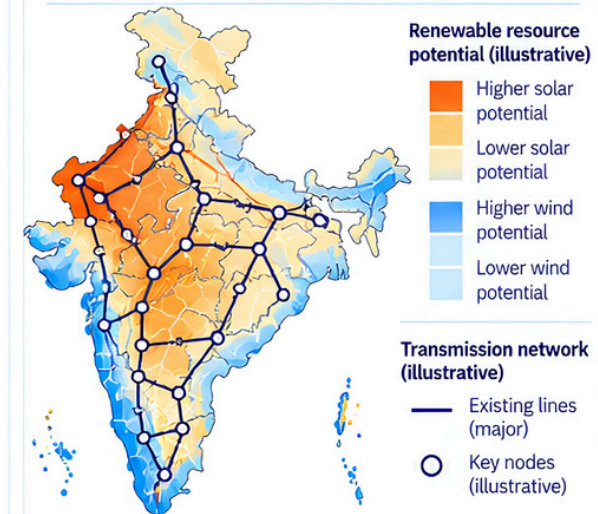
Why it is needed

- Renewable expansion must be backed by deliverability, not just capacity addition.
- Resource adequacy and transmission planning are often done separately, even though they shape each other.
- Good generation or storage options are not always grid-feasible without network readiness.
- Coordinated planning helps avoid bottlenecks, stranded investments and delayed integration.

What Trans-IRP does

- Translates resource adequacy outputs into transmission planning.
- Evaluates transmission headroom, deliverability and network constraints.
- Tests renewable, storage and transmission scenarios in one planning framework.
- Identifies bottlenecks, reinforcement needs and priority corridors.
- Supports phased, evidence-based investment decisions.

Illustrative national renewable resource and transmission context



Source: MNRE / National Institute of Solar Energy (NISE), Solar PV Potential of India (Ground Mounted) 2025 (Map); MNRE / National Institute of Wind Energy (NIWE), Wind resource map / Wind overview. Illustrative synthesis for planning context only; does not imply grid-feasible project approval or final state selection.

How it works



What it will yield

- Transmission-informed resource planning insights.
- Indicative grid-feasible renewable and storage pathways.
- Headroom, bottleneck and corridor reinforcement insights.
- Stronger evidence for coordinated generation, storage and transmission planning.

RIPE

Renewable Interconnection Planning Engine

Optimization-based Transmission Intelligence for Grid-Feasible Renewable Deployment

RIPE plans the right renewable capacity at the right location, in the right configuration, on a grid that can actually deliver it.

RIPE is a PSS®E-based, optimization-driven intelligence engine that connects resource adequacy pathways with transmission headroom, curtailment sensitivity, storage integration and reinforcement planning in one integrated workflow.



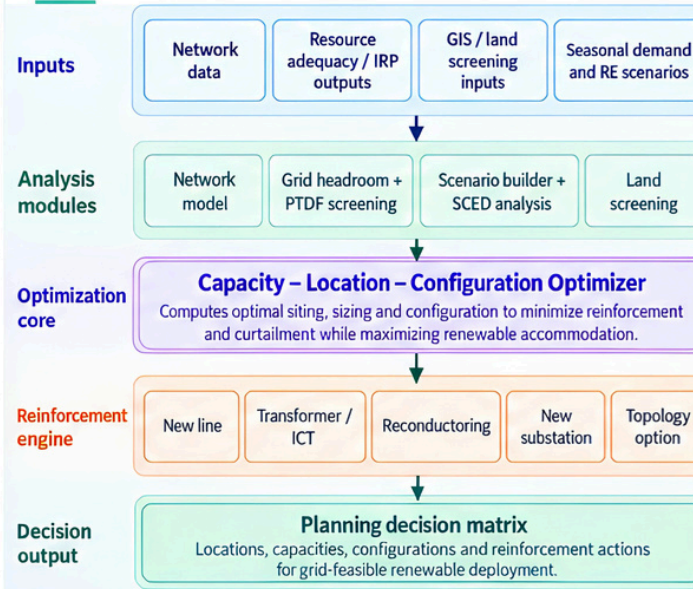
Built for utilities, planners and renewable deployment agencies.

Better Siting | Lower Curtailment | Smarter Reinforcement

Why RIPE is needed

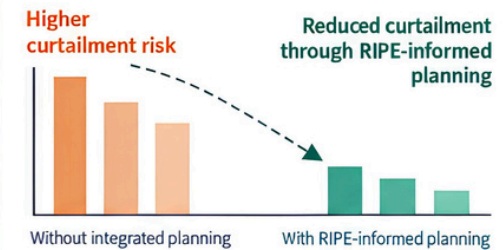
- 1 Renewable adequacy on paper does not guarantee grid-feasible deployment.
- 2 Congestion and curtailment reduce project value and delay integration.
- 3 Storage, siting and reinforcement are often planned separately.
- 4 Planners need one framework that converts adequacy pathways into network-feasible decisions for renewable deployment.

How RIPE works – optimization-based planning



Why curtailment matters

- Curtailment means renewable energy is available but cannot be fully evacuated.
- It signals insufficient headroom or corridor congestion.
- High curtailment weakens project economics and delays integration.
- RIPE helps avoid curtailment by testing scenarios, storage and reinforcements before siting decisions are finalised.



What RIPE evaluates

- Bus-wise / corridor-wise grid headroom at substations and nodes
- PTDF-based congestion sensitivity
- SCED-based seasonal and scenario outcomes
- Storage location and configuration options
- Reinforcement sensitivity and least-regret interventions

PTDF = Power Transfer Distribution Factor | SCED = Security-Constrained Economic Dispatch

What RIPE can yield

- Transmission-ready locations for renewable integration
- Indicative capacity, siting and configuration options
- Curtailment-sensitive zones and bottleneck diagnosis
- Priority reinforcement pathways
- A decision matrix for phased renewable deployment

From network analysis to planning decisions

Illustrative planning decision matrix

Location / Zone	Headroom	Curtailment Risk	Binding Constraint	Indicative Action	Planning Signal
Substation A	High	Low	None critical	Solar candidate	Proceed
Substation B	Medium	Medium	Corridor loading	Solar + BESS / phased connection	Conditional
Substation C	Low	High	ICT loading	Transformer upgrade first	Reinforce before siting
Substation D	Medium	High	N-1 thermal limit	Reconductoring / topology option	Targeted intervention

Illustrative outputs shown for communication only; actual results depend on network model, scenarios and planning assumptions.

PV + BESS

Optimal Sizing Tool

For C&I consumers and DISCOMs

Right-size solar and storage.

For the site.
For the grid.

A sizing tool that determines the best PV and battery capacity from load and solar profiles, the applicable tariff and contract terms or the grid's own limits, and shows the outcome over the project lifespan, for a consumer or a utility.

Campus and C&I consumers

DISCOMs and state utilities

RESCO or CAPEX contracts

Right-sized Solar
Smarter Storage
Stronger Grids

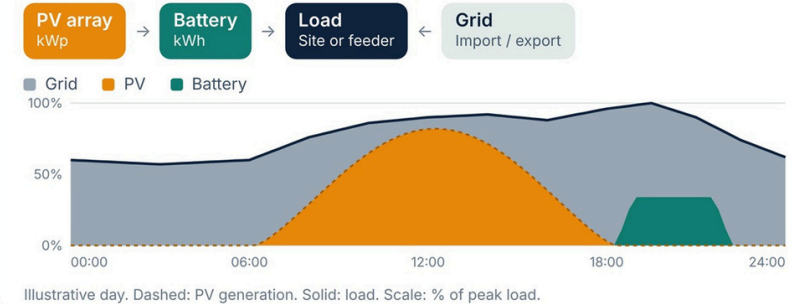
How It Works

From site data to a sized system in four steps

- 1 Load data**
Load and solar profiles for a full year, at hourly or finer resolution. Utility bills where available.
- 2 Set the objectives**
Tariff and contract terms for consumers. Transformer limits and export rules for DISCOMs.
- 3 Optimize**
Simulates operation across the project lifespan and searches PV and battery sizes.
- 4 Read results**
Recommended sizes, financial outcome and grid impact, documented in a detailed report.

What the Tool Decides

PV size and battery size, dispatched against the load



Consumer Objectives

Campus and C&I sites billed under a tariff

- 1 Lowest lifecycle cost**
Minimises discounted expenditure over the project lifespan, which maximises savings.
- 2 Contract model**
RESCO: per-kWh rate with escalation. CAPEX: capital and O&M against bill savings.
- 3 Tariff and billing rules**
Energy and demand charges, time-of-day bands and power factor terms.
- 4 Site limits respected**
Available area, budget and a curtailment cap bound the search.

Inputs: load and solar profiles, utility bills, tariff and contract terms.

DISCOM Objectives

Feeder or substation

- 1 Address peak load**
By optimising the DISCOM's procurement cost.
- 2 Optimise reverse power flow**
Reverse power flow is held within the secure limit set by the feeder's voltage limits and line losses, with surplus PV stored in the battery first.
- 3 Avoid network reinforcement**
By meeting the load locally with PV and storage.

Inputs: a load profile and a solar profile for one year.

Read the Results

Decision-ready outputs for either user

- 1 Recommended sizes**
Optimal PV capacity and battery capacity for the site or substation.
- 2 Financial outcome**
Savings, payback and IRR for the consumer.
- 3 Traceable to inputs**
A detailed report links each result to its settings and assumptions.

Built for transparency: every interval balances.

What the Tool Can Do

- | | | | |
|----------------|---|--|---|
| C&I | ✓ Tariff-accurate billing
Energy, demand, time-of-day and power factor terms. | ✓ RESCO and CAPEX
Both ownership models evaluated on the same site. | ✓ Live optimiser
Swarm search within area, budget and curtailment limits. |
| DISCOM | ✓ Peak shaving
Surplus PV stored and discharged at the daily peak. | ✓ Reverse flow control
Held within the secure limit, or zero export. | ✓ Transformer relief
Upgrade needs compared with and without the plant. |

Why It Matters

- 1 Lower energy cost**
Less spent on power across the project lifespan.
- 2 Relieved networks**
Peak load carried without overload; reverse power flow limited to the secure limit.
- 3 Deferred reinforcement**
Postpones network build-out until it is needed.
- 4 Replicable tool**
Carries across campuses, feeders and substations.

AC or DC Coupling

Rethinking Hybrid PV-BESS Architecture for the Future Grid

A technical, economic and grid-integration assessment of hybrid solar + storage architecture



Collaborative analysis by CMET, MANIT and CSTEP

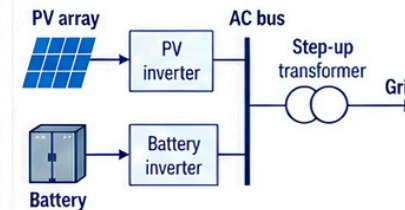
1 Why is this question important now?

- Storage is scaling and is becoming integral to renewable energy projects.
- The grid is changing, with higher inverter-based resource penetration and greater need for voltage support and flexibility.
- Architecture decisions made today affect performance over the next 10–20 years.
- Procurement decisions are being made now, and planners need to understand what capabilities different architectures can deliver.

2 What are AC and DC coupling architectures?

AC-Coupled Hybrid Plant

Separate PV and BESS inverters connected to a common AC bus.

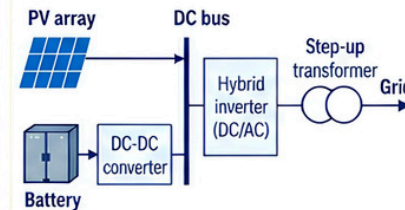


Key points:

- Independent PV and battery converters
- Battery can charge from solar or grid
- Higher operational flexibility and controllability
- Strong grid-support potential

DC-Coupled Hybrid Plant

PV and BESS connected on the DC side through a shared inverter.



Key points:

- Shared inverter architecture
- Better converter utilisation and clipping recovery potential
- Simpler plant layout in some use cases
- Grid-support capability depends on inverter headroom and controls

3 What does the analysis cover?

Technical performance	Efficiency, converter utilisation, clipping recovery.
Grid behaviour	Reactive capability, voltage regulation, dynamic response, weak-grid sensitivity.
Operational flexibility	Charging routes, dispatch flexibility, control philosophy.
Metering and commercial aspects	Energy accounting, charging source, settlement implications.
Economic assessment	CAPEX, losses, utilisation, lifecycle value.
Use-case suitability	Co-located generation, transmission-connected, distribution-connected, institutional/captive use cases.

4 What are we trying to understand?

- There may be **no universal winner**; the preferred architecture may depend on grid conditions and use case.
- The **economically preferred architecture** may not always be the one that creates the greatest system value.
- The **value of AC vs DC coupling** becomes most relevant when converter capability, grid support, clipping recovery, or charging flexibility matter.

5 What will this project deliver?

- Comparative technical assessment of AC and DC coupling
- Grid-performance insights for future-ready hybrid plants
- Economic and operational evaluation across use cases
- Metering and procurement implications for hybrid projects
- Policy-ready briefs and recommendations for planners, regulators and procurers

6 Why this matters for planning and policy

- Helps planners understand which architecture suits which application
- Supports more informed RE-BESS procurement design
- Improves alignment between plant design and grid requirements
- Contributes to better standards, performance requirements and future-ready integration

Technical Study for Scaling up KUSUM-A & C Projects in Madhya Pradesh

Optimal injection analysis to enable efficient, reliable and cost-effective deployment of decentralized solar.

1 Why is this study important?



Determines substation upgrade requirements

The choice of injection point determines how much power can be accommodated and whether substation upgrades are needed, helping DISCOMs plan cost-effectively.



Provides key knowledge for developers

Relating voltage profile, feeder length, permissible project capacity and feeder losses helps developers understand network constraints, expected losses and viable injection options.



Supports faster and better informed implementation of KUSUM-A & C

Enables selection of technically and economically viable injection points, leading to smoother approvals and efficient project implementation.

2 What does the analysis cover?



Optimal injection points

Identification of suitable locations for decentralized solar using robust technical and economic analysis.



Feeder and network assessment

Evaluation of voltage profiles, feeder loading, line length and network constraints.



Substation upgrade assessment

Assessment of upgrade needs for DISCOM substation based on projected injections at different locations.



Losses and performance

Evaluation of feeder losses and network performance to understand and mitigate potential constraints.

3 Key highlights



Identified optimal injection points for decentralized solar

through robust technical and economic analysis.



Informed decisions and potential savings

on substation upgrades for DISCOMs.



Standard Operating Procedure (SOP)

linking permissible project capacity to line length and network characteristics.



Analysed voltage profiles and feeder losses

to understand and mitigate network stress.



Analysed CUF data and recommended

targeted measures for efficiency improvement.

MP Future-Ready Grid: Transmission Planning for Madhya Pradesh

MP Future-Ready Grid

Transmission Planning for Madhya Pradesh

Plan the grid your renewable future needs, before it is built.

Brings generation adequacy and transmission planning together. It tests whether Madhya Pradesh's network can evacuate new solar and storage reliably, finds where it will be stressed, and recommends the upgrades that matter.

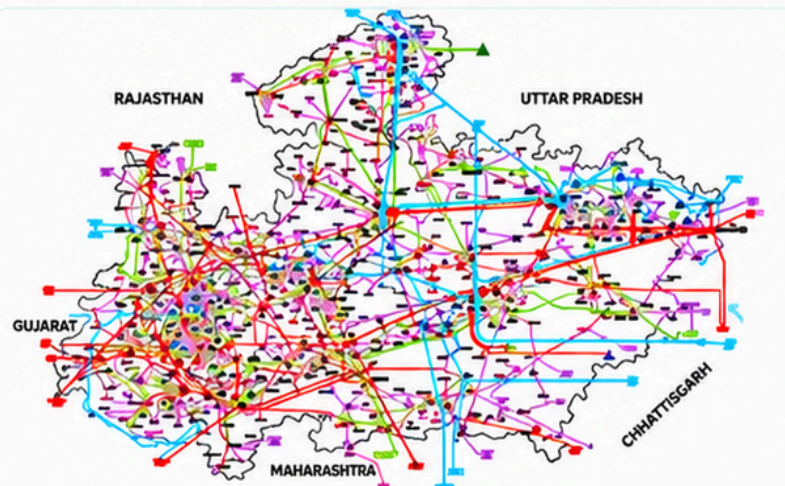


Study by MANIT Bhopal with WRL, India

Cleaner Energy
Stronger Transmission
Future-ready Grids

1 Madhya Pradesh Power Map

The state network we modelled, as on 01.06.2026 (MPPTCL).



765 kV 400 kV 220 kV 132 kV Substation Power station

Analysis at 4 specific locations: Dhar Rewa Sagar Morena-Shivpuri

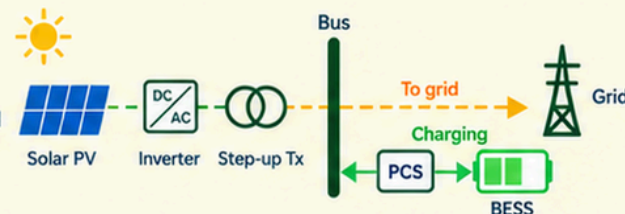
2 Solar + BESS Evacuation Check

Each of the four studied locations is tested under different operating conditions & N-1 contingency.

DAYTIME

Solar hours

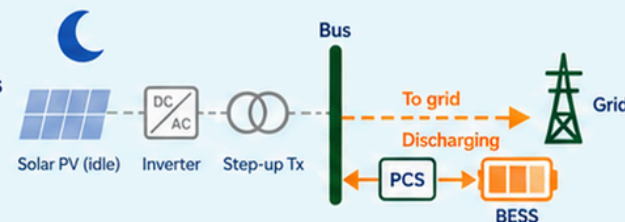
Solar feeds the grid and charges the BESS



NIGHT-TIME

Non-solar hours

BESS discharges into the grid; PV is idle



Line loading

Transformer loading

Voltage profile

N-1 outage resilience

3 Why This Study Matters

1

Growth outpacing the grid

Solar and storage are growing faster than grid upgrades.

2

Planning done in silos

Generation adequacy and transmission planning are often done separately.

3

Day and night stress

Solar and non-solar hours stress the network very differently.

4

Evidence over thumb rules

Reinforcement needs, network-specific proof, not thumb rules.

4

4 What the Study Covers

1

Grid health and N-1 security

Load flow of the existing network, thermal and voltage limits check under N-1 contingency conditions.

2

Injection point planning

Realistic solar and BESS locations, finalised with state stakeholders, co-located or standalone.

3

Solar and non-solar hour assessment

Separate studies for solar injection with BESS charging and for BESS discharge, with and without outages.

4

Targeted reinforcement planning

Parallel circuits, reconductoring, transformer augmentation and reactive support, aligned to CEA planning standards.

5

5 Key Outputs

1

Network adequacy findings

Overloaded lines, transformers and voltage problem areas, mapped.

2

Evacuation readiness

Clear verdict per solar-BESS park on safe injection and discharge.

3

Prioritised upgrade plan

What to fix now, what to plan, and what needs no action.

4

Future-year outlook

Readiness at the planning horizon with full RE and demand growth.

6

6 From Network Data to Investment Decisions

1

Build the base case

Grid data, generation, load forecast and RE plan in PSSE.

2

Run simulations

Base case load flow and N-1 contingency checks.

3

Identify needs

Solar-BESS parks in solar and non-solar hours.

4

Recommend and prioritise

Reinforcements ready for planning and investment.

MP-UP

Seasonal Complementarity

Dedicated Transmission Line Study

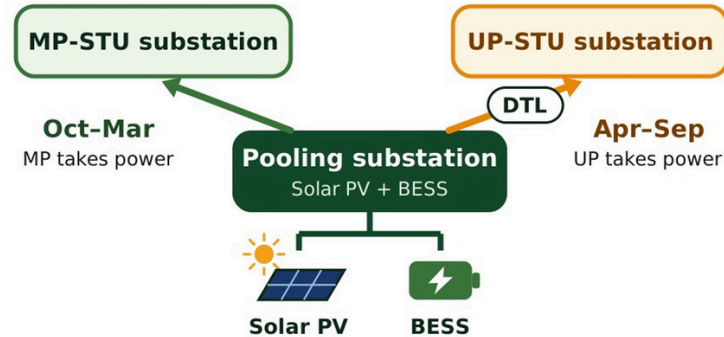
**One Solar + BESS
plant. Two states.
Two seasons.**

A transmission-constrained planning study for a Solar PV + BESS pooling plant at the MP-UP border. The plant supplies UP through a dedicated transmission line (DTL) in summer and MP in the remaining months, improving utilisation without necessity of ISTS usage.

Cleaner Energy
Smarter Corridors
Stronger Grids

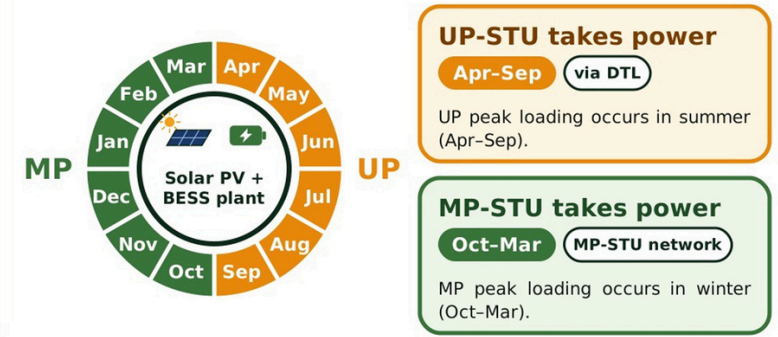
How the Corridor Works

Single-line view: one pooling substation, two states



Seasonal Complementarity

One year, one plant: each state takes power in turn



Why We Are Doing This

- 1** **ISTS charges and liability**

Post-waiver charges can be substantial, and unplanned flows can add unintended liability for the states.
- 2** **Grid decides plant size**

Deployable capacity should follow what the network can evacuate, transfer and absorb.
- 3** **Need for a proven method**

A clear, replicable approach is required to plan two-state Solar + BESS projects with confidence.
- 4** **The question to answer**

How much power can be sent, from where, and into which UP substations, without stressing either grid?

How We Checked It

- Picked the right nodes**
Border-side MP and UP substations, away from ISTS nodes, shortlisted as senders and receivers.
- Tested peak and low demand**
Every substation checked at its highest and lowest loading, with future load growth included.
- Stepped the power down**
Thermal, voltage and ISTS checks repeated at each injection level to find what the grid carries without violation.
- Verified the dedicated line**
Line loading, voltage and losses confirmed across every UP-side operating scenario.

Why It Matters Beyond This Corridor

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- ```

graph LR
 1((1)) --> 2((2))
 2 --> 3((3))
 3 --> 4((4))

```
- | 1                                                         | 2                                                             | 3                                                        | 4                                                                |
|-----------------------------------------------------------|---------------------------------------------------------------|----------------------------------------------------------|------------------------------------------------------------------|
| <b>Higher asset utilisation</b>                           | <b>Lower curtailment</b>                                      | <b>Deferred investment</b>                               | <b>Replicable method</b>                                         |
| Seasonal multi-beneficiary use of one transmission asset. | Generation better aligned with state-level demand absorption. | Avoids underutilised assets and avoidable reinforcement. | Applicable to other inter-state corridors and Solar-BESS plants. |

## A Layered Hosting Capacity Assessment for PM-KUSUM Integration in Rural Distribution Feeders

A real feeder case study to evaluate how decentralised solar PV plants can be integrated into rural distribution networks. Assessment of demand shifting, incremental solar integration, and dynamic voltage control on the 33/11 kV distribution network at Paliyamaru, Mandsaur, Madhya Pradesh.



DEMAND-SIDE  
MANAGEMENT



HOSTING CAPACITY  
ANALYSIS



SMART INVERTER  
CONTROL (VOLT-VAR)

### 1 DATA & PROTOTYPE DEVELOPMENT



#### DISCOM Data Collection

- Feeder topology and network data
- Load data (kW, kWh)
- Seasonal load profiles
- Solar resource data
- Equipment ratings
- Field measurements



#### ETAP Prototype Model

- Detailed 33 kV and 11 kV model
- Validated with field data
- Base case (no solar) verification



#### Study Locations (Mandsaur, MP)

- Paliyamaru (PM) – 33/11 kV
- Jaggakhedi N (JN) – 33/11 kV
- Jaggakhedi M (JM) – 33/11 kV
- 26 km, 33 kV radial feeder (from Mandsaur)
- Madhya Pradesh (MP)



#### Loading Scenarios

- 20%, 50%, 80% and 100% loading conditions
- Seasonal variation



#### Solar Injection

- Progressively increase solar injection at intermediate s/s
- Up to potential transformer capacity



#### Inverter Control Strategies

- Unity Power Factor (UPF)
- Fixed Power Factor (Fixed PF)
- Feed Reactive Power (Fixed VAR)
- Volt-VAR Control (VVC)



#### Performance Evaluation

- Voltage profile
- Reverse power flow
- Active power losses
- Transformer loading
- Line thermal loading
- Hosting capacity

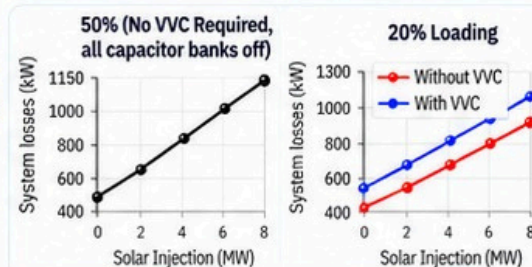
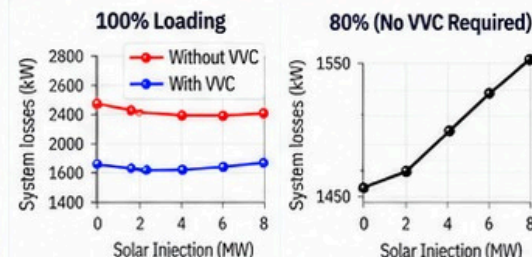


#### Evaluation metrics

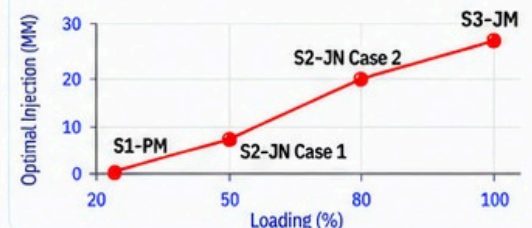
- Voltage profile, reverse power flow, active losses, transformer loading, line loading, hosting capacity

### 2 MODELLING & SIMULATION

### 3 SAMPLE RESULTS



#### Optimal Solar Injection vs Loading Level



### 4 THREE LAYERS OF HOSTING CAPACITY ASSESSMENT

1

#### Layer 1:

#### Agricultural Demand Shifting



- Shift evening agricultural load to daytime.
- Reduce upstream 132 kV grid draw.
- Lower feeder active power losses.

2

#### Layer 2:

#### Incremental Solar Injection



- Progressively increase solar injection at intermediate s/s.
- At each loading level (20%, 50%, 80%, 100%).
- Identify maximum solar capacity without violating network constraints.

3

#### Layer 3: Smart Inverter Control (Volt-VAR)



- Apply Volt-VAR control on PV inverters.
- Reactive power injection (Q+) and absorption (Q-).
- Maintain bus voltages within 0.91 – 1.06 p.u.
- Enable higher solar integration where feasible.

### 5 KEY FINDINGS

1

#### Voltage rise during high solar generation

At low load conditions, solar injection at Paliyamaru leads to over-voltage at 11 kV bus.

2

#### Under-voltage during agricultural demand

Evening agricultural load can cause severe under-voltage and higher network losses.

3

#### Reverse power flow at Paliyamaru

For high solar injection and low load conditions, reverse power flow is observed at Paliyamaru (33/11 kV).

4

#### Volt-VAR control improves performance

Maintains bus voltages within limits and can enable higher solar integration, but may increase losses under light load due to reactive power absorption.

## Estimation of Technical Losses in Distribution Network of MPMKVVCL BHOPAL

A data-driven approach to evaluate, understand and reduce technical losses for a more efficient and reliable power distribution network.

### Why It Matters ?

- Technical losses reduce energy efficiency and increase cost.
- Accurate analysis helps to decide measure voltage to improve network efficiency.
- Supports utilities in planning solutions for a sustainable power future.



### Objective

To provide a **comprehensive estimation and analysis of technical losses** in distribution network of MPMKVVCL Bhopal and suggest practical measures to improve efficiency of distribution network.



### DATA & SYSTEM OVERVIEW



#### Key Data Inputs

- Feeder details and meter data provided by DISCOM (MPMKVVCL, Bhopal)
- Loading data (MW, kW, MVA)
- Voltage levels (33/11 kV)
- Field measurements (from DISCOM)

#### Distribution Network Model



#### Software & Method

**ETAP**

- ETAP Software
- Newton-Raphson Load Flow

#### Key Parameters

- Feeder details
- Voltage level
- Meter data

### METHODOLOGY & ANALYSIS FLOW



#### Data Collection & Preparation

- Feeder data
- Load profiles
- Network parameters



#### Load Flow Simulation

- ETAP software
- Newton-Raphson method
- Peak load analysis



#### Loss Analysis

- Calculation at peak load
- LF and LLF calculation
- Annual energy loss calculation



#### Recommendations

- Feeder reconfiguration
- Reactive power compensation
- Infrastructure upgrades

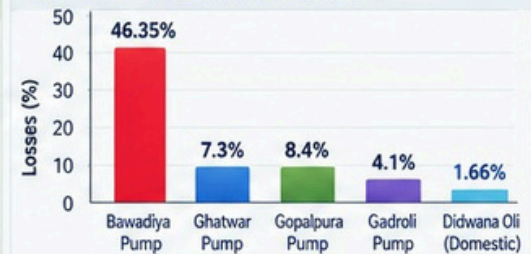


### FEEDER ANALYSIS AND KEY FINDING

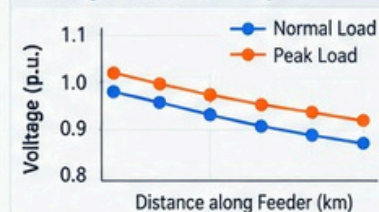
#### Type of Feeder

- Agricultural (Pump) feeders
- Domestic / Urban feeders
- Mixed feeders
- Category-wise classification

#### Technical Losses Across Feeders



#### Voltage Profile (Example)



#### LF & LLF Trend (Monthly)



#### Key Insight

Higher loading and seasonal variation in agricultural feeders lead to increased technical losses.



### COMPARATIVE FEEDER ANALYSIS

| Feeder Type        | Example Feeder | Voltage at End (%) | Losses (%) | Performance |
|--------------------|----------------|--------------------|------------|-------------|
| Agriculture (Pump) | Ghatwar Pump   | 90%                | 8.4%       | Moderate    |
|                    | Bawadiya Pump  | 64.35%             | 46.35%     | Poor        |
|                    | Gadroli Pump   | 92.3%              | 4.1%       | Good        |
|                    | Gopalpura Pump | 100.3%             | 2.8%       | Good        |
| Domestic / Urban   | Didwana Oli    | 88.65%             | 1.66%      | Good        |
|                    | Prakash Nagar  | 97.53%             | 1.7%       | Good        |
| Mixed              | Landiya        | 96.33%             | 3.4%       | Moderate    |
|                    | Ghanesh Ghat   | 93%                | 7.1%       | Poor        |

● Good ● Moderate ● Poor



### KEY CONCLUSIONS



Losses vary significantly across feeders (< 1% to > 46%).



Agricultural pump feeders show highest losses.



Targeted interventions can improve efficiency, voltage profile and reduce technical losses.



ETAP + Load Flow provides a reliable framework for network loss analysis and planning.

## Sustainable Framework and Control Strategies for Rural Microgrid

Developing intelligent control and optimisation strategies for reliable, cost-effective rural microgrids.

### 1 Why is this project important?

-  Rural microgrids must balance reliability, affordability and local energy access.
-  Variable distributed energy resources and changing loads require coordinated control.
-  Intelligent scheduling and optimisation can improve performance while reducing operating cost.

### 2 What does the work cover?

-  Planning-based controller for dynamically scheduling loads.
-  Co-optimisation of distributed energy resource (DER) operation.
-  Load categorisation and load-shedding rules.
-  Price-aware decision logic for economic optimisation.

### 3 Highlights

-  Planning-based controller developed for dynamic load management.
-  Co-optimisation framework for DER operations.
-  Implementation of load categorisation and shedding logic.
-  Price-aware economic optimisation strategy.
-  Market-ready prototype demonstrated on laboratory testbed.

### 4 Outcomes and value

-  Prototype framework for smarter rural microgrid control.
-  Improved operational efficiency and economic decision-making.
-  Better readiness for practical deployment and scale-up.
-  A useful foundation for resilient, market-ready rural energy systems.



# From Demonstration to Policy

These initiatives contribute to the development of practical technical and regulatory approaches for obtaining grid-support services from distributed renewable energy assets.

CMET's engagement with utilities, state agencies and regulators has supported the translation of engineering findings into procurement provisions, operational practices and regulatory frameworks, including work associated with reactive power compensation in Madhya Pradesh.

## OUR APPROACH

1

### **Understand the network.**

Use actual system data to identify technical and operational challenges.

2

### **Develop the solution.**

Apply modelling, simulation, optimisation and engineering design.

3

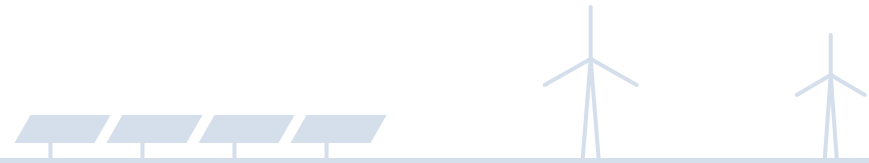
### **Validate in the field.**

Test practical interventions under real operating conditions.

4

### **Enable adoption.**

Translate findings into utility practices, technical specifications, procurement frameworks and policy recommendations.



# From Research to Impact: Partnerships That Deliver

**Addressing real power-system challenges. Developing solutions that can shape practices across states.**

Every state faces a different set of challenges in its energy transition—transmission bottlenecks, limited distribution hosting capacity, voltage management issues, or the need to determine where and how energy storage can deliver the greatest value.

The solutions cannot emerge from isolated technology assessments or conventional planning approaches alone.

CMET brings together the institutions that plan, operate, regulate and invest in the power system to address these challenges collectively. Our collaborations combine actual network data, advanced engineering analysis, field demonstrations and policy insights to develop solutions grounded in technical feasibility and implementation realities.

## OPPORTUNITIES FOR COLLABORATION



### State-Level Planning

Integrated resource planning, transmission readiness, renewable siting and grid investment strategies.



### Grid Innovation and Demonstrations

Hosting capacity enhancement, inverter-based reactive power support and field validation of emerging technologies.



### Storage and Procurement Innovation

Storage opportunity assessment, solar-storage optimisation and performance-based procurement frameworks.



### Digital Tools and Institutional Capacity

Development of planning and decision-support tools, regulatory frameworks and capacity building for utilities.

## Taking Innovation Beyond Individual Projects

Our ambition is to ensure that the learning from one network, one pilot or one state can inform solutions elsewhere—while recognising the unique technical, economic and institutional conditions of each power system.

For CMET, the true measure of research is what changes on the ground: how renewable projects are planned, how networks are operated, how storage is procured and how emerging grid services are recognised and valued.

# Let's Build a **Grid-Ready** Energy Future



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Research that informs planning.  
Innovation that supports implementation.

