Electricity Distribution Conference (EDICON 2026)

Session 3: Challenges in Renewable Energy Integration

Title: Role of Digitalization in Cost-Effective Renewable Energy Integration

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About India Smart Grid Forum (ISGF)

- ISGF, established as a Public Private Partnership (PPP) initiative of Government of India in 2011, is spearheading the mission to accelerate electric grid modernization, electric mobility and energy transition in India
- The India Smart Grid Forum (ISGF) has evolved as a Think-Tank of global repute on Smart Energy, Electric Mobility and Energy Transition
- 200+ members comprising of ministries, utilities, technology companies, academia and research
- 8 **Working Groups:** Grid Modernization and Smart Cities; Smart Metering (AMISPs); IoT, AI and Analytics; Digital Architecture and Cyber Security; Policy, Regulations and Business Models; Renewables & Microgrids; Flexibility & Electric Mobility; Smart Gas; and Smart Water
- ISGF has been driving the digitalization of utilities and is actively involved in standards development, technology demonstration pilots; training and capacity building and various advisory and research activities

More about ISGF: www.indiasmartgrid.org

Indian Power Sector - Future Projections

Installed Capacity (GW)

Electricity Generation (GW)	Jan 2026 (Actual)	2027-32*
Thermal	245	284
Large Hydro	50	62
Nuclear	9	20
Solar	133	365
Wind	54	122
Small Hydro	5.1	6
Biomass	11.5	16
Pumped Storage Plants (PSP)	6.4	26
Total	**~ 510**	**901**

India taken a Big Leap from 1.3 GW in 1947 to 510 GW in 2025! – 392X in 78 Years

*Sources: National Electricity Plan (NEP) 2022-32 by CEA & **https://npp.gov.in**

Omniscience Capital Report estimates INR 60-65 Lakh Crore (trillion) investment between 2025 and 2035 in the Indian Power Sector

"**Watt's the Future**" Report by Omniscience Capital – Dec 2025

Power Demand in BU*	2023	2035
Total Demand – nearly tripling in 12 years!	**1399**	**4041**
Industry	590	1650
Commercial & Services	181	798
Agriculture	241	333
Railways	33	60
Data Centre	-	300
EV – Numbers in million EV – Power Demand in BU	3.9 25	162 162
Per Capita Consumption (kWh)	**1400**	**2575**
*BU is one billion kWh or Trillion Watt-Hour		

Key Challenges with Renewable Energy Resources

- **Intermittancy:** Unexpected drop in generation requiring sudden ramp up of other generation resources
- **Inaccurate Generation Forecasting:** Leads to scheduling and dispatching errors and imbalance costs
- **Demand – Supply Variability:** Huge change in demand and supply profiles in a day – 24 hours
- **Seasonal Variability:** Long periods of surpluses and shortages
- **Reverse Power Flows**: Rooftop Solar (RTS) and other RE resources connected to LV grid causes reverse power flows

Remedial Measure for Intermittancy is Flexibility!

A. Supply-Side Flexibility

(Fast response from generation and storage resources)

- **Spinning and Operating Reserves** – Immediate response to sudden RE drops
- **Hydro Reserves** – Rapid ramp-up and ramp-down capability
- **Quick-Start Gas Turbines** – Short-duration balancing support
- **Energy Storage Systems** - Pumped Storage Plants (PSPs); Battery Energy Storage Systems (BESS); Flywheels
- **Vehicle-to-Grid (V2G)** – EVs as distributed storage resources

B. Demand-Side Flexibility

(Demand adjusts to available renewable supply)

- Demand Response (DR) – Load reduction or shifting during stress periods
- Smart Cooling and Heating Systems – Thermal storage for flexibility
- EV Charging (Smart Managed) – Absorbing mid-day solar surplus
- Microgrids and Flexumers – Local balancing and resilience
- Time-of-Use (ToU) Tariffs – Price signals to shift consumption

Flexumer Enablement is the Future!

Reverse Power Flow Management

Challenges:

- Increasing penetration of rooftop solar (RTS) at the LV network level
- Power flowing from consumers to the grid, reversing traditional one-way flow
- **Over-voltage conditions** in feeders during high solar generation hours
- Increased instances of **inverter tripping and mal-operations of protection relays**
- **Stress on distribution transformers**
- Limited preparedness of legacy distribution infrastructure for bi-directional power flows

Potential Solutions:

- **Smart Inverters:** Utilizing inverters with reactive power control, voltage and frequency ride-through capabilities can help regulate local voltage issues caused by high PV penetration.
- **Reverse Power Relays (RPR):** Installing RPRs can detect and act on reverse power flow, preventing power from back-feeding into sensitive upstream equipment
- **Optimal Sizing and Placement of Energy Storage:** Strategically deploying battery storage can help absorb excess solar generation and mitigate RPF
- **Policy Interventions to Promote Consumption during Solar Generation Hours:** Reduced Tariff (or free power) for EV charging and other industrial applications during high solar hours

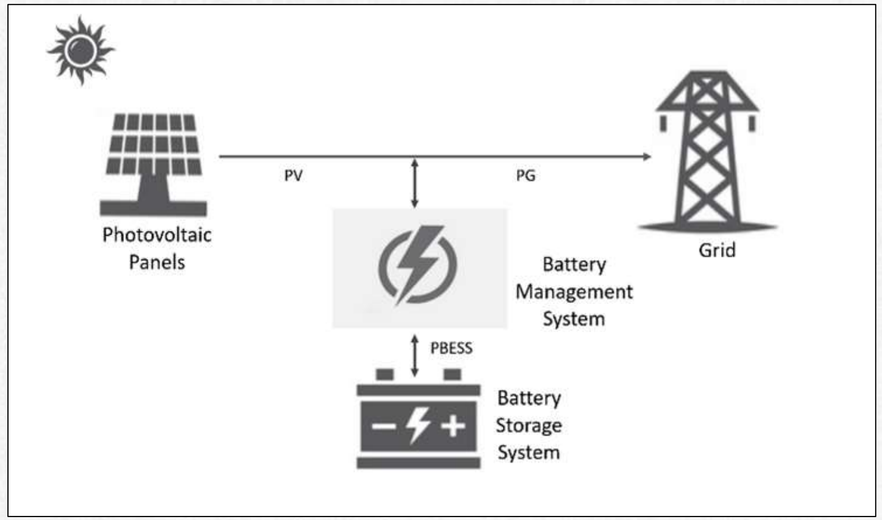
Paschim Gujarat Vij Company Limited (PGVCL)

- PGVCL is one of the four government-owned electricity distribution companies in Gujarat
- PGVCL is actively modernizing the network through underground cabling, advanced system upgrades, and loss-reduction initiatives
- PGVCL has over **300,000 RTS connections**, which is the **highest in any distribution utility in India**
- PGVCL has identified **reverse power flow issues at 66/11 kV substations**
- There are **68 number of 11kV feeders in Rajkot City of which 20+ feeders** are experiencing reverse power flow conditions

Battery Energy Storage Systems (BESS)

BESS AS A Digital Flexibility Resource: Real-time data and control enable BESS to absorb renewable surplus and supply peak demand

- **MV/LV Grid Support: Addresses voltage rise, reverse power flow, and congestion, deferring network reinforcement**
- **Value Stacking: Digital orchestration enables energy shifting, peak shaving, and ancillary services, improving project economics**



Policy Enablers:

- Enable BESS participation in distribution-level flexibility and ancillary service markets, supported by digital platforms, clear interconnection standards, and multi-service revenue stacking
- ISGF recommends policy frameworks enabling multi-service value stacking and DISCOM-led pilots to demonstrate cost savings and scalable RE integration

Solution Approach

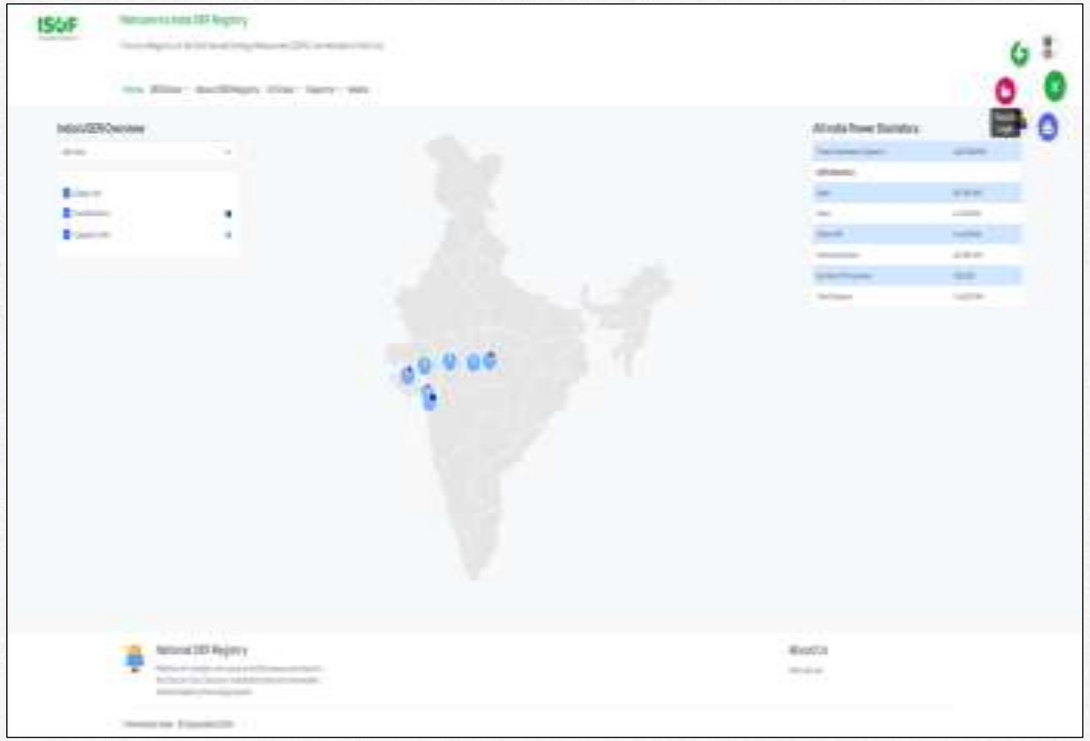
- DERMS-integrated, digitally controlled BESS to deliver RE firming, peak shaving, voltage support, and congestion management at the distribution level.
- Mandate BESS for Standby Power Supply instead of DG sets

Australia's distribution-connected BESS has increased rooftop solar hosting capacity and deferred network investments through digitally orchestrated storage dispatch.

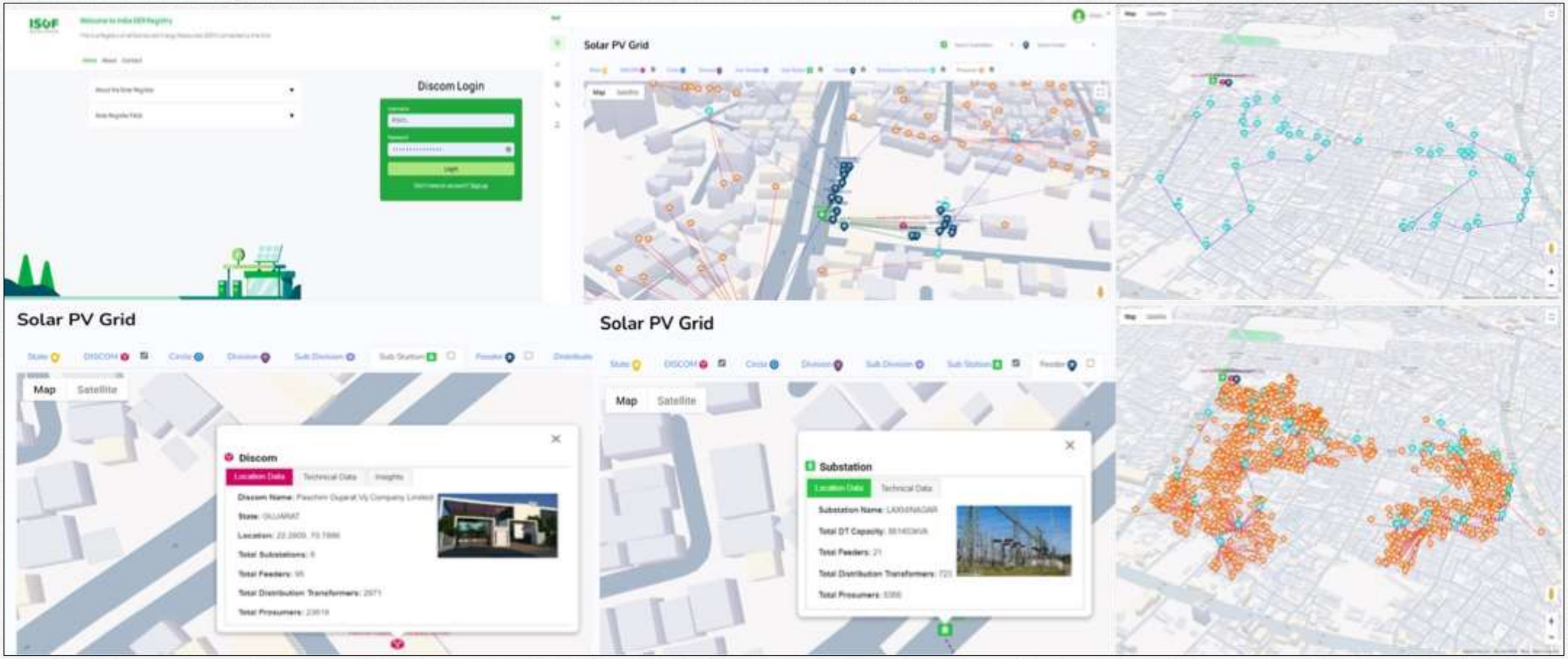
ISGF Initiatives Addressing Grid Variability and Flexibility Challenges

National Registry of Rooftop Solar (RTS)

- India has **~2 million RTS systems (18 GW)** connected to the **LV grid**. Under **PM Surya Ghar Yojana**, another **10 million systems (30 GW)** will be added in the next **3 years**, posing major **MV/LV grid management challenges** for utilities.
- **Utility-, Feeder-, and DT-wise visibility** of RTS installations is essential for monitoring generation, performance, and grid impacts. DISCOM-level registries can be **scaled to State and National levels**.
- **ISGF has developed a National RTS Registry** to support effective planning, monitoring, and integration of rooftop solar (www.indiaderregistry.in).
- The platform is **highly scalable** and can evolve into a **National DER Registry**, covering **BESS, EV charging, and flexible industrial loads** to enable grid flexibility services.



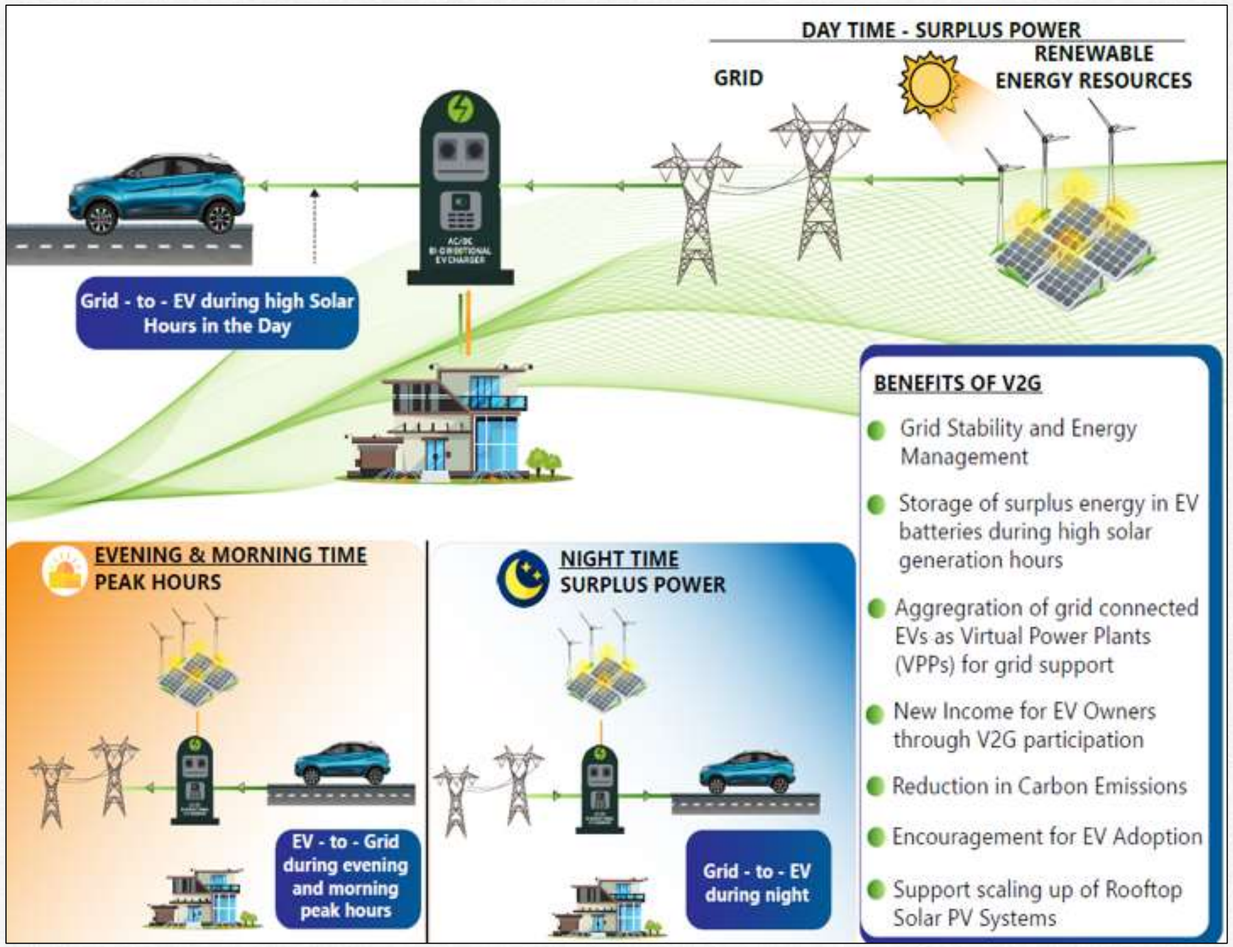
National RTS Registry – Registry Architecture



Registry being handed over to CEA (porting to NIC) and will be integrated with PM Surya Ghar Portal 2.0

V2G Technology Demo for Flexibility Support for DISCOMs

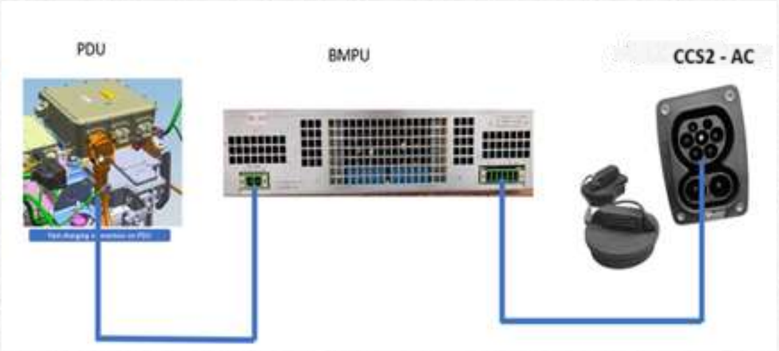
- The batteries in EVs are charged with electricity from the grid; and the EV batteries can send electricity back to the grid during peak hours to support the grid. This technology is called **Vehicle-to-Grid or V2G**
- ISGF demonstrated AC V2G successfully in technical collaboration with University of Delaware, USA – retrofitted 4 Tata Nexon EVs
- Through bidirectional chargers, V2G allows EVs to act as **mobile energy storage units**, helping to balance **electricity supply and demand**, especially during hours of surplus generation and peak demands.



The Key Benefits of V2G Technology:

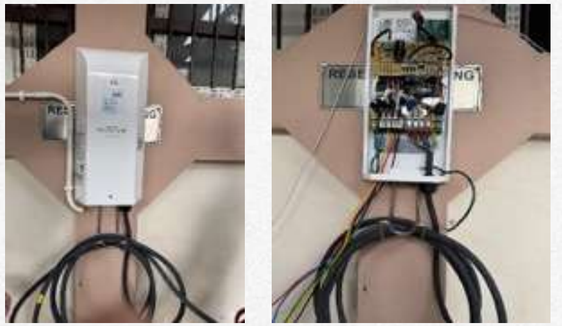
- Load Balancing on the Distribution Grid
- Reduction in Peak Power Purchase Cost to Utilities
- Additional Income for the EV Owners - encouragement for EV Adoption and Emission Reduction
- **Support RE Integration – Both EVs and RTS are connected on LV Grid which can support each other**
- Thousands of EVs can be aggregated as Virtual Power Plants (VPP)

V2G Pilot Project in India



Architecture

Bidirectional Modular Power Unit (BMPU)



Bidirectional Charger

EV Communication Controller

Demonstrated by ISGF in March 2025

Digitalising Rooftop Solar through Smart Inverters

- ISGF worked with **BIS for adoption of Smart Inverter Standards** – In Jan 2025; BIS issued IS-18968 adopted from IEEE 1547 - 2018
- ISGF bought a 8kW 3-phase Inverter of SolarEdge make and conducted the initial round of tests at the **UL Laboratory in Bengaluru in May 2025**
- Later the Inverter was shifted to the **National Institute of Solar Energy (NISE),** Haryana, where **Voltage Ride Through, Frequency Ride Through, Volt-Watt, and Volt-VAR tests** were carried out in November 2025
- Demo to key stakeholder held at NISE Campus on 8th Jan 2026

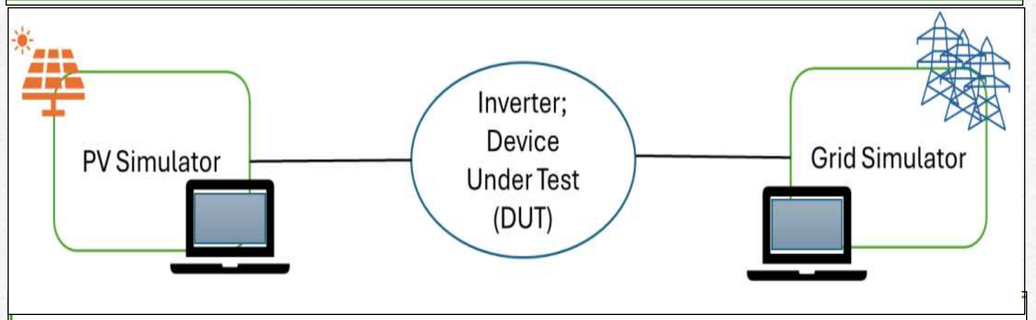
Key Findings:

- Smart inverter **remained connected during voltage and frequency disturbances**, avoiding unnecessary tripping
- Demonstrated **autonomous active and reactive power control** to manage over-voltage conditions on solar-rich feeders
- Showed **smooth ramping and stable response**, critical for high DER penetration scenarios

ISGF Way Forward:

- Multi-vendor smart inverter testing under Indian grid conditions
- DISCOM-led field pilots for real-world validation
- Development of deployment guidelines and certification frameworks
- **Policies mandating Smart Inverters for all new DER connection to the grid**
- Foundation for a digitally managed DER ecosystem supporting India's 500 GW RE target

Power and Hardware level setup



Software Level

Peer-to-Peer (P2P) Trading of Rooftop Solar Energy

ISGF successfully carried out 3 pilot projects of P2P Trading of Rooftop Solar Energy on blockchain platform between 2020 and 2022 which has led to enabling regulations for P2P Trading of green energy in 4 states in India

1. Uttar Pradesh (UP), India:

- Pilot implemented under the **regulatory sandbox** approach to test the technical feasibility and customers willingness to participate in P2P trading
- **12 participants (9 prosumers and 3 consumers)** were recruited in the pilot project - **Project Go-Live: Dec 2020**
- Pilot project price discovery was around **INR 5.60/kWh (Win-Win for Prosumers and Consumers)**
- **UP Electricity Regulatory Commission (UPERC) issued P2P Regulations in April 2023**

2. Delhi, India:

- P2P trading of solar power from over 2 MW of solar PV undertaken in 2021 in Delhi with Tata Power Delhi Distribution Ltd (TPDDL)
- **117 participants** were identified and recruited in the pilot project; **Project Go-Live: Nov 2021**
- Based on the project results, **ISGF + Powerledger + TPDDL** had submitted detailed findings and recommendations to Delhi Electricity Regulatory Commission (DERC) in November 2021
- DERC published **Peer to Peer Energy Transaction Guidelines, 2024 in June 2024**

3. Kolkata, India

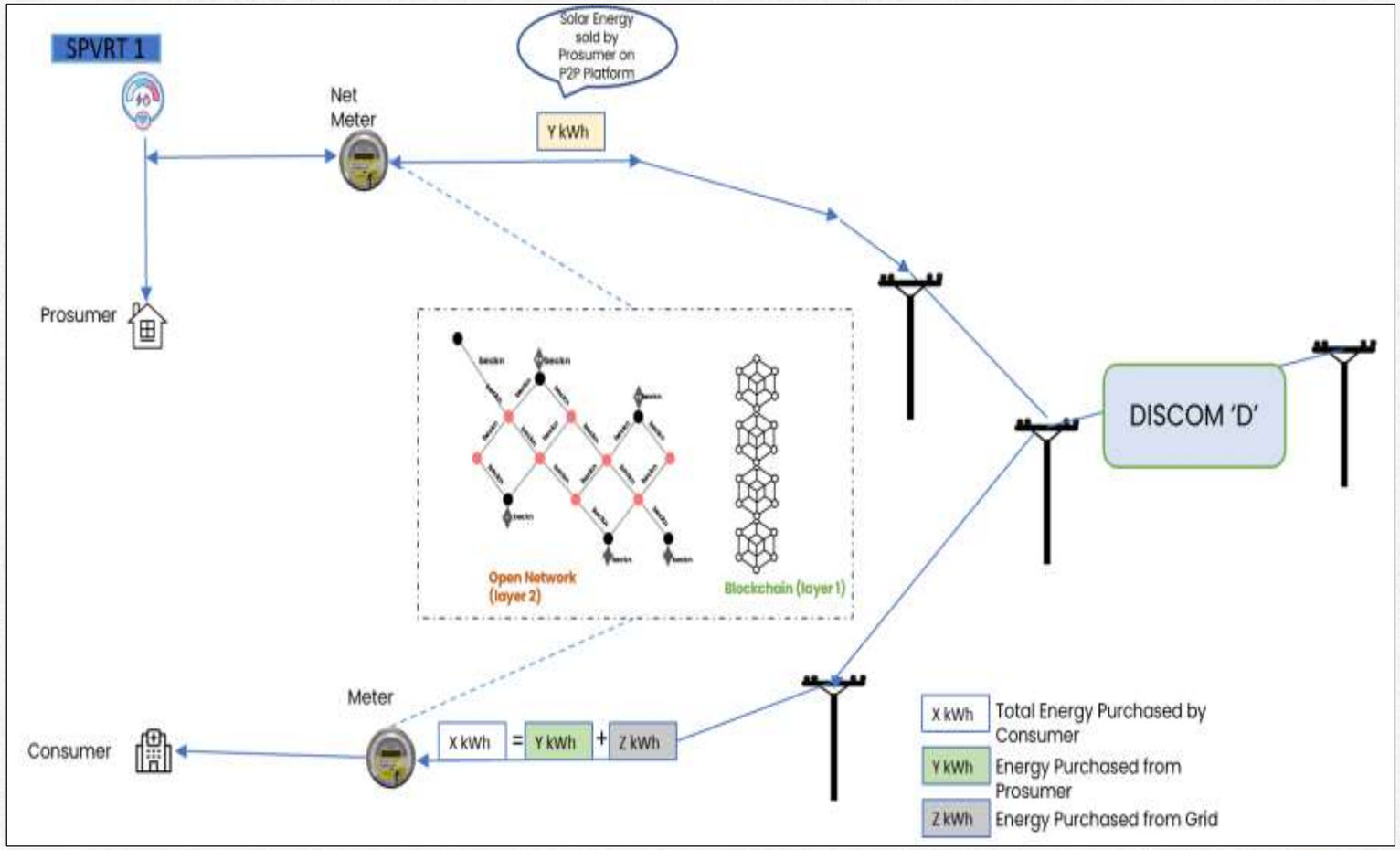
- Built a P2P trading platform on blockchain for CESC Kolkata in 2022 and run a 6-month pilot with 1002 C&I Customers with AMR meters (26 MW PV installations); **Project Go-Live: August 2022**
- Formulated a viable business model for CESC
- Documented the outcomes of the project

Demonstration of P2P Trading Powered by Unified Energy Interface (UEI) Architecture

- ISGF successfully demonstrated a first-of-its-kind project of P2P trading of rooftop solar energy in **Lucknow**, powered by the innovative **Unified Energy Interface (UEI) architecture** — a significant step toward building a **Digital Energy Grid** of the future

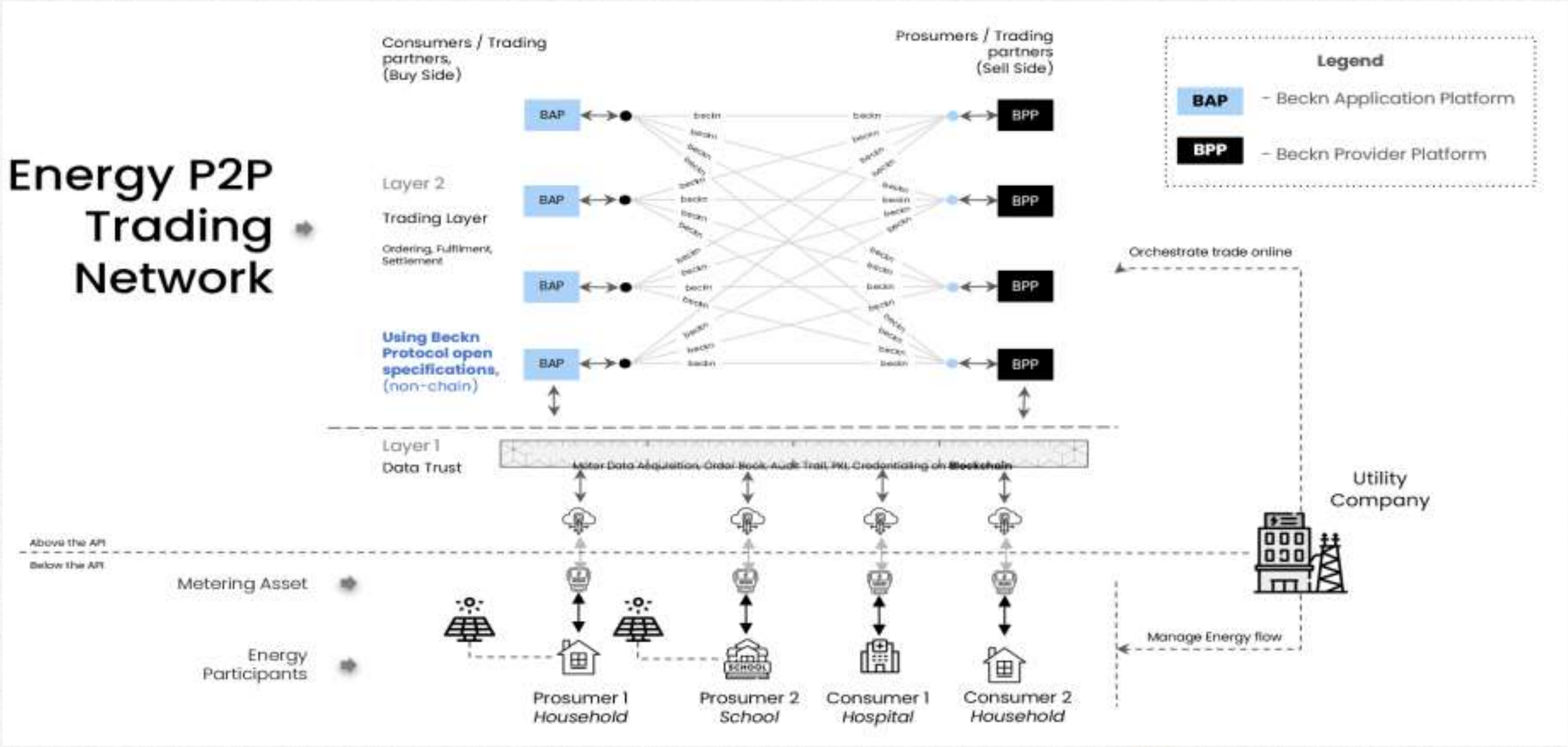
- The project is under testing with limited participants since 15 July 2025

Digital Energy Grid
Transforming Energy for a Sustainable Future



P2P Energy Trading Platform Architecture

Energy P2P Trading Network – Beckn Protocol



Key Recommendations

Managing Grid Variability, Forecasting Errors and Reverse Power Flows

- Treat demand–supply variability as a system-level planning and operational challenge
- Mandate advanced (AI/ML-based) RE forecasting and real-time data sharing across utilities and system operators
- Enable demand-side flexibility (DR, smart cooling, EV charging, electric cooking) to absorb RE surplus
- Deploy smart inverters and hosting-capacity-based planning to manage reverse power flows at the LV grid
- Accelerate energy storage deployment (short- and long-duration) for intra-day and seasonal balancing
- Introduce time-of-day tariffs and flexibility markets to align consumer behavior with RE availability
- Strengthen digital grid capabilities (ADMS, DERMS) and utility capacity building

"Flexibility, Digitalization and Markets will define the success of India's RE transition"

THANK YOU FOR YOUR KIND ATTENTION

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