
# Optimal sizing and placement of Batteries for Solar power acquisition

Dr. Dwipen Boruah

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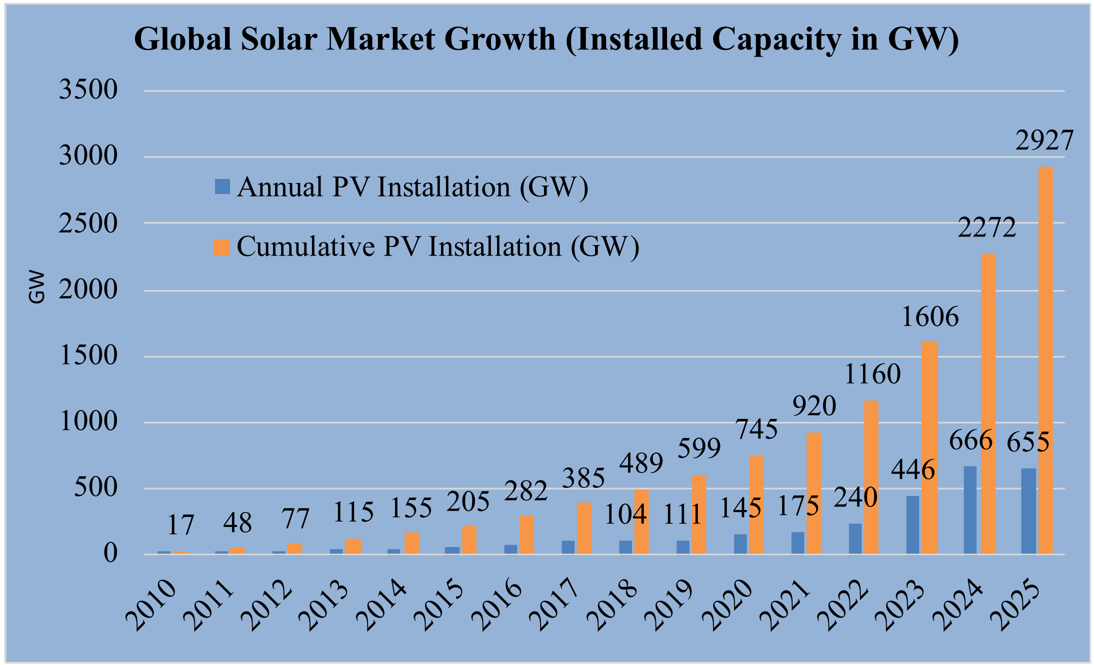
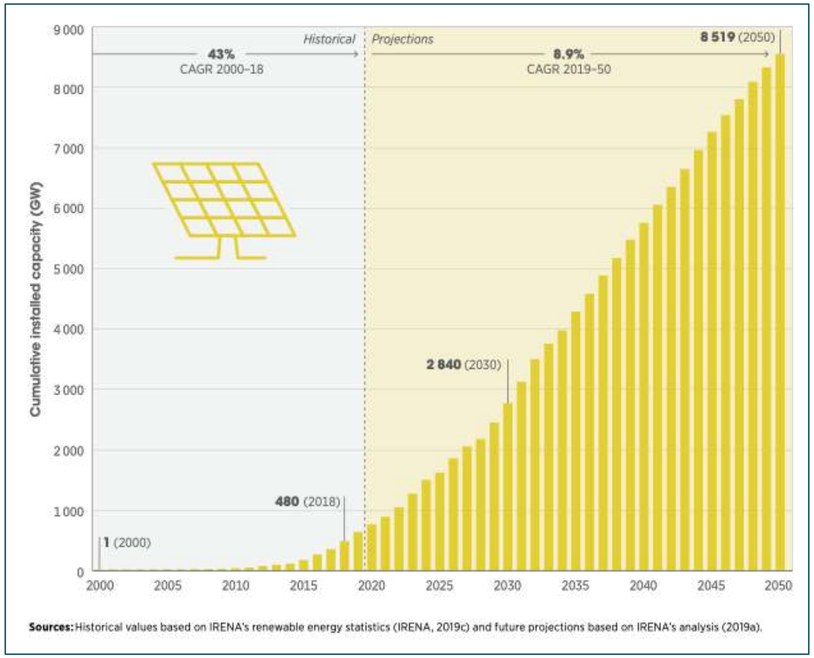
# PV MARKET TREND - GLOBAL AND SAARC COUNTRIES

# PV market trend – global and SAARC countries




Source: IEA PVPS Trend Report 2025
Global market outlook for solar power 2025-29




Cumulative solar PV capacity is expected to grow sixfold by 2030, with a CAGR of nearly 9% up to 2050

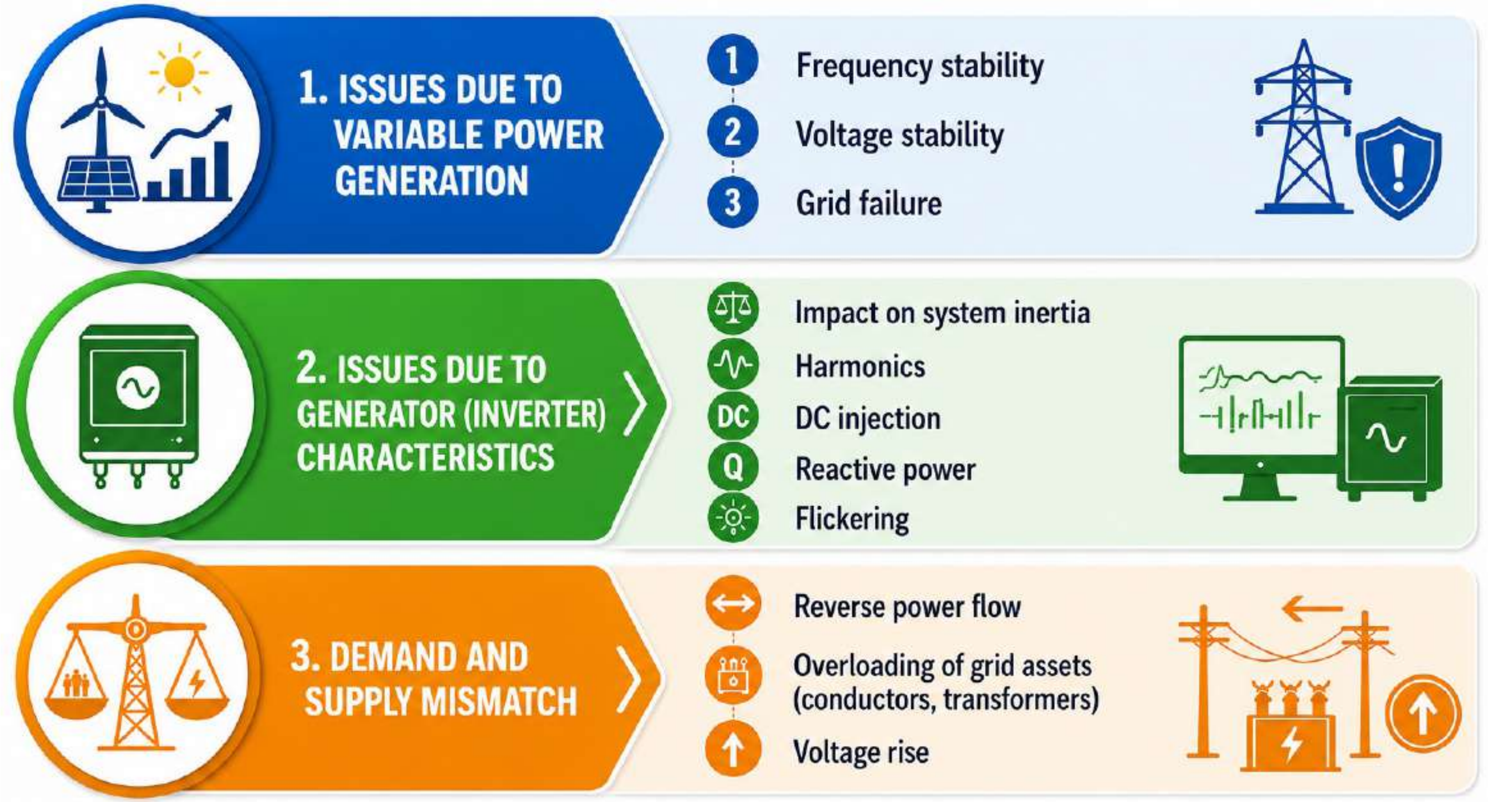
# PV market trend – global and SAARC countries

| SAARC Countries | Solar Installed caoacity | Source |
|---|---|---|
| India | 162 GW | MNRE as of May 2026 |
| Pakistan | ~ 38 GW (51 GW) | Renewables First, Pakistan Electricity Review, March 2026 |
| Bangladesh | ~ 1.51 GW | SREDA \| National Database of Renewable Energy |
| Sri Lanka | ~1.70 GW | The Ceylon Electricity Board (CEB) |
| Nepal | ~0.18 GW | (0.96 GW proposed) The Nepal Electricity Authority (NEA) |
| Afghanistan | ~0.18 GW | Mostly decentralized and donor-supported projects. |
| Bhutan | ~0.12 GW | DGPC/DOE - Utility scale and rooftop |

# Challenges in solar power integration to the grid

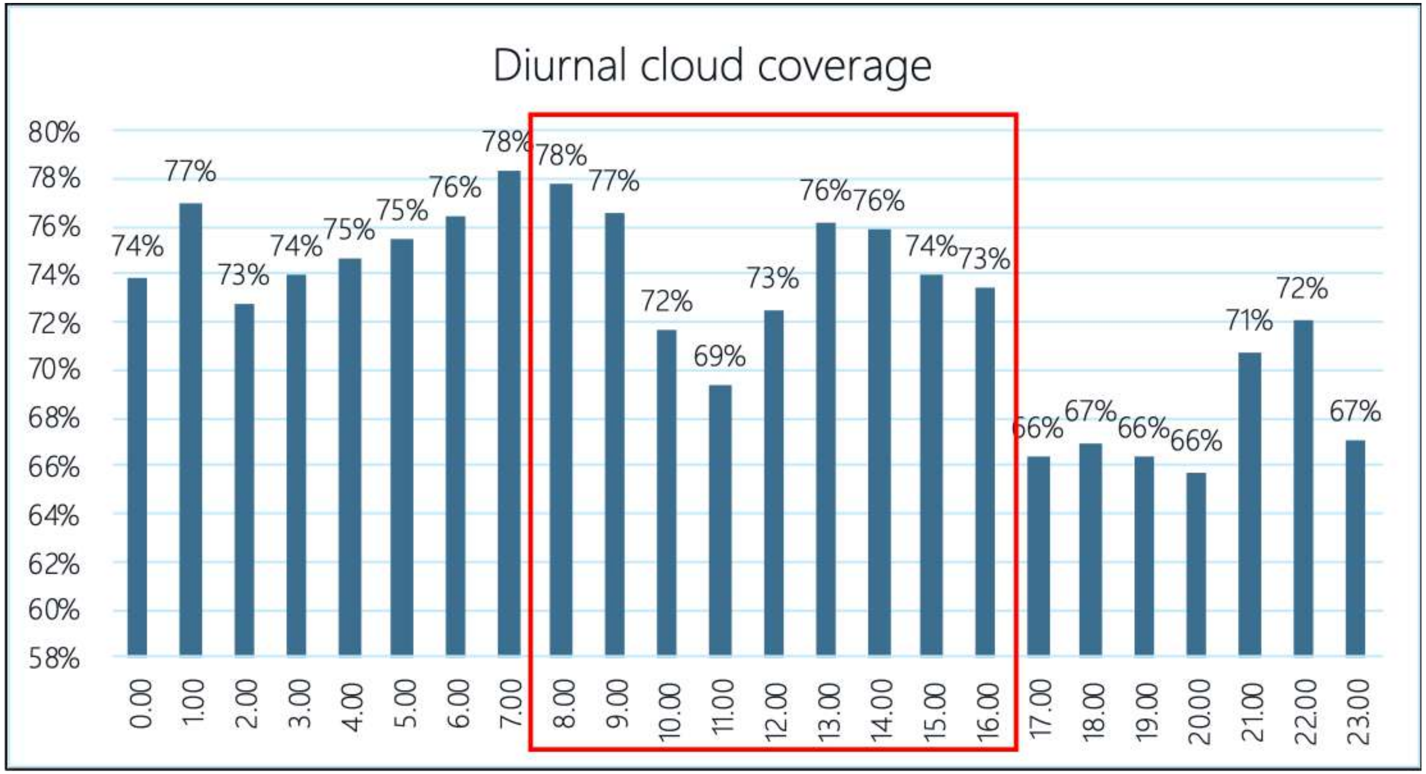
# Challenges in grid integration of solar power

## Technical challenges



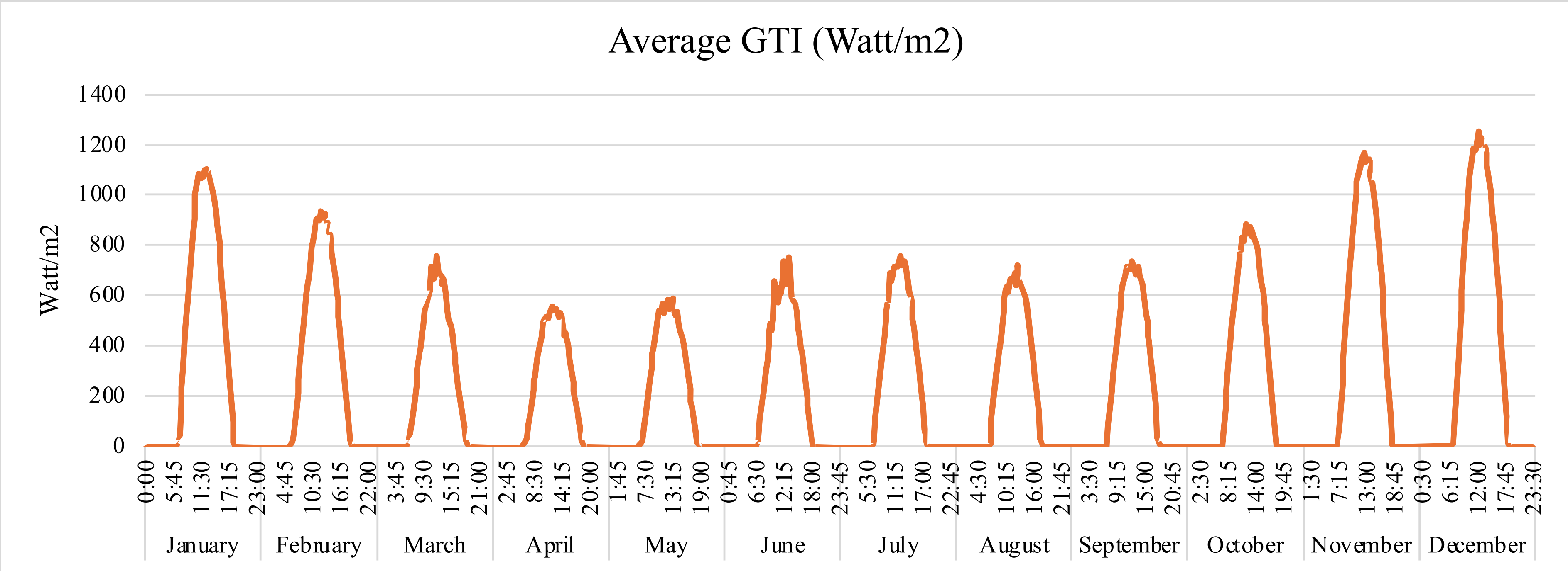
# Challenges with variable solar energy integration to the grid

Diurnal cloud coverage



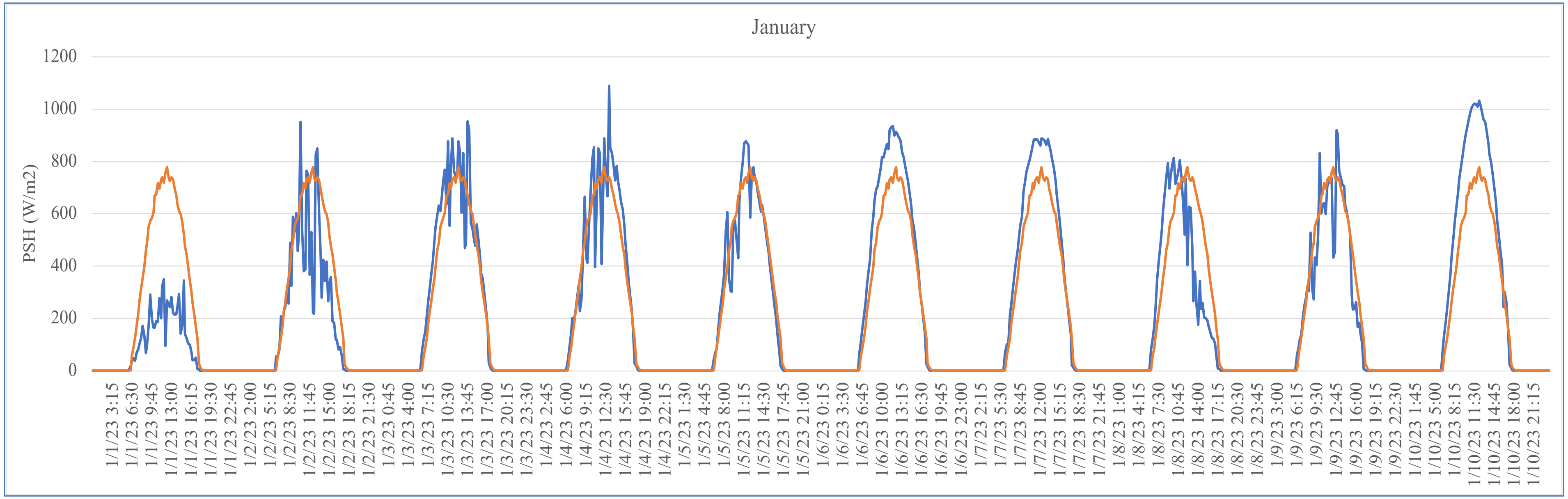
# Challenges with variable solar energy integration to the grid

Seasonal variation of solar radiation (Example)



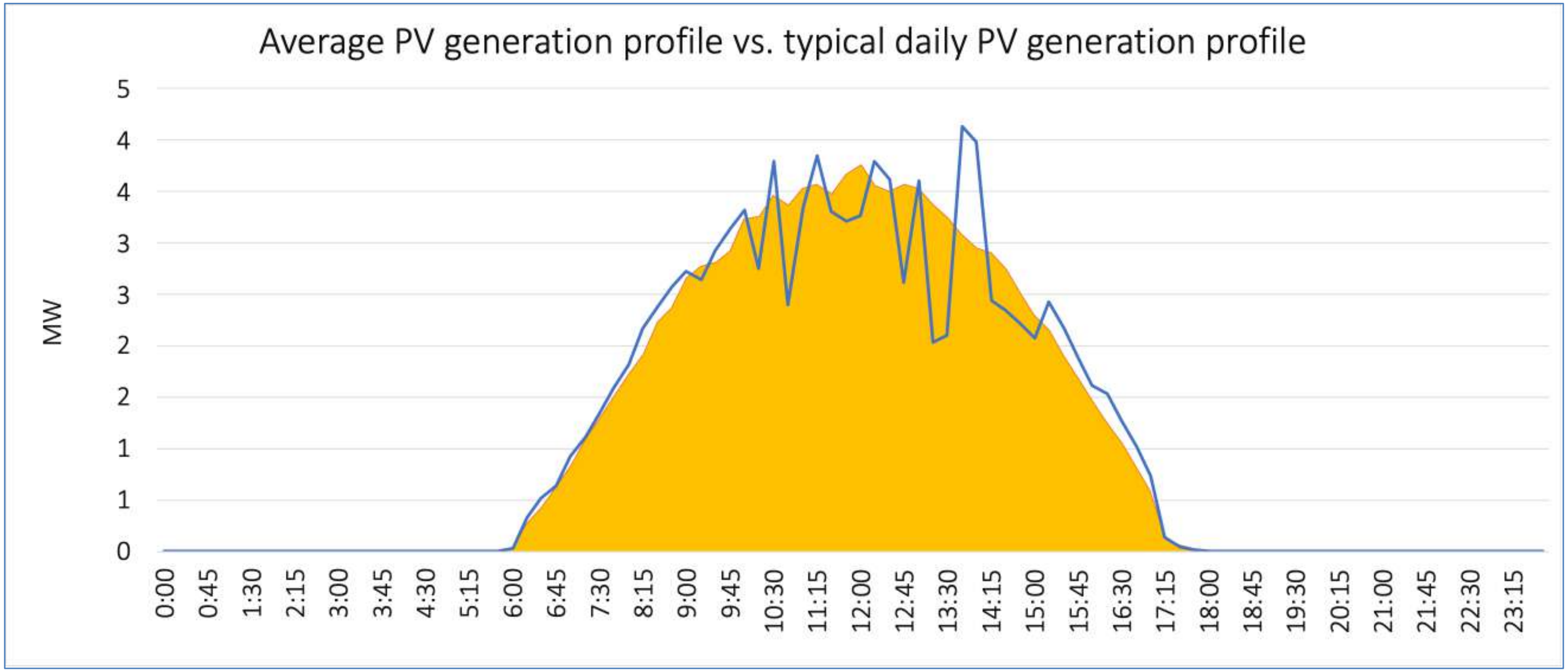
# Challenges with variable solar energy integration to the grid

## Daily variation and intermittency (Example)



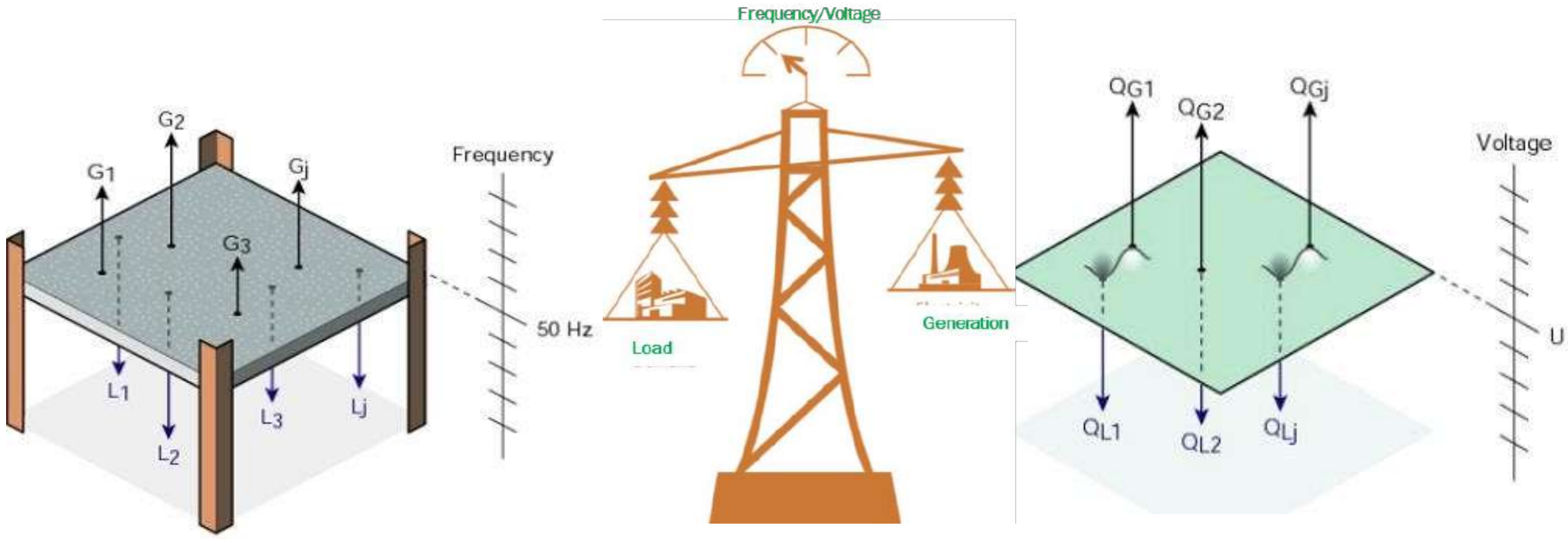
# Challenges with variable solar energy integration to the grid

Average generation vs typical daily generation profile of solar power plant



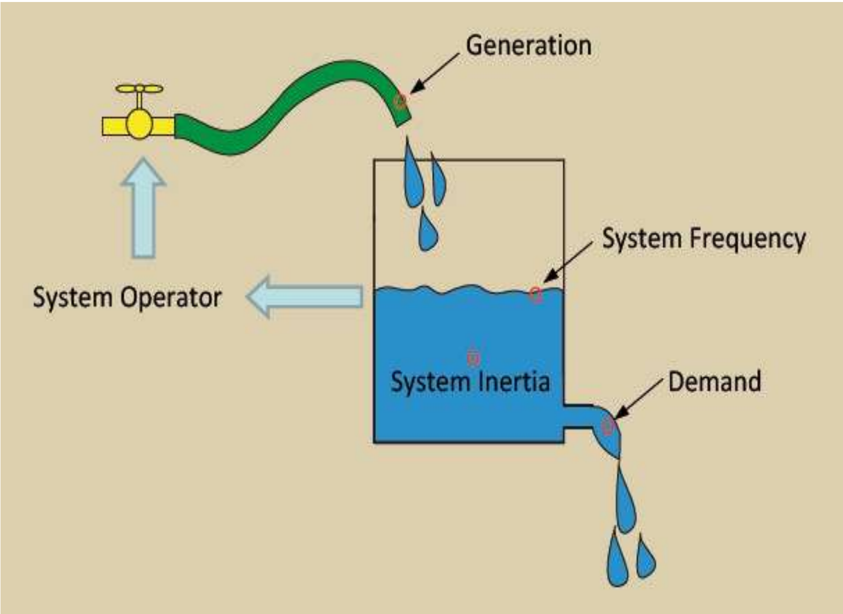
# Challenges with variable solar energy integration to the grid

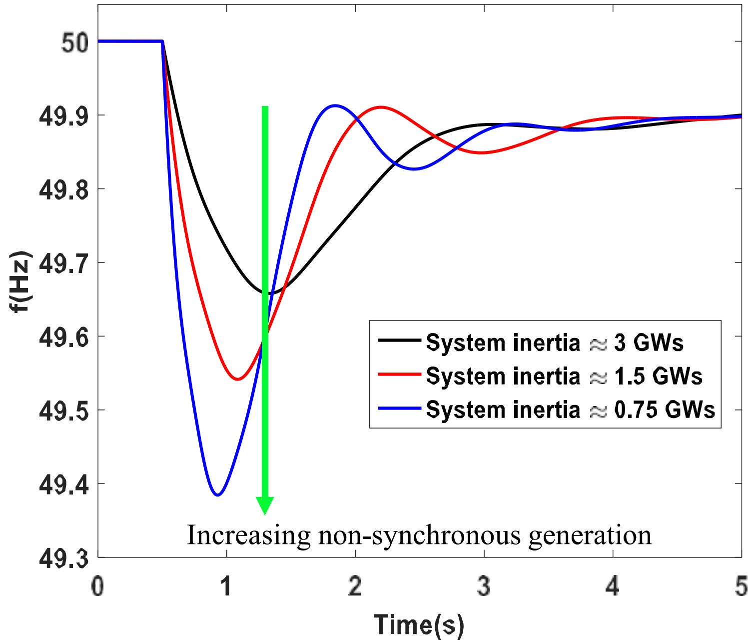
## Frequency and voltage stability



# Challenges with variable solar energy integration to the grid

## Impact on system inertia



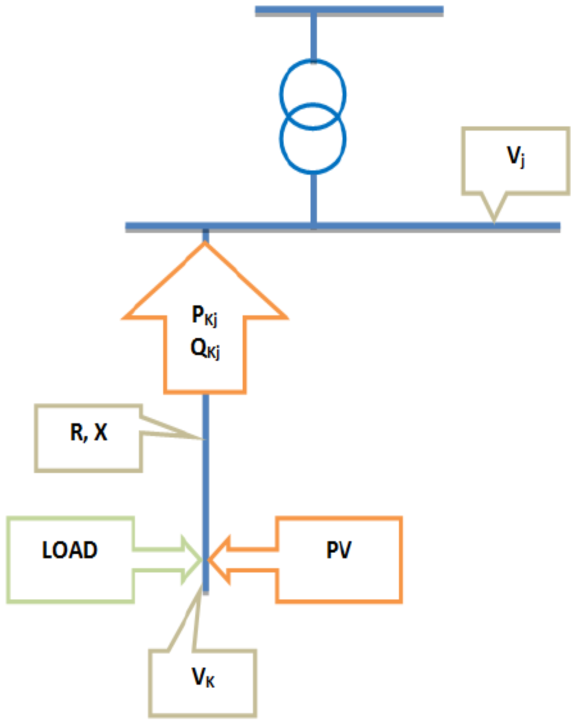
## Reverse Power Flow – impact and control

The basic equation to define Reverse Power Flow is –

$$\boldsymbol{Reverse\ Power\ Flow\ (P_{reverse}) = P_{PV\ max} - P_{LOAD\ min}}$$

**Possible Impact on the grid:**

1. Excess heating of Grid Asset (s)
2. Reduced life of Transformers
3. Permanent failure of Power Cables
4. Voltage rise at the point of common coupling

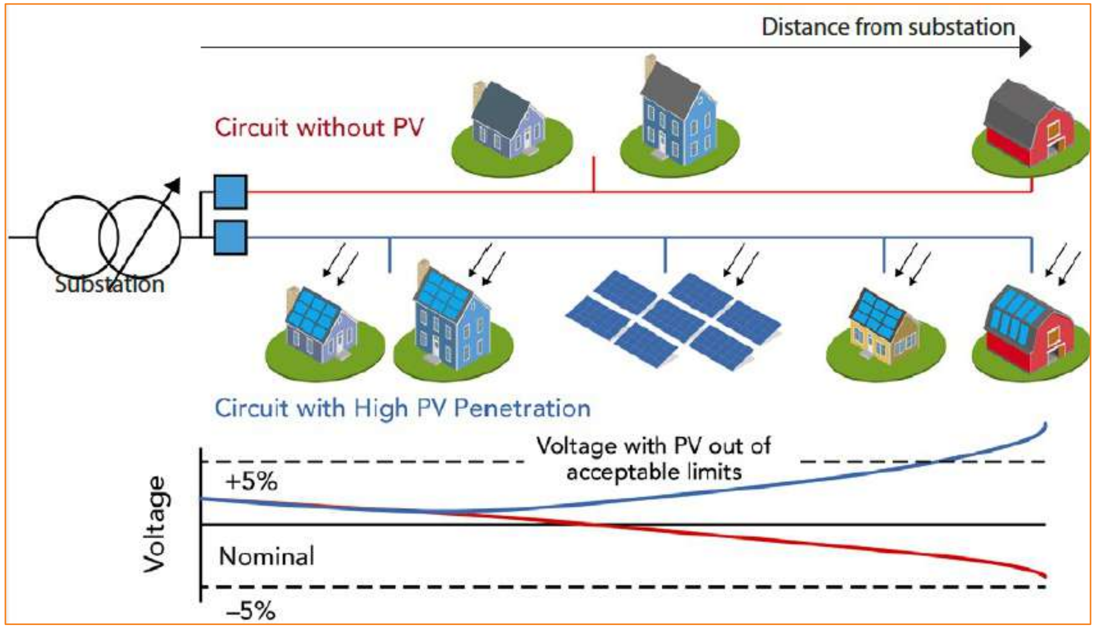


# Challenges with variable solar energy integration to the grid

## Reverse Power Flow – impact and control

- Integrating PV may cause voltage rise in long distribution feeder circuits that serve rural or developing areas if the load and PV generation are not closely matched.

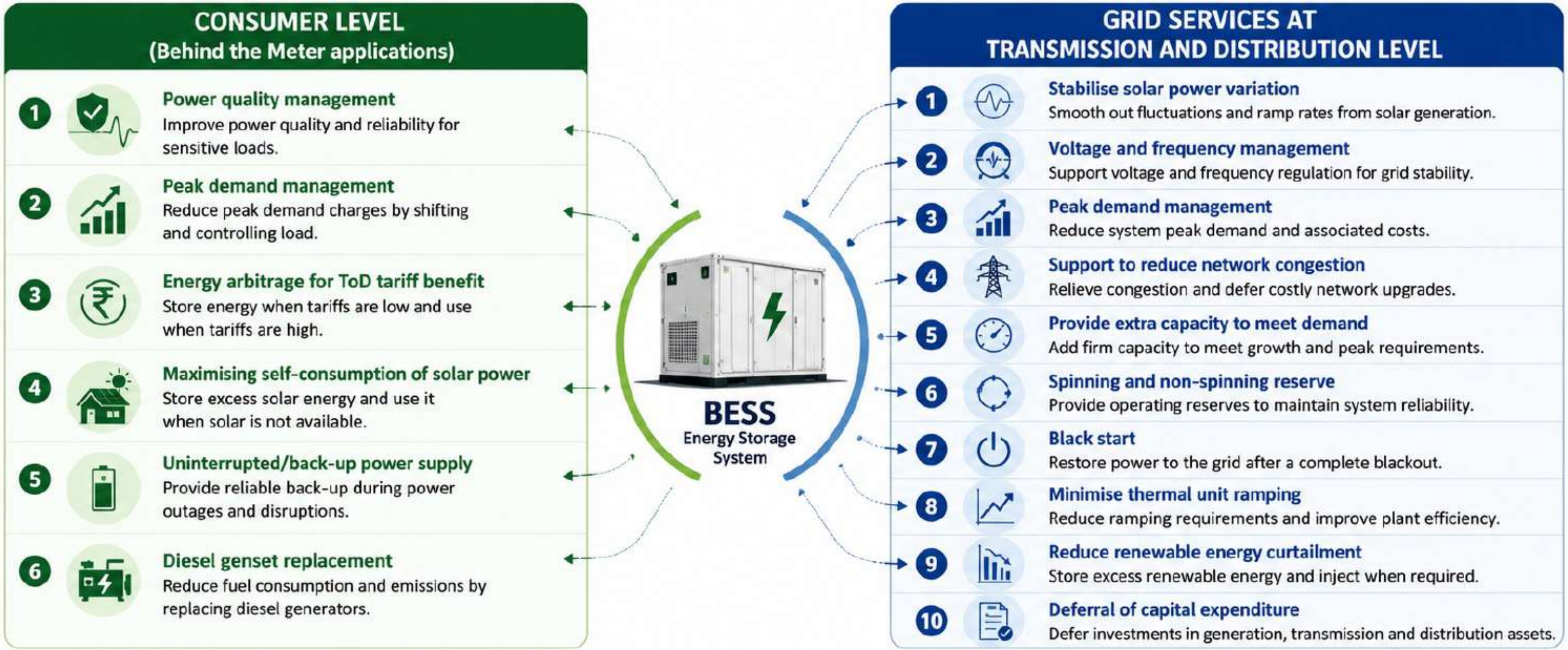
- The figure on the right illustrates the increased voltage range in systems with high PV penetration.




Illustration/Source credit: NREL

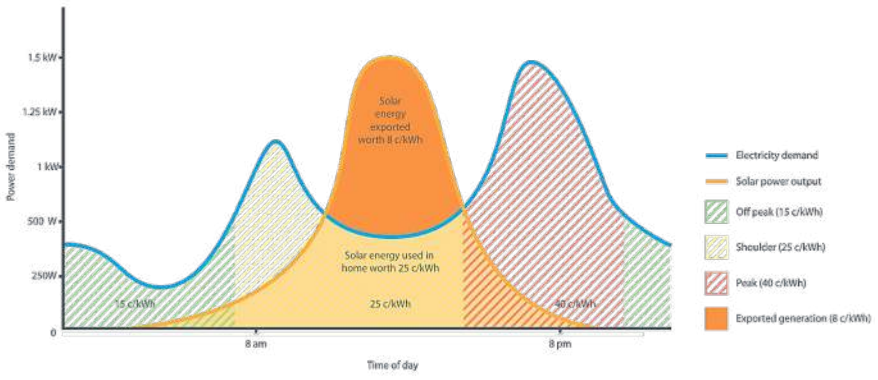
# Use of batteries for power management

# Use of batteries for power system management

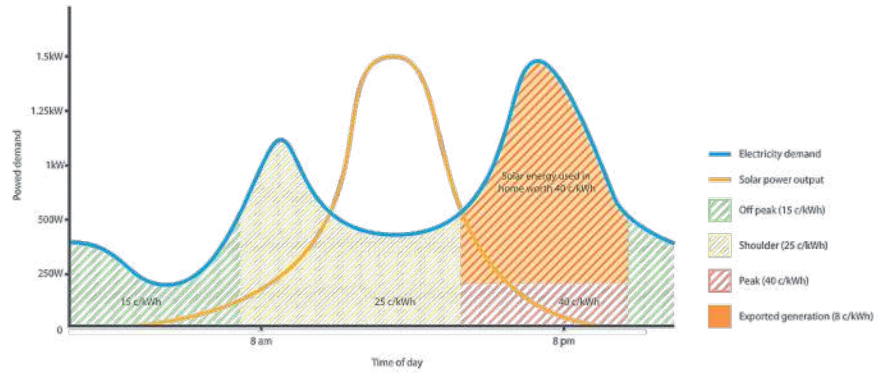


# Use of batteries for power system management

## BESS for Tariff Arbitrage with RE Integration




**Power Demand of a grid-connected PV system without battery storage**

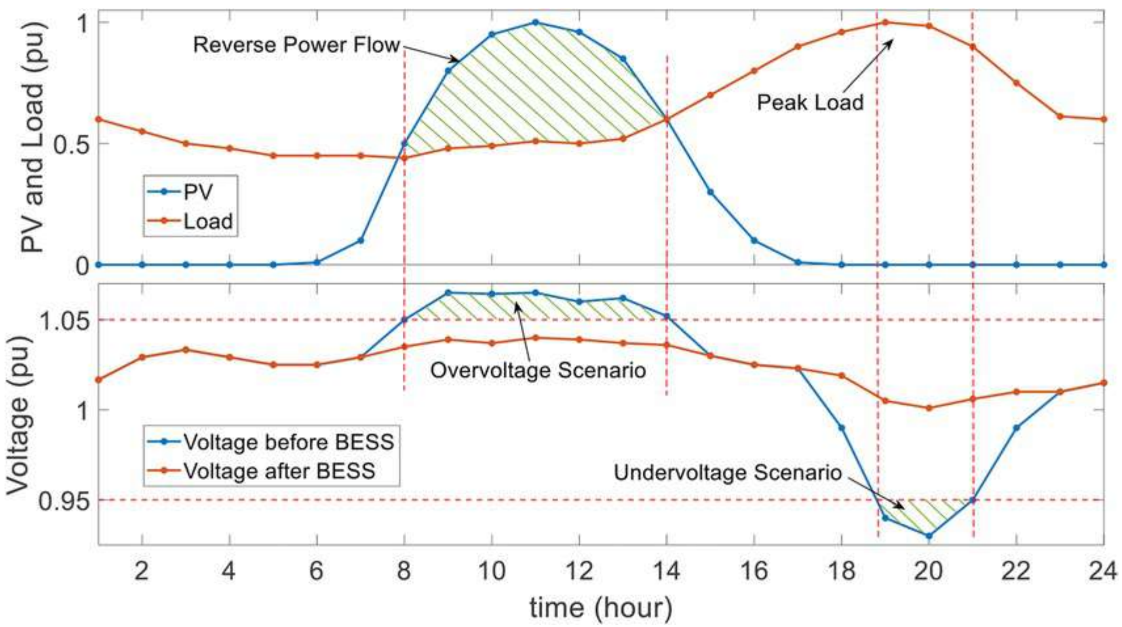



**Power Demand of a grid-connected PV system with battery storage**

# Use of batteries for power system management

## Voltage control with battery storage

- The electricity generation exceeds the load demand between 08:00 to 14:00
- Excessive reverse power flow at the substation and resulting in overvoltage issues.
- BESS system can be charged during this period.
- Between 19:00 to 21:00, the peak load causes under-voltage issues when BESS can be discharged to mitigate undervoltage

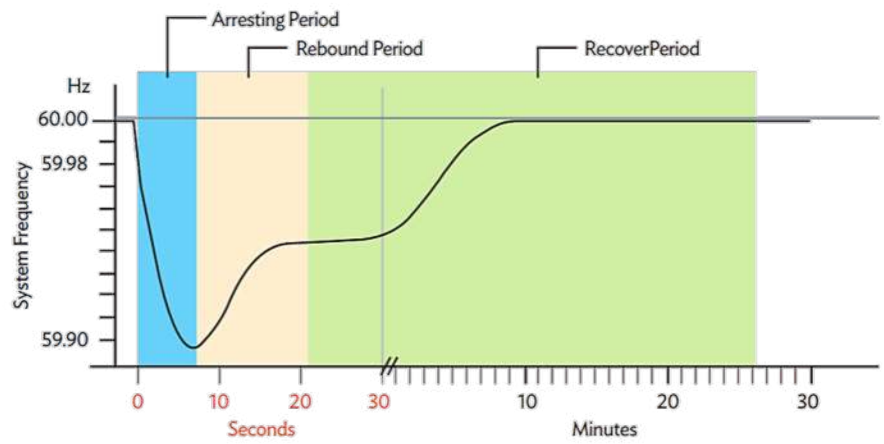


# Use of batteries for power system management

## BESS for Frequency Regulation

- Frequency regulation needs constant **second-by-second adjustment** of power to maintain system frequency at the nominal value (50 or 60 Hz).
- If demand exceeds supply, the system **frequency falls, causing blackouts**.
- If utilities generate more power than consumers demand, the system frequency increases, possibly **damaging** all connected electrical devices.
- Battery energy storage can provide regulating power with **sub-second response times**. This makes it an extremely useful asset for grid-balancing purposes.

Figure 3.2: Frequency Containment and Subsequent Restoration*




Hz = hertz.

* Following a contingency such as an outage at a large power station.

Source: Sandia National Laboratories (2013).

Sandia National Laboratories, "DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA," DOE, 2013.

# Optimisation of the battery energy storage systems

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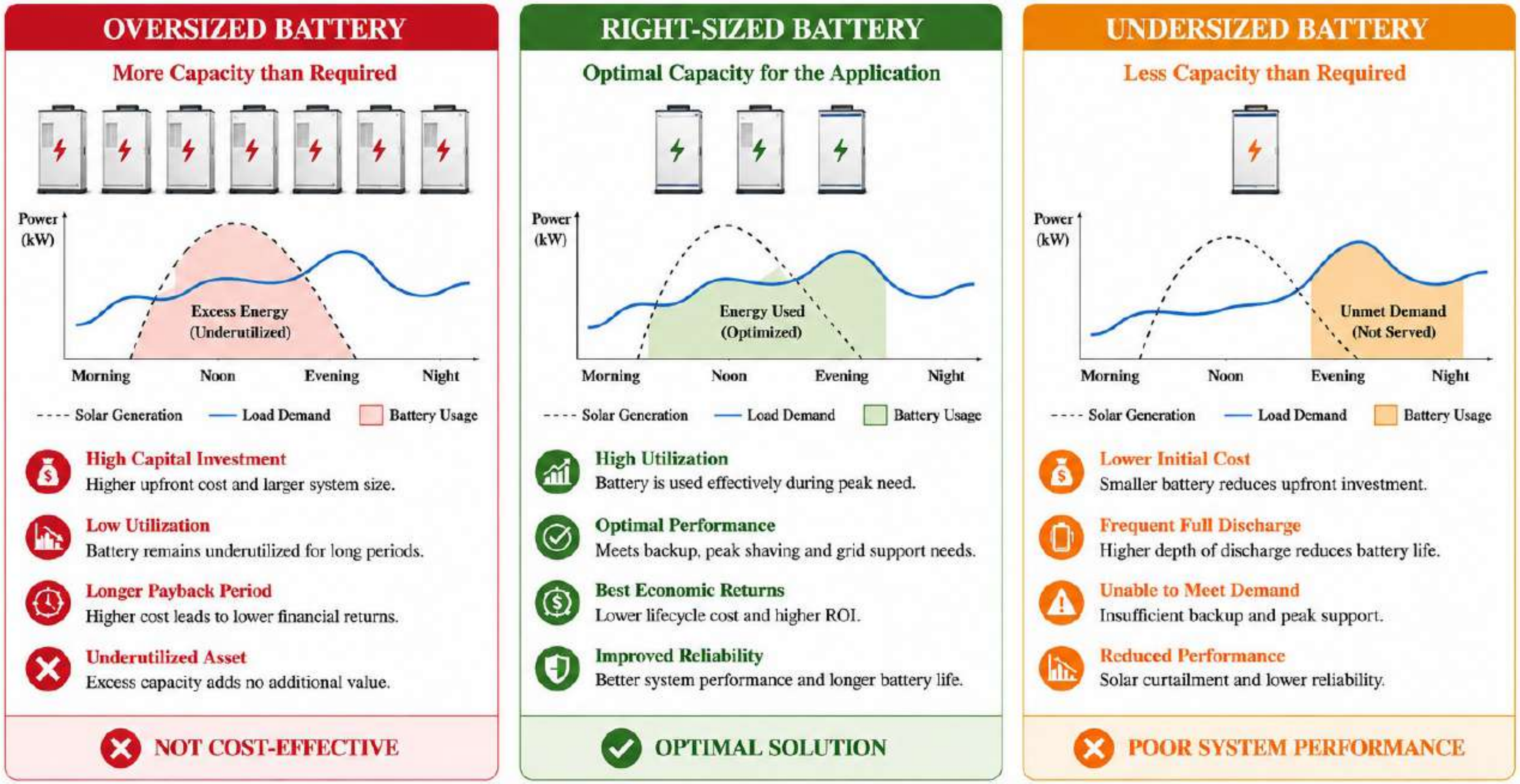

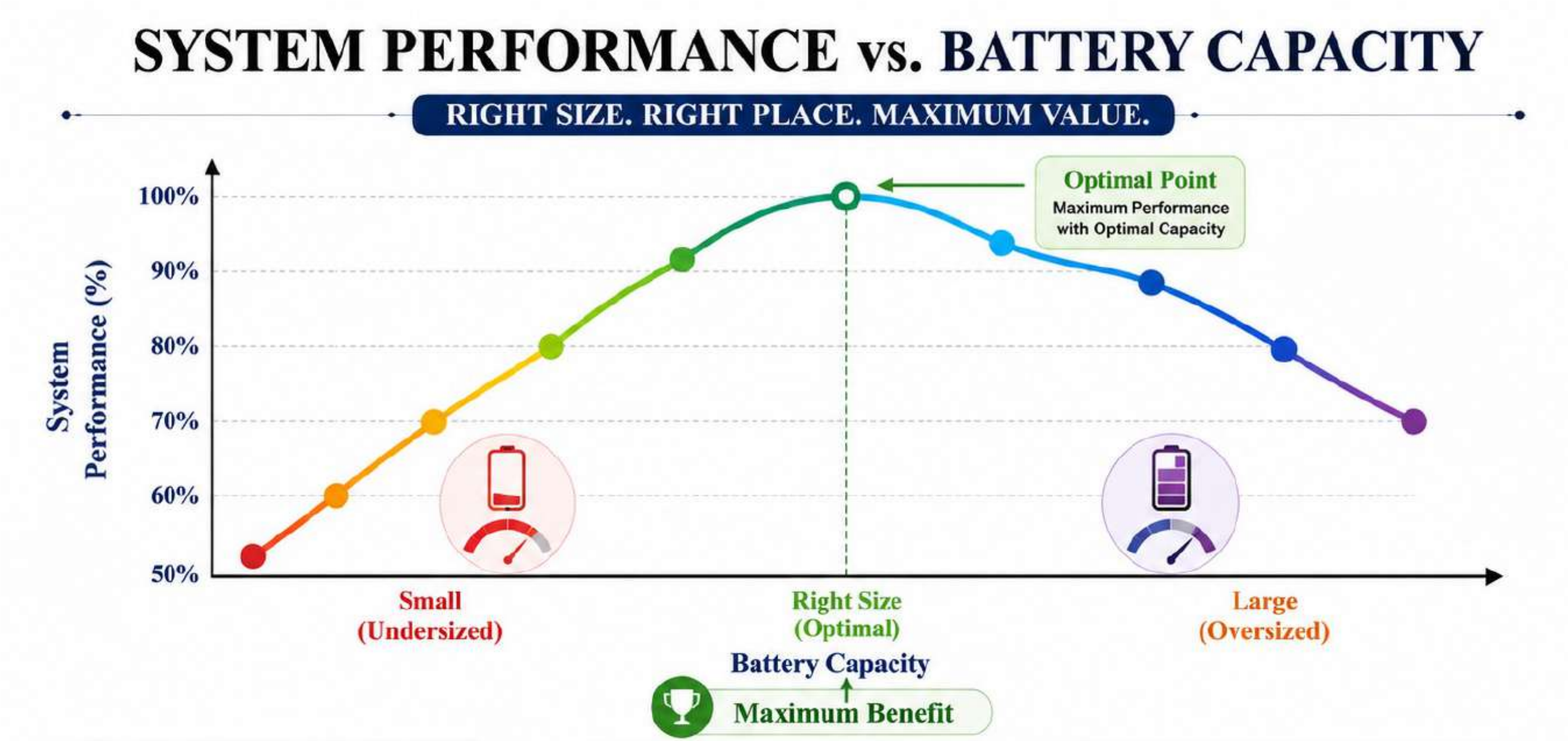
SYSTEM PERFORMANCE vs. BATTERY CAPACITY
RIGHT SIZE. RIGHT PLACE. MAXIMUM VALUE.
Optimal Point
Maximum Performance with Optimal Capacity
System Performance (%)
100%
90%
80%
70%
60%
50%
Small (Undersized)
Right Size (Optimal)
Large (Oversized)
Battery Capacity
Maximum Benefit

# Key Factors Influencing Battery Sizing

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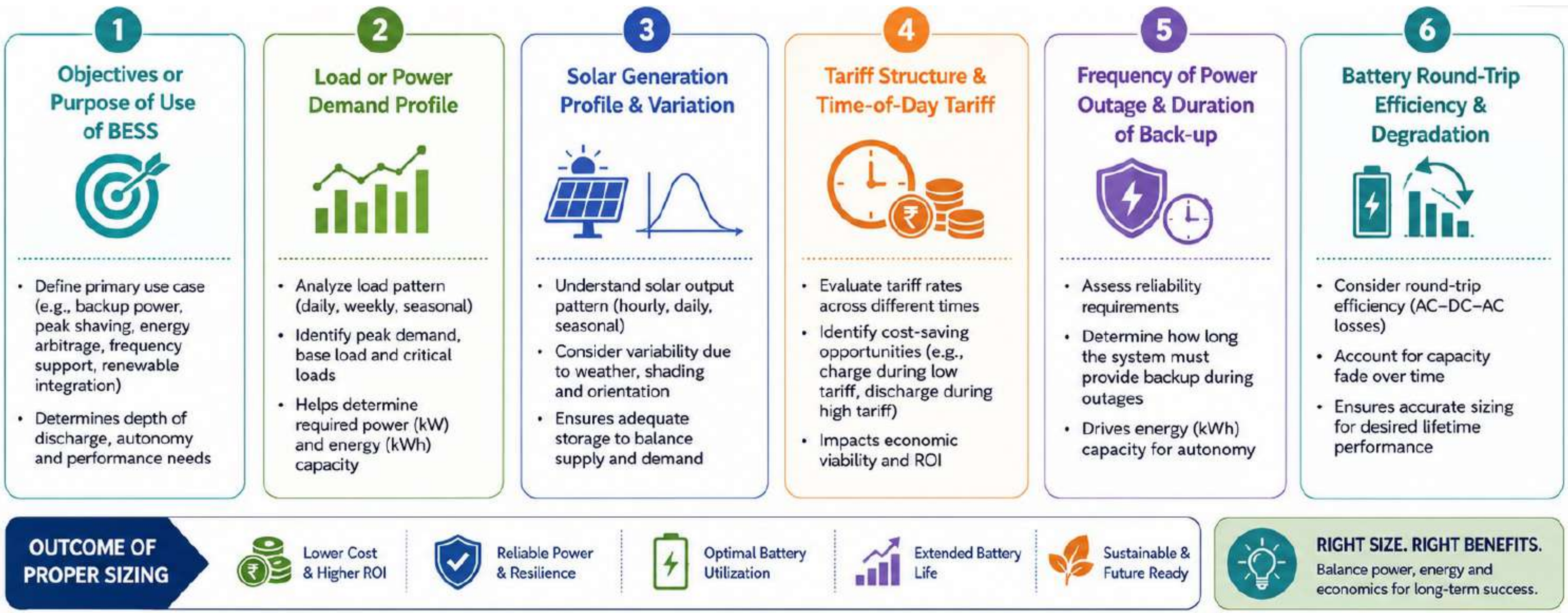

# Strategic Placement of BESS within Solar Power Systems

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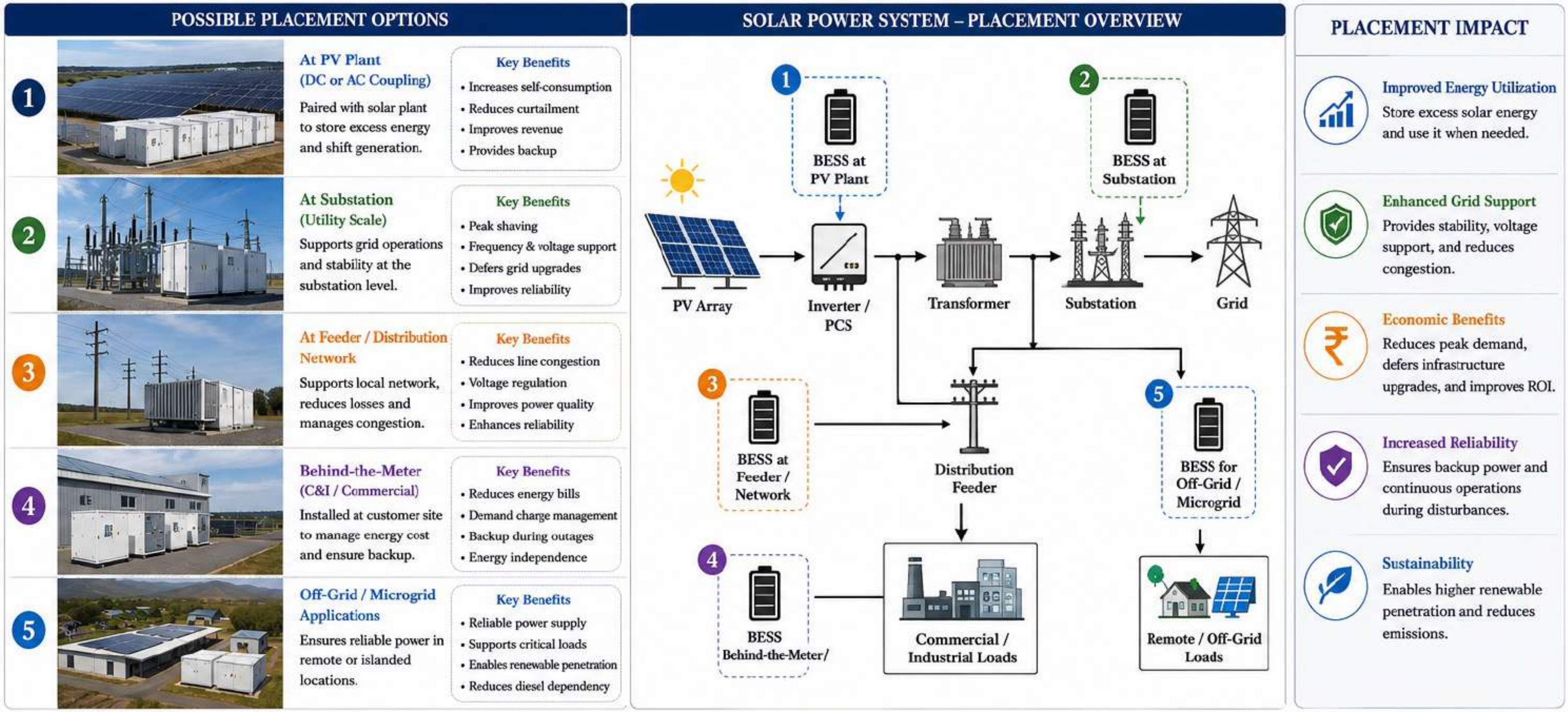


# Optimization Methodologies for BESS Planning and Operation

# Optimization Methodologies for BESS Planning and Operation

## WHY OPTIMIZATION?

**Maximize solar energy utilization**
Capture and use more clean energy from your solar system.

**Minimize energy curtailment**
Store excess energy instead of wasting it.

**Reduce operating cost and maximize ROI**
Lower energy bills and improve financial returns.

**Improve grid reliability and power quality**
Provide stability, backup and support to the grid.

**Extend battery life through optimal operation**
Reduce stress and degradation for longer battery lifespan.

## WHAT IS OPTIMIZED?


## COMMON OPTIMIZATION METHODS

**Rule-Based / Heuristic Methods**
Simple rules and engineering judgment based on experience.

**Analytical / Mathematical Methods**
Use mathematical models to derive optimal solutions.

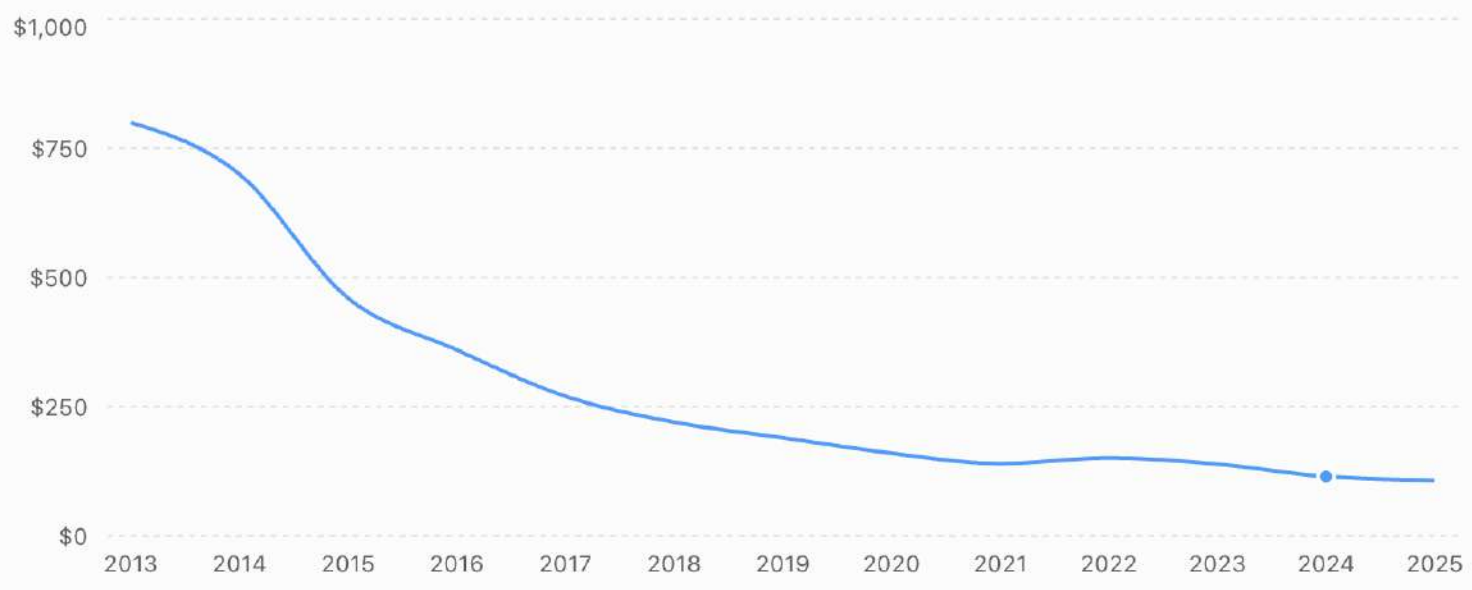
**Simulation-Based Optimization**
Evaluate performance using time-series simulations and iterate to optimize.

**AI / Machine Learning Approaches**
Data-driven techniques to predict, optimize and adapt in real time.

# Economics and Business Models of BESS Deployment

# Global cost trend of BESS

## Global Average Lithium-Ion Battery Pack Price Trend (2013–2025)




Source: BloombergNEF Battery Price Surveys (2024 & 2025).

# Key Factors Affecting the Economic and Financial Viability of BESS

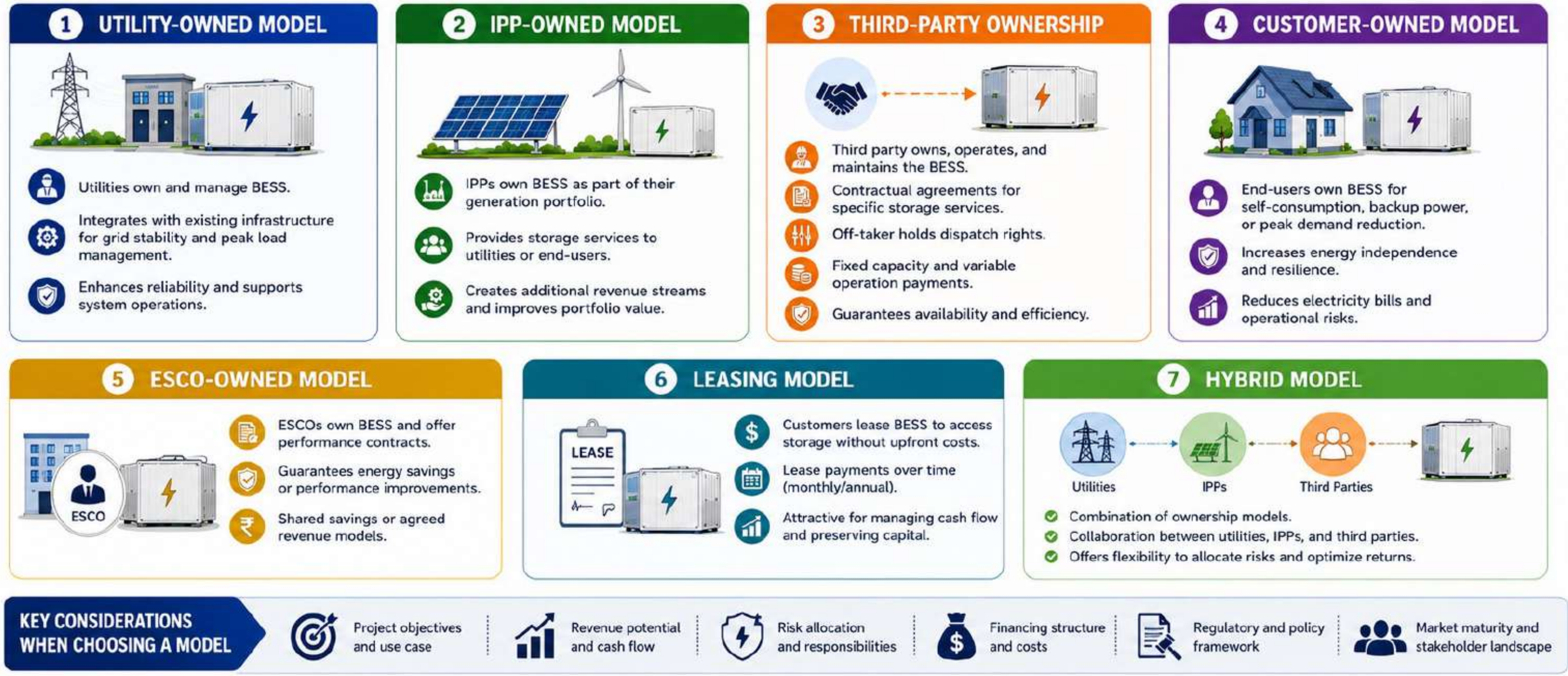
| FACTOR | IMPACT ON PROJECT VIABILITY |
|---|---|
| 1. COST OF STORAGE | Battery costs, while falling, are still the most significant driver of project viability. Costs depend on the MW/MWh ratio of the battery. The terminal value at the end of the project's economic life also has a bearing, with a higher terminal value improving project economics. |
| 2. NETWORK REINFORCEMENT COST | Higher conventional network reinforcement costs increase the value of deploying storage as an alternative, improving project economics (and vice versa) directly for distribution network operators and third-party projects with a contract for peak shaving with a DNO. |
| 3. COMMERCIAL SERVICES | Increased access to and higher value from the provision of commercial services (for example, ancillary service markets, the wholesale market, the capacity market) increase project revenue streams, improving project economics (and vice versa). It is generally accepted that value streams will need to be stacked to increase the economic viability of BESS projects. |
| 4. POLICY DEVELOPMENTS | Removing barriers to storage or creating a more favourable environment for investment enhances the realisable value of a project, improving project economics (and vice versa). |

Source: Asian Development Bank.," Handbook On Battery Energy Storage System", 2018

# BESS Economics Cost Benefit Analysis - Key Components


Source: Asian Development Bank.," Handbook On Battery Energy Storage System", 2018

# Business Models for BESS




Source: Asian Development Bank.," Handbook On Battery Energy Storage System", 2018

# Questions and Discussion

# THANK YOU

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