Solar Plus Storage:

Cost Analysis of Round-the-Clock Supply for a Typical Day

India has declared its intention of creating 500 GW of non-fossil capacity by 2030 and becoming net zero by 2070[1]. Solar power is providing the major share in the growth of non-fossil fuel capacity in the country. As of August 2025, the installed solar power capacity is 125 GW out of about 495 GW installed capacity in India[2], whereas in 2020, the total solar power installed was 61 GW out of 371 GW total installed capacity. India has also witnessed solar tariffs drop from ₹17.91/kWh (2010–11) to ₹1.99/kWh (2020) — a 91% fall in costs between 2010 and 2020[3].

Solar generation takes place only when the sun shines. With storage, solar power can be used to provide electricity at night and also when solar generation is less than demand in the day. Accordingly, the necessity of developing large-scale storage was recognised. The Central Electricity Authority (CEA) estimated a project requirement of 411.4 GWh (175.18 GWh from PSP and 236.22 GWh from BESS) of energy storage systems by 2032[4].

The business case for batteries is strengthening: they charge when solar is cheap and sell power during evening peaks, making them profitable standalone assets.

Previous analyses have shown that **solar plus storage systems are becoming increasingly cost-competitive with new thermal power**, with recent analyses indicating that their combined tariffs are approaching or even undercutting those of new coal-based generation[5,6].

Objective of Theoretical Exercise

In this paper, a theoretical exercise is undertaken to assess the per-unit blended tariff of electricity required to meet the full demand on four representative days in the service area of BRPL in Delhi. The analysis estimates the cost of supplying all of BRPL's past electricity demand for the selected days, using solar power with storage, considering both battery energy storage systems (BESS) and pumped storage (PSP).

Methodology to Assess the Blended Cost of Solar + Storage (Case Study: Delhi, BRPL)

The methodology involved selecting four representative days (2022–23) from BRPL's electricity demand data. Theoretical solar generation curves were created using PVWatts calculator[7] for each season's day. Hourly solar output was then matched against demand to determine the solar energy directly used during daylight hours and the additional energy required from storage to meet non-solar-hour demand. Solar and storage capacities were iteratively sized to ensure full daily demand

[1] https://www.pib.gov.in/PressReleasePage.aspx?PRID=2144627
[2] https://iced.niti.gov.in/
[3] https://www.teriin.org/sites/default/files/files/Roadmap-to-India-2030-Decarbonization-Target.pdf
[4] https://www.pib.gov.in/PressReleasePage.aspx?PRID=2140223
[5] https://iecc.gspp.berkeley.edu/wp-content/uploads/2025/05/IECC-Implications-of-Indias-SolarStorageauctions-for-24-7-clean-power.pdf
[6] https://energywithalex.wordpress.com/2025/09/19/will-building-new-coal-plants-help-make-indias-grid-more-reliable/
[7] https://pvwatts.nrel.gov/

coverage. For the analysis, BRPL's electricity demand for the year 2022-2023 of one peak day's demand is selected for each season. These days are:

Table 1 Selected Season Peak Days' Demand Statistics

Season	Date	Energy Demand (MWh)	Peak Demand (MW)
Winter	10 January 2023	36,996	2,311
Spring	30 April 2022	51,914	2,680
Summer	28 June 2022	66,240	3,325
Autumn	09 September 2022	58,328	2,944

Then, a computation is done of the per-unit cost of electricity for supplying electricity to meet the demand curve.

The system design is based on a set of simplified assumptions reflecting recent market conditions. The **cost of solar generation is assumed at ₹2.5 per kWh**, in line with the average of prevailing tariffs for solar bids over the past few years. For storage, a conversion cost of ₹3.81 per kWh is considered for pumped storage plants (PSP), excluding pumping energy costs[8], while battery energy storage systems (BESS) are assumed at ~₹2.8 per kWh for two-hour systems[9]. The round-trip efficiencies are taken as 80% for PSP and 85% for BESS[10]. This theoretical assessment accounts only for generation and storage costs; transmission and distribution losses, open access and wheeling charges, cross-subsidy surcharges, and financing costs are excluded from the analysis.

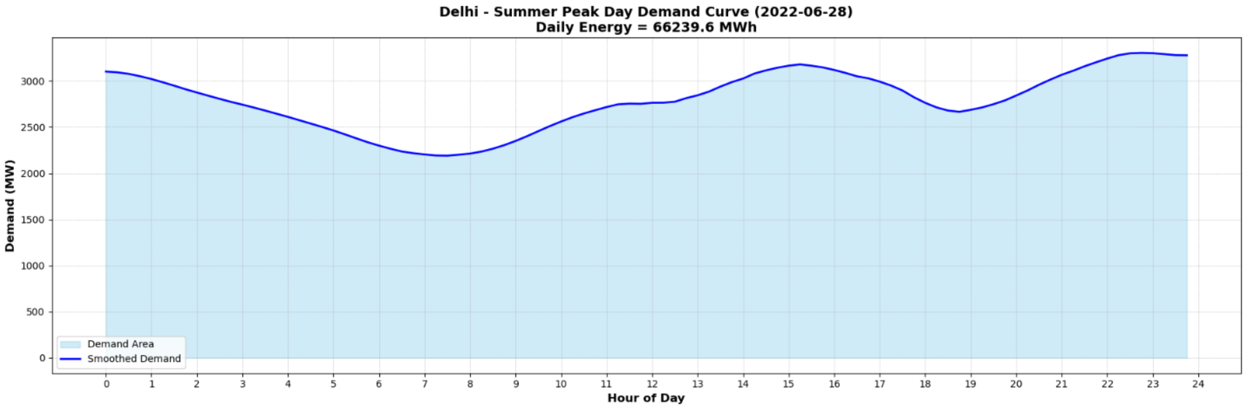

Figure 1 Area Under the Curve Showcasing the Demand for the Summer Peak Day

Summer Peak Day Demand (28 June 2022)

Figure 3 shows the load profile for Delhi on the summer peak day of **28 June 2022**, when total daily demand reached ~**66,240 MWh**. Demand remained high and relatively flat throughout the day, with late afternoon and late evening peaks exceeding 3,200 MW. The shaded area under the curve represents the total daily energy requirement that must be supplied by solar generation during daylight hours and by stored energy during non-solar hours.

[8] Based on TERI's Report on Pumped Storage, 2024
[9] Based on GUVNL Ph-6, April 2025 awarded bid (IESA compilation)
[10] Based on Indian Technology Catalogue (CEA, DEA, GSP)

Table 2 Demand Statistics for Summer Peak Day

Parameter	MWh
Total daily energy demand	66,240
Energy demand during solar hours	36,675
Energy demand during non-solar hours	29,565

Figure 3 presents a theoretical solar generation curve profile for Delhi, modelled using PVWatts for a 1 MWp system. The output follows the typical bell-shaped pattern, beginning around 6:00 AM, peaking close to midday with a normalised output of about 0.6 MWh/MWp, and tapering off after 6:00 PM. The total daily yield is ~**4.46 MWh per MWp**, which serves as the base profile for scaling up solar capacity in the analysis. This curve is superimposed on demand to determine how much electricity can be supplied directly during solar hours and how much extra generation is needed to supply electricity to fully match the demand curve.

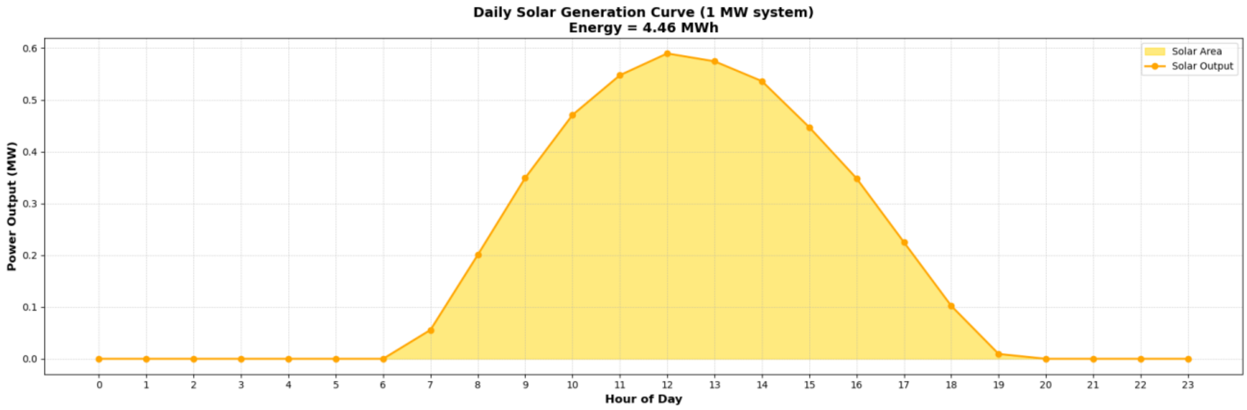

Figure 2 Theoretical Solar Curve for Delhi using PVWatts Calculator

To size a solar plus storage system capable of meeting BRPL's summer peak day demand, the total daily demand (66,240 MWh) was compared against the energy that could be produced from 1 MW of solar (≈ 4.46 MWh/day) to arrive at the size of solar plant needed to both meet the demand during solar hours and store surplus generation to meet the demand during non-solar hours.

To meet demand across the day, solar capacity must satisfy **two conditions**:

- **Solar-hour demand** can be met directly by PV plus storage discharge during weak-sunlight periods.
- **Non-solar-hour demand** must be fully met from storage, which is charged by solar surplus.

The optimal solar multiplier for sizing the solar plant was calculated according to the above conditions.

CASE 1: For Battery Energy Storage System (BESS) as ESS, the efficiency (η) is assumed to be 85%

The analysis indicates that an approximate total solar capacity of **16,270 MW** would be needed to meet the day's demand. The total solar energy generation amounts to **72,503 MWh**, of which **30,967 MWh** of solar generation is directly used for demand. The **excess solar generation** is **41,536 MWh**, and the **energy available for storage after losses** is **35,305 MWh**. The **energy drawn from storage for solar-hour deficit** is **5,740 MWh**, while the **non-solar hour demand met through storage** amounts to **29,565 MWh**. Overall, **42.7%** of the solar generation is used directly for meeting the demand during solar hours, and **57.3%** of the solar generation is sent to storage before losses.

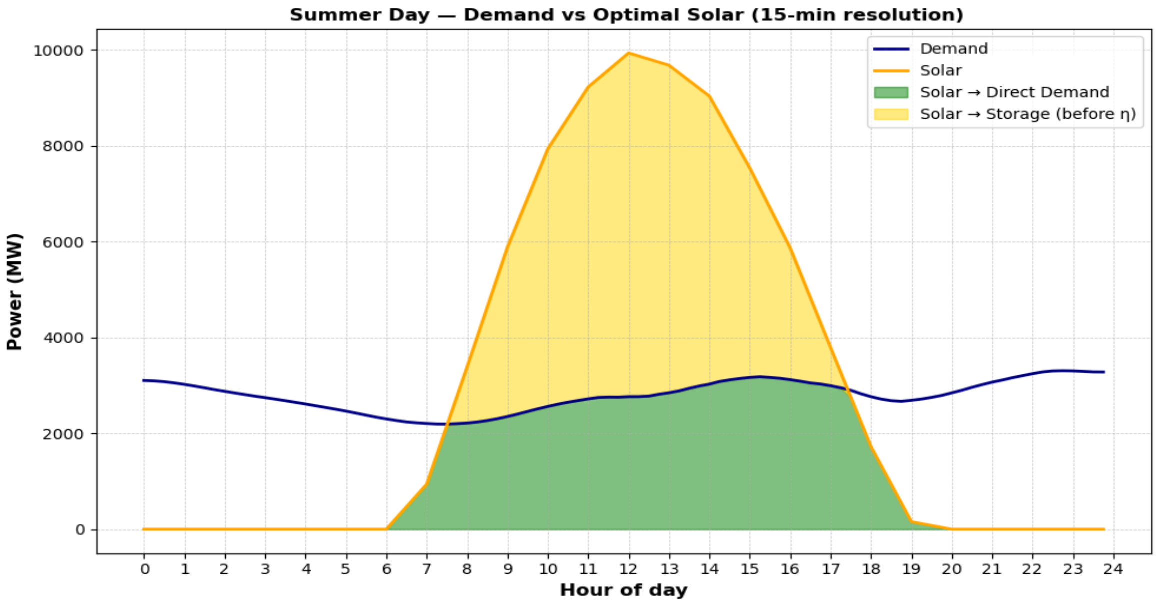

Figure 3 Optimised Solar Capacity to Meet Demand During Solar and Non-solar Hours (through storage)

CASE 2: For Pumped Storage System (PSP) as ESS, the efficiency (η) is assumed to be 80%[11].

The same calculations were carried out for the case of solar plus PSP, to get the following numbers:

Table 3 Calculations for Solar plus PSP

Parameter	MWh/MW
Approximate total solar capacity needed (MW)	16,845
Total solar energy generation (MWh)	75,066
Solar generation directly used for demand (MWh)	31,104
Excess solar generation (MWh)	43,962
Energy available for storage after losses (MWh)	35,170

11 https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/10/20231012132305426 5.pdf

Energy drawn from storage for solar-hour deficit (MWh)	5,605
Non-solar hour demand met through storage (MWh)	29,565
% of solar generation used directly for demand	41.4
% of solar generation sent to storage (before losses)	58.6

Calculations for the Per-Unit Cost of the System to Meet the Day's Complete Demand

To arrive at a per-unit cost of a solar-powered storage system, the solar plus storage system's per-unit cost of electricity to meet the demand can be arrived at through the following equation:

$$\textit{Per Unit Cost}_{System}\textit{to meet Demand} = \frac{\textit{Generation}_{Solar} \times \textit{Cost}_{Solar} + \textit{Generation Delivered}_{ESS} \times \textit{Cost}_{ESS}}{\textit{Total Generation Delivered}}$$

The solar PV cost applies to all PV generation, and the storage cost excludes the charging energy. A 2-hour BESS system has been assumed, as competitively discovered prices for such systems are available and serve as good references. Multiple 2-hour BESS installations can be deployed to enable the supply of electricity that fully meets the demand curve of the day.

Table 4 Results from the Calculation for Per-Unit Cost of RTC System

SUMMER DAY 28 June 2022	BESS	PSP
Total generation by solar (MWh)	72,503	75,066
Total generation delivered by storage (MWh)	35,305	35,170
Solar PV tariff (Rs/kWh)	2.5	2.5
Standalone Storage tariff (Rs/kWh, excluding charging costs)	2.8	3.81
Total energy demand (MWh)	66,240	66,240
Cost per unit system (Rs/unit)	**4.23**	**4.86**

As seen in Table 5, BESS-based systems are consistently cheaper than PSP-based systems, and both solar plus storage configurations are cheaper than new thermal generation. The results presented here exclude additional costs such as transmission charges and losses, open access charges, land cost, and financing cost, focusing only on generation and storage costs. **Considering the recently discovered thermal power tariffs in the range of ₹5.4–₹5.8 per kWh, solar + storage is emerging as a viable and cleaner 24×7 supply option.**

Table 5 Analysis of all Four Representative Days

COST ANALYSIS	SUMMER DAY 28 June 2022 BESS	PSP	WINTER DAY 10 January 2023 BESS	PSP	AUTUMN DAY 9 September 2022 BESS	PSP	SPRING DAY 30 April 2022 BESS	PSP
Total generation by solar (MWh)	72,503	75,066	39,870	41,039	63,906	66,189	56,914	58,962
Total generation delivered by storage (MWh)	35,305	35,170	16,181	16,096	31,445	31,325	28,189	28,085
Solar PV tariff (Rs/kWh)	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Standalone Storage tariff (excluding charging costs)	2.80	3.81	2.80	3.81	2.80	3.81	2.80	3.81
Total energy demand (MWh)	66,240	66,240	36,996	36,996	58,328	58,328	51,914	51,914
Weighted average cost per unit system (Rs/unit)	**4.23**	**4.86**	**3.92**	**4.43**	**4.25**	**4.88**	**4.26**	**4.90**

This exercise was conducted in discussion with the following members:

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