ISSN 2004-2965 Energy Proceedings, Vol. 21, 2021

International Conference on Applied Energy 2021
Nov. 29 - Dec. 5, 2021, Thailand/Virtual
Paper ID: 036

Techno-Economic Feasibility of Grid-Scale Solar Photo-Voltaic Energy Storage System (GSPV-ESS) Hybrids for Daily Peak Power Shaving in Assam, India

Debanjan Mukherjee [1], Karuna Kalita [2*]

1 School of Energy Science and Engineering, Indian Institute of Technology Guwahati, Assam, India

2 Mechanical Engineering Department, Indian Institute of Technology Guwahati, Assam, India (Corresponding Author)

ABSTRACT

The principal objective of the paper is to study the techno-economic feasibility of developing the following types of Grid-Scale Solar Photo-Voltaic Energy Storage System (GSPV-ESS) Hybrids having capacity to deliver 350 MWh for one hour to shave the daily peak power demand contributed entirely from the state-owned installed generators of Assam, India:

i. Grid-Scale Solar Photo-Voltaic Lithium-Ion Battery Energy Storage System (GSPV-LiBESS) Hybrid
ii. Grid-Scale Solar Photo-Voltaic Pumped Hydro Energy Storage System (GSPV-PHESS) Hybrid

The amount of solar photovoltaic panels and the capacity of grid-scale energy storage systems required are well established in this paper. Further, the paper discusses the investment costs and the payback period required under the following two scenarios in Assam for Peak Power Shaving (PPS):

i. Scenario I: to shave the peak load, exclusively
ii. Scenario II: to shave the peak load and sell surplus electricity to consumers

The novelty of the paper lies in developing models of two different grid-scale solar photovoltaic energy storage system hybrids of capacity 350 MW each to shave daily peak power demand for one hour and contribute towards Demand Side Management (DSM) for India and abroad. The two models under two scenarios of Assam can be referred to as a template for similar grid-scale solar photovoltaic energy storage system hybrids, developed and erected for daily peak power shaving in other states of India and elsewhere in the world.

KEYWORDS: renewable energy resources, solar photovoltaic energy, lithium ion battery energy storage system, pumped hydro energy storage system, demand side management, peak load shaving

NOMENCLATURE:

Abbreviations	
Demand Side Management	DSM
Peak Power Shaving	PPS
North-East Regional Grid	NERG
North-East Region	NER
Grid-Scale Solar Photo-Voltaic Energy Storage System	GSPV-ESS
Grid-Scale Solar Photo-Voltaic Lithium-Ion Battery Energy Storage System	GSPV-LiBESS
Grid-Scale Solar Photo-Voltaic Pumped Hydro Energy Storage System	GSPV-PHESS
North-East Load Dispatch Centre	NERLDC
Power System Operation Corporation Limited	POSOCO
Standard Test Conditions	STC
Levelized Cost of Energy	LCOE
Conference of Parties	COP
Symbols	
P_{rated} (kW)	SPV Array Rated Power
I_{PV} (kW/m^2)	Solar Radiation Incident on the PV Array
I_{STC} (kW/m^2)	Incident Solar Radiation at STC
m_{water} (kg)	Mass of Water
h (m)	Head Height
$\rho_{discharge}$ (m^3/sec)	Flow Rate during discharging of PHES
ρ_{charge} (m^3/sec)	Flow Rate during charging of PHES
η_{gen}	Generator Efficiency
v (m^3)	Volume of the Reservoir

1. INTRODUCTION

Peak power demand is the maximum of all the average power consumptions occurring in a specific interval (of 15 mins to 1 hr) [1]. The peak demand can exceed the maximum supply capacity of the installed generators in the grid [2]. This complication is simplified by developing grid-scale energy storage hybrid systems. These hybrid energy storage systems are discharged when the peak load occurs [3]. Moreover, energy storage systems associated with solar photo-voltaic systems, allow the ESS to charge during peak sunshine hours, adding to the overall savings in energy costs on the generation, transmission and distribution side [4]. Globally, U.S, Japan, Europe, China and Australia are leading the energy storage or clean energy market [5]. These countries have developed their grid infrastructure resiliently and reliably, by investing in dedicated grid-scale energy storage system hybrids for peak shaving and ancillary grid applications.

2. BACKGROUND

The grid capacity of India is 386.89 GW as of July, 2021. The NERG capacity stands at 4.98 GW with renewables contributing around 482.57 MW into the energy generation mix of the region [6]. The NER meets a daily peak (evening) demand of 2875 MW into which Assam contributes an average daily (evening) peak load of 1842 MW as of August, 2021 [7] (Fig.1.).

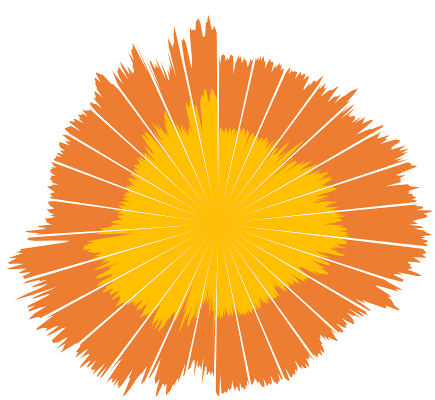

Fig.1. Peak Power Demand (in MW) NER and Assam

Assam located in the northeast region of India has a state-owned installed generation capacity of 412.5 MW and is represented in the NERG (Fig.2.). These state-owned generators contributed a minimum of 84 MW and a maximum of 337.91 MW from January, 2021 till June, 2021 towards PPS. The well-established state-owned network of thermal (24.5 MW), hydel (116.25 MW), gas (266.7 MW) and solar (5MW) installed generation capacities in Assam cannot meet the peak power demand of the state and the remaining power demand is facilitated from the central and private owned electricity generation facilities in the NERG or is imported from other regional grids [7,8].

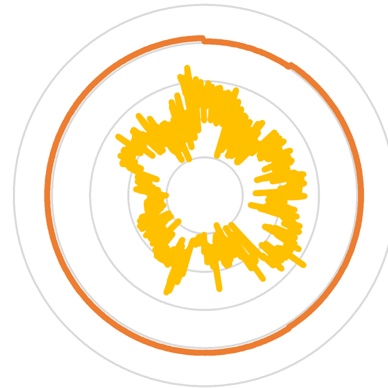

Fig.2. State-owned installed generation capacity (in MW) and demand met

2.1 Objective

The focal objective of the paper is to study the techno-economic feasibility of GSPV-LiBESS Hybrid and GSPV-PHESS Hybrid under two scenarios having capacity to deliver 350 MW for one hour to curtail the daily peak power demand contributed entirely from the state-owned installed generators of Assam, India.

Pumped Hydro (169 GW) shared 96% and Electro-chemical batteries (1.63 GW) shared 1% of the world's total energy power capacity. [9].

The percentage share of energy storage applications dedicated for grid ancillary services in India is 1% [10]. A combined capacity of 1.25 MW of BESS and a BESS capacity of 0.52 MWh dedicated for peak shaving, frequency regulation and power back up in case of a grid outage has been recently commissioned in India [4,11].

India has an overall PHESS capacity of 4.79 GW with two plants of 1.08 GW are under construction. 63 sites have been identified for developing PHES plants with a total potential of 96 GW. [12]

2.2 Methodology

The daily peak power demand data of Assam and the NER along with the power contribution from state-owned installed generators for PPS were collected and plotted from NERLDC situated in Guwahati under PSOCO since January 1, 2021 till June 30, 2021 to generate and analyze the daily peak load curve of the region and thereby, adjudicated to perform a techno-economic feasibility study of grid-scale solar photovoltaic based two different types of 350 MWh energy storage systems dedicated for PPS of Assam.

The data of annual daily average sunshine hours is collected for a span of last 22 years and the average daily maximum sunshine hours is analyzed to be 5.845 hours in Assam [13]. The present-day cost details of the different components for setting up the total infrastructure for GSPV-ESS Hybrids in Assam, India have been collected and interpreted from various government and private sources [14–16].

2.3 Theory/calculation

The solar output, P_{out} from the PV arrays is given by [17]:

$$P_{out}(kW) = P_{rated}\ x \left(\frac{I_{PV}}{I_{STC}}\right) \qquad \text{(i)}$$

The P_{out} is calculated for the maximum sunshine hours daily to determine the daily and annual energy output from the PV arrays. The energy generated and the net present cost incurred throughout the lifetime of the SPV installations is further calculated to determine the LCOE generated. The minimum grid-scale lithium-ion battery capacity is found to be 1 MWh [17]. Hence, the battery bank can be designed accordingly.

The power generated, $P_{discharge}$ from the PHES during the discharge phase for PPS is given by [17]:

$$P_{discharge}(kW) = m_{water}\ x\ g\ x\ h\ x\ \rho_{discharge}\ x\ \eta_{gen} \qquad \text{(ii)}$$

$P_{discharge}$ for one hour determines the energy output, $E_{discharge}$ (kWh) required to shave the peak. The amount of energy required to pump the water to the head height is known as charging and and is given by E_{charge} (kWh) [17]:

$$E_{charge}\,(kWh) = \frac{P_{discharge}\,(kW)\ x\ v\ x\ 3600}{\rho_{charge}} \qquad (iii)$$

The round trip efficiency, $\eta_{r\text{-trip eff}}$ of PHES is determined by [17]:

$$\eta_{\text{r-trip eff}} = \frac{E_{discharge}\,(kWh)}{E_{charge}\,(kWh)} \qquad (iv)$$

The capital investment costs are determined and accordingly, the revenue generated under Scenario II is calculated to determine the payback of both the GSPV-ESS Hybrids capable to shave 350 MW of peak power for one hour.

2.4 Results

Table I: Techno-Economic Feasibility Models for Assam, India

	Scenario I	**Scenario II**
I. Grid-Scale Solar Photo-Voltaic Lithium-Ion Battery Energy Storage System (GSPV-LiBESS) Hybrid		
SPV Capacity (MW)	57	500
Daily Energy Generated from SPV (MWh)	350	3074.76
Operating Hours	1	1
Lithium-Ion Battery Bank Energy Capacity (MWh)	350	350
Round Trip Efficiency (%)	90	90
Surplus Energy (MWh)	0	2724.76
Area (km^2)	0.285	2.5
Capital Investment (Billion INR)	7.56	51.86
LCOE (INR/kWh)	3.03	2.52
Annual Revenue Generated (at tariff = 7 INR/kWh) (Billion INR)	NA	6.96
Payback (years)	NA	7.45
II. Grid-Scale Solar Photo-Voltaic Pumped Hydro Energy Storage System (GSPV-PHESS) Hybrid		
SPV Capacity (MW)	70.4	500
Water Reservoir Volume (m^3)	1430000	1430000
Head Height (m)	100	100
During Discharging		
Daily Energy Generated (MWh)	350	350
Flow Rate (m^3/sec)	397.22	397.22
Operating Hour	1	1
During Charging		
Daily Energy Required (MWh)	432.72	432.72
Flow Rate (m^3/sec)	321.75	321.75
Hours Required	1.23	1.23
Round Trip Efficiency (%)	81	81
Daily Energy Generated from SPV (MWh)	432.72	3074.76
Surplus Energy (MWh)	0	2641.79
Capital Investment (Billion INR)	16.36	37.84
Annual Revenue Generated (at tariff = 7 INR/kWh) (Billion INR)	NA	6.74
Payback	NA	5.6

**NA- Not Applicable*

3. DISCUSSION

The significance of the results obtained from the two models envisages the optimal technical and economic capacity of solar photo-voltaic system and the two energy storage systems required to curtail a daily peak demand of 350 MW for one hour to compensate the state-owned generators of Assam. The model discussed under Scenario II broadens the scope of investment where the surplus energy can be sold to the industrial and commercial consumers. Moreover, the GSPV-PHESS Hybrid can be utilized for frequency regulation purposes to provide active power support during a demand-supply mismatch of power in the region.

4. CONCLUSION

India aims to secure 50% of its energy consumption from renewables by 2030. Further, it also wishes to increase its non-fossil fuel energy capacity to 500 GW by 2030 as per COP 26. Thus, eyeing on a huge deployment of energy storage solutions along with renewable energy deployment would require renewable energy storage hybrids of grid-scale capacity that can suffice to the energy needs and the grid infrastructure of India thereby, reducing chances of frequency triggered fault events.

The techno-economic feasibility study performed in this paper is unique and novel as it is dedicated exclusively for grid-scale renewable energy storage hybrids used for PPS unlike other techno-economic feasibility studies performed for energy storage solutions in India or elsewhere in the world. Moreover, the study performed highlights the technical and economic parameters required for the successful deployment of solar photovoltaic lithium ion battery energy storage system hybrid and solar photovoltaic pumped hydro energy storage hybrid for peak power shaving purposes under two scenarios. Similar techno-economic feasibility studies on solar photovoltaic energy storage hybrids are not performed extensively as authors in previous published papers tend to perform such studies at the product development and generic level without a specific cause. Moreover, such studies performed exclusively for peak power shaving purposes are remote and vague both at the national and global level.

India is in the exploration phase when it comes to renewable energy deployment. The details of the present-day energy storage systems deployed in India are reviewed briefly in *Section 2.1*. Thus, there is a need at the ground level to assess the feasibilities of such huge

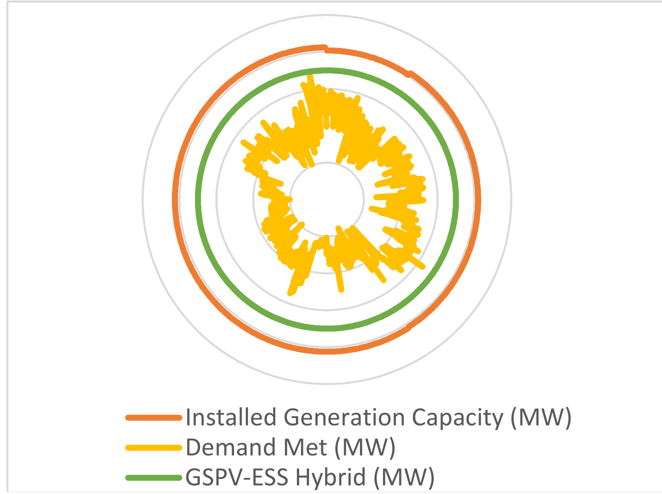

Fig.3. GSPV-ESS Hybrid for PPS in Assam (in MW)

grid-scale energy storage solutions for peak load curtailment concerning with both investments and technicalities involved. Further, frequency response and low inertia issues can also be addressed through deployment of grid-scale energy storage system hybrids.

The two scenarios discussed for Assam, India has yielded payback periods incurred in the second model under Scenario II for both GSPV-ESS Hybrids indicating an emergence of a business model where private investors and shareholders can contribute towards developing, commissioning and operation of a GSPV-ESS Hybrids. The two models can act as a reference template for developing similar grid-scale solar PV energy storage hybrid systems exclusively for peak shaving and ancillary grid operations in India and elsewhere in the world.

ACKNOWLEDGEMENT

The feasibility study performed acknowledges the contribution of POSOCO and NERLDC for providing the necessary peak load data of Assam required for this feasibility study and appreciates the efforts of Mr. Vidya Sagar Vepa, Department of Mechanical Engineering, IIT Guwahati and Mr. Jibanjyoti Kalita, Department of Mechanical Engineering, IIT Patna for mining, collecting and compiling the daily peak load data of Assam from January, 2021 to June, 2021 from the NERLDC database.

REFERENCE

[1] Nourai A, Kogan V, Schafer C. Load Leveling Reduces T\&D Line Losses. IEEE Trans Power Deliv 2008;23:2168–73.

[2] Salles RS, Souza ACZ de, Ribeiro PF. Energy Storage for Peak Shaving in a Microgrid in the Context of

Brazilian Time-of-Use Rate. Proceedings 2020;58:16. https://doi.org/10.3390/wef-06913.

[3] Mahesh M, Bhaskar DV, Reddy TN, Sanjeevikumar P, Holm-Nielsen JB. Evaluation of ancillary services in distributiogrid using large-scale battery energy storage systems. IET Renew Power Gener 2020;14:4216–22. https://doi.org/10.1049/iet-rpg.2020.0169.

[4] Mahesh M, Bhaskar D V, Reddy TN, Krishan R, Jisha RK, Singh SK. Study of different use cases of the grid connected Battery Energy Storage System in India n.d.

[5] Popper K, Hove A. Energy Storage World Markets Report. 2017.

[6] (CEA) CEA, (GOI) M. All India Installed Capacity (in MW) of Power Stations Installed Capacity (in MW) of Power Utilities in the States / UTs located in Northern Region. New Delhi: 2021.

[7] (NERLDC) RLDC. Power Supply Position (PSP) Report August, 2021. Guwahati: 2021. https://doi.org/23/08/2021.

[8] (NERLDC) RLDC. Power Supply Position (PSP) Report June,2021. Guwahati: 2021. https://doi.org/23/08/2021.

[9] Argyrou MC, Christodoulides P, Kalogirou SA. Energy storage for electricity generation and related processes: Technologies appraisal and grid scale applications. Renew Sustain Energy Rev 2018;94:804–21. https://doi.org/https://doi.org/10.1016/j.rser.2018.06.044.

[10] Srivastava A, Karnam B, Rai B, Singh H, Seethapathy R, Suri R, et al. Energy Storage System (ESS) Roadmap for India: 2019 - 2032 | NITI Aayog 2019:204.

[11] Times TE, Economic Times. Nexcharge, Tata Power inaugurate India's 1st grid-connected community energy storage system. India Times (Renewable Enrgy Ind 2021:1. https://economictimes.indiatimes.com/industry/renewables/nexcharge-tata-power-inaugurate-indias-1st-grid-connected-community-energy-storage-system/articleshow/81757910.cms.

[12] TheAsianFoundation/AustralianAid/IRADe. Role of Pumped Hydro Energy Storage in India's Renewable Transition (IRADe-PR-63). vol. 63. 2020.

[13] NASA. NASA Prediction of Worldwide Energy Resources (POWER) Database. Guwahati: 2021.

[14] MNRE. Benchmark costs for Grid Connected Rooftop Solar Power Plants for the Year 2019- 20. New Delhi: 2019. https://doi.org/318/33/2019.

[15] Solar K. Hybrid 20kW Solar System Price 2021:1. https://doi.org/01.01.2021.

[16] Karaduman O. Economics of Grid Scale Energy Storage. Job Mark. Pap. 2020, 2014, p. 1–53.

[17] Homer Energy. Homer Pro. Man Homer Energy 2019:1–241.

