# Optimal Battery Size using Predicted PV Power and Load

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***Abstract- With the increasing adoption of renewable energy systems, such as photovoltaic (PV) systems, in buildings, the effective sizing of battery storage systems becomes crucial to ensure a balanced energy supply and demand. This study uses PV power prediction with the Facebook Prophet model to examine the ideal battery sizing for net-zero energy buildings (NZEB). In order to ensure effective energy usage and create a net-zero energy balance, the paper discusses the difficulties associated with integrating renewable energy sources, particularly photovoltaic systems, into buildings. Accurate projections of PV power generation are generated by utilizing the Facebook Prophet model's capabilities, making it easier to choose the right battery size and model the PV system to accomplish NZEB. The research has important implications for energy management and sustainable building design, allowing net-zero energy buildings to store excess energy during times of high generation and use it during times of low generation or high demand.***

***Indexed Terms- PV Modelling, Battery sizing, Load Forecasting, Facebook Prophet, Net Zero Energy Buildings***

## I. INTRODUCTION

Net zero energy buildings (NZEBs) are a recent development in sustainable architecture and are designed to produce as much energy as they consume. These buildings utilize various energy-efficient technologies and renewable energy sources, such as solar panels, to produce the energy needed to power the building. Homeowners can potentially lower their electricity bills by installing solar panels, depending on their energy consumption and location. This study aims to achieve the optimal sizing of the battery for the considered building through the precise prediction of the building load and the output of photovoltaic panels. By integrating these two variables, we can anticipate the energy surplus or shortfall of the building and optimize the battery capacity accordingly. This approach guarantees the self-sufficiency of the building and minimizes its dependence on the power grid for energy requirements. Additionally, the findings of this study can have practical implications for the wider community. As the world becomes increasingly conscious of the need for sustainable energy sources, net zero-energy buildings are becoming more prevalent. The study is based on a college building(6th Block) of Netaji Subhas University of Technology located in Dwarka, Delhi and is aimed at making this particular building a Net-Zero Energy Building. the motivation behind our research is to set up and improve the ways a building can harness power by accurately predicting PV panel output and building load and optimizing the battery size accordingly. This will help to reduce dependence on the power grid and minimize the carbon footprint of the building, contributing to global efforts to combat climate change. Battery energy storage systems are playing an increasingly important role in reducing electric loads on the power grid. These systems store excess energy generated by solar panels during the day and release it when energy demand is high or when sunlight is not available. They are particularly useful in areas with high energy demand during peak hours or when there are frequent power outages. By using battery energy storage systems, net-zero energy buildings can operate independently of the power grid, reducing their environmental impact and energy costs.

## II. RELATED WORK

"The paper 'Battery Sizing for Grid-Connected Photovoltaic Systems with Demand Response' by W. Liu et al. (2018) investigates the optimal sizing of battery energy storage systems (BESS) for grid-connected photovoltaic (PV) systems with demand response (DR) [1]. The authors emphasize the significance of BESS in addressing the intermittency challenges of PV systems and enhancing the performance of DR programs. Various deterministic and stochastic approaches for BESS sizing are reviewed, and a novel two-stage stochastic programming model is proposed. This model considers uncertainties in PV generation and electricity demand, formulated as a mixed-integer linear programming problem, and solved using scenario reduction techniques. The authors validate the effectiveness of their model through numerical experiments. Overall, the paper provides insights into the opportunities and obstacles of BESS sizing for grid-connected PV systems with DR and presents a promising approach for optimal BESS sizing under uncertainties.

In their paper, Nguyen et al. present an optimization model for designing a grid-connected solar PV-battery hybrid system for household applications [2]. The objective is to minimize the annualized cost of the system, considering household electricity demand and the grid tariff structure. A mixed integer linear programming (MILP) technique is employed to optimize the sizing of the solar PV array, battery bank, and system operating strategies. The model is tested on an Australian household case study and compared with simulation results. The findings demonstrate that the proposed optimization model can reduce the annualized cost of the system by up to 20% compared to a conventional solar PV system without battery storage. Sensitivity analyses are conducted to assess the impact of factors such as electricity tariff, battery capacity, and solar PV capacity on the system cost. This study provides valuable insights into the design and optimization of grid-connected solar PV-battery hybrid systems for households, contributing to the adoption of renewable energy technologies and the transition to a low-carbon future.

Abanda et al.'s paper titled 'Solar Energy Systems for Net Zero Energy Buildings: A Review' offers a comprehensive review of solar energy systems for net-zero energy buildings [3]. The authors provide a detailed overview of key components like photovoltaic panels, energy storage systems, and solar thermal systems. They discuss factors influencing system performance and efficiency, such as climate conditions, orientation, and shading. Design strategies and tools for integrating solar energy systems into net-zero energy buildings are also highlighted, including energy management systems and smart controls. The paper concludes by identifying research gaps and future directions for the development of solar energy systems in net-zero energy buildings. Overall, this paper serves as a valuable resource for researchers and practitioners interested in solar energy systems for net-zero energy buildings.

Ramos-García et al. present an optimization model for battery storage systems in wind farms in their paper 'Optimization of Battery Storage Systems for Wind Farms Considering Dynamic Loads' [4]. The objective is to find the optimal battery storage system size to minimize total energy costs and enhance grid reliability by reducing power fluctuations. The paper emphasizes the importance of considering dynamic loads, such as wind speed fluctuations and battery degradation effects, in the optimization model. The results demonstrate that the optimal battery storage system size depends on the wind farm capacity and dynamic loads. The authors conclude that battery storage systems can effectively improve the economic and technical performance of wind farms.

The article titled 'Design and performance analysis of a small-scale power generation system using biomass gasification and Stirling engine for rural electrification' presents a study on a small-scale power generation system based on biomass gasification and Stirling engine technology [5]. The authors aim to design and analyze the performance of a system that can provide electricity to rural areas using locally available biomass resources. The article provides an overview of biomass gasification and Stirling engine technology principles and discusses the design and optimization of the proposed system

## III. METHODOLOGY AND MODELLING

The study follows a multi-faceted approach which involves gathering hourly weather data for 10 years i.e. from 2012-2022, this weather data was used to simulate the PV power yield, thus giving us a PV Power dataset for the same duration. Simultaneously, the load consumption patterns of the building were studied for a period of 5 years and a separate load dataset was generated. These two datasets formed the basis of the predictions of the PV Power yield and Load for the year 2024. An appropriate PV configuration and model was designed based on the load requirement. The difference between the predicted PV Power of the overall system and the load forecasted was used for the modelling of an optimal battery size. This has been demonstrated in figure-1. The PV power prediction and load forecasting for the next two years was done using Facebook Prophet.

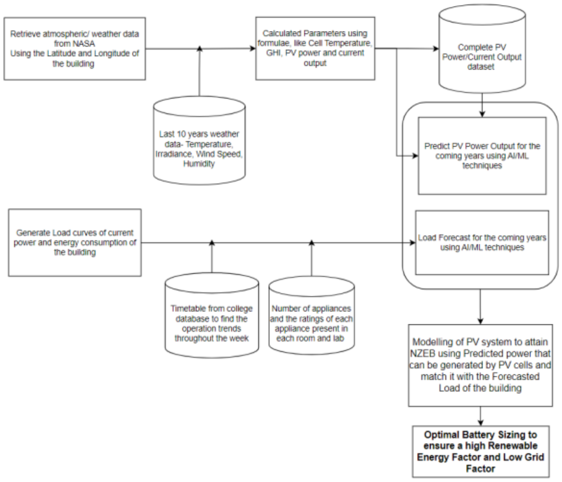


Fig. 1. Flowchart demonstrating the methodology

### *a. PV Power Dataset*

To obtain the PV power data set used in this research, weather data was obtained from the National Aeronautics and Space Administration website[1]. The information gathered is exclusive to the area where the building being studied is located, i.e. the sixth block of Netaji Subhas University of Technology in Delhi. The collection of data spans a duration of ten years, starting from January 1st, 2012, and ending on December 31st, 2021, with readings taken every hour. By mentioning the latitude (28.6104) and longitude (77.0378) of the location, the following parameters were extracted:

'All Sky Surface Shortwave Downward Irradiance (W/m$^2$)', 'Clear Sky Surface Shortwave Downward Irradiance (W/m$^2$)',' Ambient Temperature (℃)', 'Wind Speed (m/s)', Wind Direction (Degrees)', 'Surface Pressure (kPa)' and Specific Humidity (g/kg)'

Furthermore, selecting the appropriate solar panel was necessary to reduce the dependency of the load on the grid. Hence, the panels considered for the purpose are MBB P-Type PERC half-cut belonging to the ETERNAL PRIDE Series and are manufactured by Adani Solar[15]. The specifications have been showed in figure 2.2. Using these weather parameters and the specifications mentioned in the datasheet of the aforementioned solar panel, equation(1) is applied to calculate the PV output. It is to be noted that the PV output calculated corresponding to each hour from 2012 to 2021 represents the output of a single solar cell.

$$Ppv = Ypv \times fpv(\frac{Gt}{Gt,stc})[1 + \alpha(Tc - Tc,stc)]$$

(1)

Where,

Ypv refers to the maximum power output that the PV cell can produce under standard test conditions (Taken 0.64kW),

Gt is the solar radiation incident on PV cell in the current time step (kW/m$^2$),

Gt,stc indicates the radiation received by the PV panel during testing under standard conditions (1 kW/m$^2$),

α is temperature coefficient of power (Taken -0.34 % /°C),

fpv is the PV derating factor (Assumed to be 1%),

TC is the PV cell temperature in the current time step (°C),

TC,stc is PV cell temperature under STC (25°C).

### *b. Load Dataset*

The Load dataset is the dataset containing the hourly power and energy consumption of all the rooms in the considered building. It was generated using the power ratings of the appliances present in each room and the approximate running time of each appliance. The approach followed was to first compute the running time of each appliance based on the college timetable. Ratings of appliances present in each room were used to get the power; coupled with the running time the energy was calculated. The whole year was divided into two categories based on the weather and variations in load. The summer months namely- April, May, June, July, August, September, and October, and the winter months namely- January, February, March, November, and December. The Air conditioners were considered to be switched off throughout the winter months and they were considered to be switched on throughout the summer months. The college remains closed in the month of June, therefore, there was no load demand in the month. For the purpose of the generation of the dataset, Changes in load due to the Lab variability were not considered. Contingency due to the Covid-19 pandemic was not considered. The building has a similar infrastructure throughout the analysis. Table-1 shows the building information and Table-2 shows the Power Ratings of the appliances of the building[14].

$$Load(kWH) = Running\ Time \times Power\ Rating \quad (2)$$

Eqn-4 above gives the formula used for load calculation.

Table. 1. Building Information

| | |
|---|---|
| Floors in the considered building | 4 (Ground Floor, 1st Floor, 2nd Floor and 3rd Floor) |
| Total Area of each floor | 24,451.8 Sq. Ft. |
| Total Number of Classrooms | 14 |
| Total Number of Labs | 24 |
| Total Number of Staff/Prof Rooms | 60 |
| Total Number of Dean/HOD Rooms | 4 |
| Total Number of Washrooms | 8 |

Table. 2. Power Ratings of the appliances of the building

| Appliance | Rating(W) |
|---|---|
| Light | 30 |
| Fan | 60 |
| Elevator | 4000 |
| AC | 1027 |
| Exhaust | 50 |
| Computer | 350 |

A sample classroom is shown in figure-2(a) below, each classroom consists of the following appliances: 9 fans and 16 lights. A sample lab is shown in figure-2(b) below, each lab consists of the following appliances: 3 ACs, 40 lights, 8 fans and 8 computers. Each Staff Room: 2 lights, 1 Fan. Each Prof/Faculty Room: 2 Fan, 6 lights. Each Dean/HOD Room: 4 lights, 2 Fans, 2ACs. Each Washroom: 1 Light, 2 Exhaust Fans, 1 Fans. For the non-operational hours i.e. from 6pm to 8am and on all weekends it was considered that the building operated at a minimum load of 6kWh

Fig.2.(a) Sample classroom (b) Sample Lab considered for the analysis

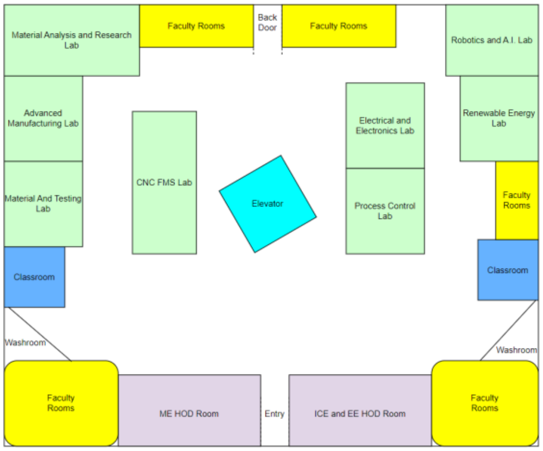


Fig.3. Sample floorplan for all the 4 floors

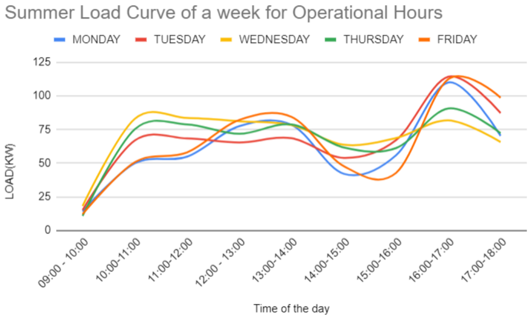


Fig.4. Load Curve for Summer

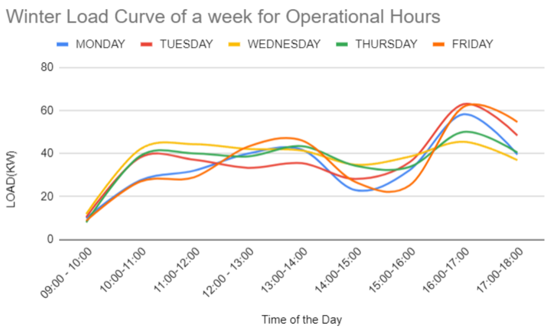


Fig.5. Load curve for Winter

Fig-3 demonstrates the building floor plan which is similar for all the 4 floors. Fig-4 is a load curve for the summer season and Fig-5 is the load curve for the winter season. The load curves were utilized to study the power consumption patterns.

## IV. RESULTS AND DISCUSSION

This study used a Machine learning algorithm known as Facebook Prophet for the task of PV Power prediction and load forecasting.

### *a. PV Power Prediction*

1. This study aims to develop a reliable forecasting model by leveraging 10 years of historical weather data, including parameters like irradiance, temperature, and wind. The model utilizes the Facebook Prophet framework to improve the accuracy of PV power predictions. Accurate forecasts are crucial for optimizing energy dispatch and ensuring a stable power supply, but traditional models often overlook the complex relationship between weather conditions and PV power output. The proposed model addresses this by incorporating comprehensive historical weather data and utilizing the Facebook Prophet model's ability to handle multiple seasonalities in time series data. The study's outcomes can significantly contribute to renewable energy integration and promote the widespread adoption of solar power systems for a sustainable future.

Additionally, Fig. 6 displays the Actual and predicted values of PV power using the Facebook Prophet model. Table 3 illustrates the performance metrics for predicted PV power data.

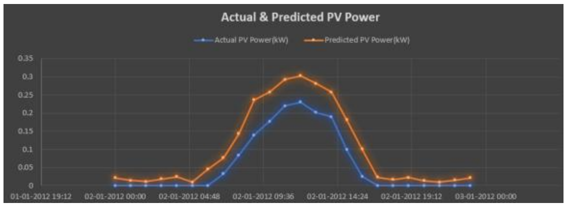


Fig. 6. Actual and Predicted PV Power

TABLE.3- PERFORMANCE METRICS FOR PREDICTED PV POWER DATA

| *Horizon* | *rmse* | *mae* | *mdape* | *smape* | *coverage* |
|---|---|---|---|---|---|
| 36 days 08:00:00 | 0.057712524 | 0.036246276 | 2.940462773 | 1.136995194 | 0.850321396 |
| 36 days 09:00:00 | 0.05781043 | 0.036291947 | 2.917736798 | 1.136019811 | 0.849908173 |
| 36 days 10:00:00 | 0.057830364 | 0.036298261 | 2.908159482 | 1.135592608 | 0.849785736 |
| 36 days 11:00:00 | 0.057786056 | 0.036270691 | 2.881325981 | 1.135468285 | 0.849709213 |

a.

### *b. Load Forecasting*

Accurate load forecasting plays a crucial role in efficient energy planning, grid management, and resource allocation. The aim of this study is to develop a robust load forecasting model by leveraging previous data of load consumption from the 6th block of NSUT (Netaji Subhas University of Technology) during summers and winters. Additionally, the model assumes no load consumption in the month of June. To achieve this, the study employs the Facebook Prophet model, a powerful time series forecasting tool, which can effectively capture complex patterns and seasonal variations in load consumption. By incorporating the Facebook Prophet model, the forecasting accuracy is expected to be significantly enhanced, resulting in more reliable load predictions. Table 4 illustrates the performance metrics of Facebook Prophet for forecasted load power. The proposed model has the potential to assist energy planners, facility managers, and grid operators in making informed decisions, optimizing resource allocation, and ensuring efficient energy utilization.

Fig. 7 represents the Actual and Forecasted values of load power using Facebook Prophet.

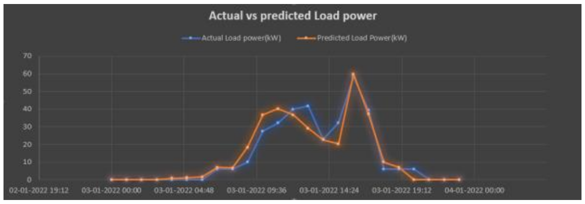


Fig. 7. Actual and Predicted Load

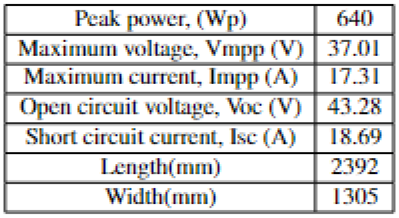
TABLE.4- PERFORMANCE METRICS FOR FORECASTED LOAD DATA

| *Horizon* | *rmse* | *mae* | *mdape* | *smape* | *coverage* |
|---|---|---|---|---|---|
| 34 days 22:00:00 | 19.98311189 | 14.04601619 | 3.753239974 | 1.396788124 | 0.852303861 |
| 34 days 23:00:00 | 19.98300569 | 14.04619793 | 3.753239974 | 1.396789983 | 0.852303861 |
| 35 days 00:00:00 | 19.98309228 | 14.04627139 | 3.760668009 | 1.39722825 | 0.852303861 |
| 35 days 01:00:00 | 19.98069193 | 14.03959188 | 3.762497059 | 1.397692707 | 0.852303861 |

*c. PV System Modelling*

PV system modelling is the technique for designing and optimizing rooftop PV systems. The study proposes a rooftop PV system utilizing the ETERNAL Pride Series MBB P- Type PERC Half-cut Monofacial PV Modules with model number ASM-M12-132-AAA (AAA=630-650)|132 Cells| 640 Wp manufactured by Adani Solar. Table-5 below shows the important electrical parameters of the PV Module. Some of the key features of the PV cell are[15]-

1. MBB cell technology with 12 BB, Smart Soldering
2. Excellent low light performance
3. Least Degradation for LID & LeTID with Ga Doped wafer technology.



| | |
|---|---|
| Peak power, (Wp) | 640 |
| Maximum voltage, Vmpp (V) | 37.01 |
| Maximum current, Impp (A) | 17.31 |
| Open circuit voltage, Voc (V) | 43.28 |
| Short circuit current, Isc (A) | 18.69 |
| Length(mm) | 2392 |
| Width(mm) | 1305 |

Table-5. Electrical Parameters of the PV Module at STC

The total rooftop area was found to be 24,451.8 Sq. Ft. since it is possible to use only 90% of the total area the effective usable area is 22,006.62 Sq.Ft. The product of the length and width of the PV cell gave the area which is approximately 33 Sq. Ft. This means that the rooftop can accommodate a maximum of 666 such PV Cells. After cost optimization and ensuring maximum energy productivity along with maximum inverter efficiency, a PV system with 280 cells was found to be the most optimal solution, as shown in the fig-8. The cost as a function of the Number of PV Cells in the system was used to find out the minimum value of the cost and plot the curve. The cost function depended on the capital cost for the installation of PV Cells, the capital cost for the battery, the grid electricity, the operation cost of the battery, the operation cost of the PV Cells, and the maintenance cost over a 10-year period.

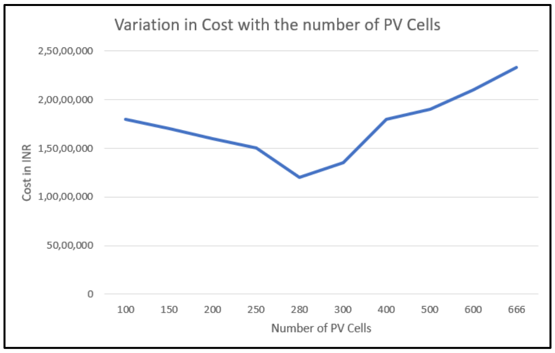


Fig.8. Variation in cost with the number of PV Modules installed

Fig.9. shows the PV system output voltage should be as close to the total supply voltage i.e. 400V AC to attain maximum inverter efficiency. As a result the configuration with voltage closest to 400V AC was chosen, thus 14S20P meaning 14 PV Modules in series and 20 such parallel strings, fig.10. demonstrates the configuration.

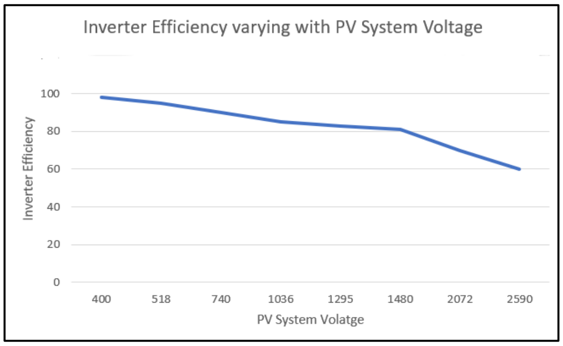


Fig-9. Inverter efficiency varying with PV system voltage

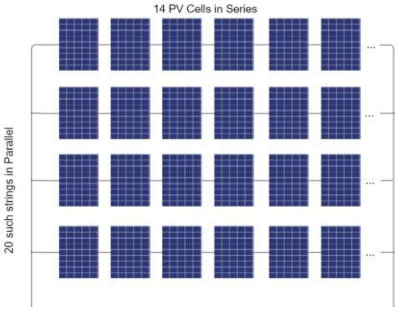


Fig.10. PV system configuration

*d. Optimal Battery Sizing*

Battery sizing and modeling are crucial components of designing a photovoltaic system, especially for off-grid usage. The battery bank stores extra energy generated by the PV panels during high solar irradiance and discharges it during periods without sunlight. Determining the battery capacity and number needed to fulfill energy demands is part of sizing the battery. Meanwhile, battery modeling constructs a mathematical model to predict battery behavior in different situations like varied temperatures and loads. Accurate battery modeling guarantees the optimal charging and discharging strategies to maximize efficiency and longevity, ensuring a PV system's effective operation and maintenance. The parameters considered used in battery sizing are Capacity, Depth of Discharge(DoD), Cycle Life, State of Charge(SOC), Discharge Current. For the day with the peak load demand, a line plot was for the PV power and Load giving a comparison between the trend of both the values, as shown in figure 11.

Fig.11. Battery Charging and Discharging Time periods

From the figure it was interpreted that the battery has to supply a total of 163KW of power across 5 hours, that is from 3 pm to 8 pm. The peak energy discharge value came out to be 78KWh. The battery voltage is kept as close to 400V as possible to ensure maximum inverter efficiency.

Battery Capacity = Maximum energy stored in a battery / Voltage of the battery

This gives us an ideal battery capacity value of 408Ah.Table 5 below compares the commonly used battery types and their approximate costs and Depth of discharge values for proper optimization.

TABLE 6- COMPARISON OF VARIOUS COMMONLY USED BATTERY TYPES

| *Battery Type* | *Depth Of Discharge (%)* | *Cost per Ah(INR )* | *Capacity Required (Ah)* | *Total Cost(INR)* |
|---|---|---|---|---|
| Lithium Ion | 85 | 350 | 480 | 1,68,000 |
| Lead-acid | 65 | 125 | 628 | 78,500 |

| *Battery Type* | *Depth Of Discharge (%)* | *Cost per Ah(INR)* | *Capacity Required (Ah)* | *Total Cost(INR)* |
|---|---|---|---|---|
| Nickel-cadmium | 75 | 175 | 544 | 95,200 |
| Sodium-sulfur | 90 | 550 | 456 | 2,50,800 |

After evaluating different types of batteries, the Lithium-ion battery was determined to be the most suitable due to its high energy density, long cycle life, and low maintenance requirements. It also has a high depth of discharge and round-trip efficiency, and a smaller size, making it ideal for rooftop installations. Additionally, it has a stable voltage output due to its flat discharge curve. A Lithium-Ion battery with a capacity of 480Ah, a nominal voltage of 400V, and a discharge rate of 80A was the most optimal choice.

## CONCLUSION AND FUTURE SCOPE

This study focuses on optimal battery sizing for net-zero energy buildings by utilizing PV power prediction with the Facebook Prophet model. The research addresses the challenges of integrating renewable energy sources into buildings while ensuring efficient energy utilization and achieving a net-zero energy balance. The study accurately predicts PV power generation using the Facebook Prophet model, enabling determination of the optimal battery size for net-zero energy operation. By appropriately sizing battery storage systems based on predicted PV power generation, NZEBs can store excess energy and reduce reliance on the grid.

The outcomes of this study have significant implications for sustainable building design and energy management. The Facebook Prophet model provides a reliable approach for predicting future power generation patterns, facilitating informed decision-making for battery sizing and energy storage investments. The integration of renewable energy sources and energy storage technologies is crucial for achieving resilient and sustainable buildings, and the study highlights the potential of the Facebook Prophet model in advancing the transition to a clean energy future.

Moreover, the study suggests a specific setup for achieving net-zero energy building status, utilizing parallel and series connections of PV cells and a lithium-ion battery with specific characteristics. Further research in this area can explore additional factors and constraints to develop more comprehensive models for optimal battery sizing and NZEB design, considering factors such as building energy demand patterns, grid interaction, and economic considerations. Incorporating real-time data and adaptive forecasting techniques can also enhance prediction accuracy and further optimize energy storage and utilization strategies. Overall, this study provides valuable insights and a practical framework for integrating PV power prediction and battery sizing optimization, contributing to a greener and more energy-efficient future.

Future research on optimal battery sizing for net-zero energy buildings using PV power prediction with the Facebook Prophet model can explore several areas. Integration of net metering schemes can be considered to maximize self-consumption and minimize grid dependence. Analysis and mitigation of harmonics introduced by power electronics circuits, such as inverters, can ensure reliable operation and maintain power quality. Optimization of inverter operation, including efficiency, power quality, and control algorithms, can improve overall system performance. NZEBs can contribute to grid stability, and future studies can investigate their potential to provide ancillary services to the grid. Advanced power flow analysis can optimize energy flows and system efficiency. Integration of energy management systems and demand response strategies can enhance energy efficiency and intelligent decision-making. Life cycle assessment can evaluate the sustainability and environmental impact of net-zero energy buildings comprehensively. Pursuing these research directions can promote sustainable building practices, improve energy efficiency, and advance the transition to a carbon-neutral future.

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