ENERGY MANAGMENT IN GRID CONNECTED SOLAR PV SYSTEMS INTERGRATED WITH BATTERY STORAGE

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In Sri Lanka, the continuous growth in peak demand, which increases daily, raises the possibility of a power failure and the marginal costs of supply. To supply the peak demand, standby plants such as diesel power plants are usually used. Such power plants operate only during the peak demand period and have led to expensive operation and maintenance costs. Therefore, the electricity cost becomes high, as does the electricity tariff. In particular, the existing demand curve of Sri Lanka is not uniform and hence, costly peak powerplants are used to cater to the peak demand. Therefore, the tariff options like the Time of Use Tariff discourage consumers from using electrical energy during peak hours. If a lesser fluctuated flat shaped pattern in the power demand curve is obtained, it is beneficial to the utility companies as it would reduce the operation and maintenance costs of the standby powerplants. Furthermore, it can reduce the maximum demand charge for customers and hence reduce the electricity bill. In this context, if such an energy management system is widely spread across the country, along with renewable sources, the energy cost of the country can be significantly decreased by achieving a cost reduced quality network.

Therefore, this research focusses on the energy management of a grid-connected solar photovoltaic (PV) system equipped with battery storage. The primary objective of this study was to analyse electrical tariffs and determine the optimal battery capacities and solar panel sizes necessary to maintain electricity bills within specified limits over a month. A comprehensive cost analysis was performed, considering the initial investment, operational costs, and potential savings. The findings aim to provide practical g

uidelines for optimising solar PV and battery storage systems to achieve financial and energy efficiency, ensuring a reliable and uninterrupted power supply while minimising reliance on the national grid.

Keywords: Electricity Tariff, Battery Management Systems, Solar PV

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INTRODUCTION

In Sri Lanka, the continuous growth in peak demand, which increases daily, raises the possibility of a power failure and the marginal cost of supply (Morimoto. et al., 2004). To supply the peak demand, standby plants such as diesel powerplants are usually used. Such power plants operate only during the peak demand period and have led to expensive operation and maintenance costs. As a result, the electricity generation cost of the existing system is far above the average selling price of electricity. Therefore, the electricity cost becomes high, as does the electricity tariff. In particular, the existing demand curve of Sri Lanka is not uniform and hence costly peak powerplants are used to cater to the peak demand. Therefore, tariff options like the Time of Use Tariff discourage customers from using electrical energy during the peak hours. If a lesser fluctuated flat-shaped pattern in the power demand curve was obtained, it is beneficial to utility companies as it would reduce the operation and maintenance costs of standby powerplants. Furthermore, it can reduce the maximum demand charge for customers and hence reduce the electricity bill. In this context, if such an energy management system is widely spread across the country, along with the renewable sources, the energy cost of the country can be significantly decreased by achieving a cost reduced quality network (Upasani et al., 2018 and, Wang et al., 2016).

Further, the cost of electricity generation by the existing system is far above the average selling price of electricity in Sri Lanka. Therefore, electricity utilities are trying to implement a loss reduction solution. Therefore, it is necessary to find an alternative solution that leads to the reduced use of standby powerplants in the grid system. Therefore, this research focusses on the energy management of a grid-connected solar photovoltaic (PV) system equipped with battery storage. The primary objective of this study was to analyse the electrical tariffs and determine the optimal battery capacities and solar panel sizes necessary to maintain electricity bills within specified limits for a month. By incorporating time-of-use (ToU) tariffs and Block rate tariffs, this study evaluates various scenarios to identify the most cost-effective configurations. A comprehensive cost analysis was performed, considering the initial investment, operational costs, and potential savings. The findings aim to provide practical guidelines for optimising solar PV and battery storage systems to achieve financial and energy efficiency, ensuring a reliable and uninterrupted power supply while minimising reliance on the national grid.

METHODOLOGY

Initially, a comprehensive literature survey was undertaken to explore the available techniques for optimising the dispatch of battery banks connected to rooftop solar installations. Then, a suitable customer with a power consumption of around 200 units was chosen. Once the customer was selected, their average power demand was calculated using past electricity bills, ensuring accuracy in the estimation process. Moreover, the demand of this customer was also calculated using his load duration data. The Average Daily Load Profile of the customer that was obtained is shown in Figure 1.

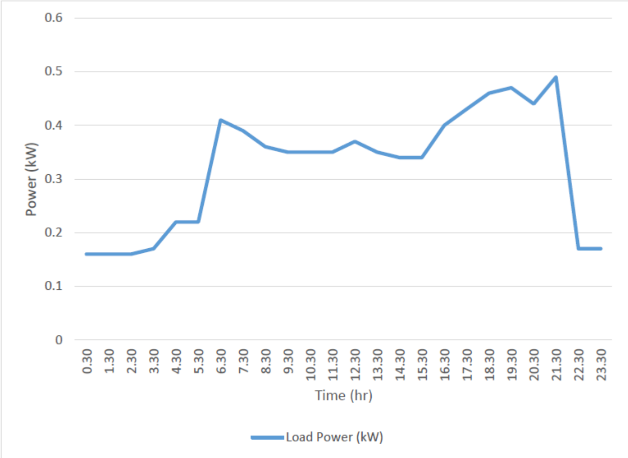

Figure 01: Average Daily Load Profile of the customer

Next, the research moved forward to predict the solar energy generation values per unit area. This was achieved by analysing six months of data from a nearby solar system. This data was crucial for accurately forecasting the solar energy production, guiding decisions in later stages of the project. Using the detailed load and solar generation profiles gathered, precise calculations were made to determine the best battery capacity and solar panel size. Accuracy in these calculations is essential to ensure the efficient functioning of the distributed generation system (Hill et al., 2012).

As the research progressed, a comprehensive performance analysis was conducted to evaluate the system's effectiveness in reducing reliance on grid power. Various performance metrics were carefully examined to assess the system's efficiency, and its impact on grid power usage. Additionally, precise calculations were carried out to determine the necessary battery capacity to maintain a consistent grid power supply throughout a specific month, ensuring uninterrupted power for the customer.

Finally, the research concluded with a thorough examination of the most optimal deployment scenario across different electricity tariff structures. This involved a detailed economic analysis aimed at identifying the most cost-effective approach to deploying the distributed generation system for the selected customer. By carefully considering factors such as initial costs, ongoing expenses, and potential savings, conclusions were made to maximise the project's economic feasibility and long-term sustainability

RESULTS AND DISCUSSIONS

As mentioned earlier, based on the collected data, the customer’s power demand curve and solar generation profile was determined. In accordance with the generated solar generation and load profiles, various scenarios were considered to determine the required solar panel size and battery capacities under minimum grid power usage. Here, basically block rate tariff and time-of-use tariffs (TOU) are considered for the following five scenarios:

Scenario 1 -To keep the electricity bill at a constant of 60 units per month under block tariff;
Scenario 2 -To keep the electricity bill at a constant of 90 units per month under block tariff;
Scenario 3 -To keep the electricity bill at a constant of 120 units per month under block tariff;
Scenario 4 - Without keeping grid power (0 units); and
Scenario 5 - To keep the electricity bill at the lowest value under the time-of-use tariff (ToU)

Case i – Only the complete peak load is supplied from the battery; and

Case ii – Required power is supplied from the battery when required, within both the day time and peak time.

Once all the scenarios were defined, the required solar panal sizes and battery capacities for each scenario was calculated based on the previously calculated load requirements and solar generation prediction results. The power distribution curves for each scenario is shown in Figure 2.

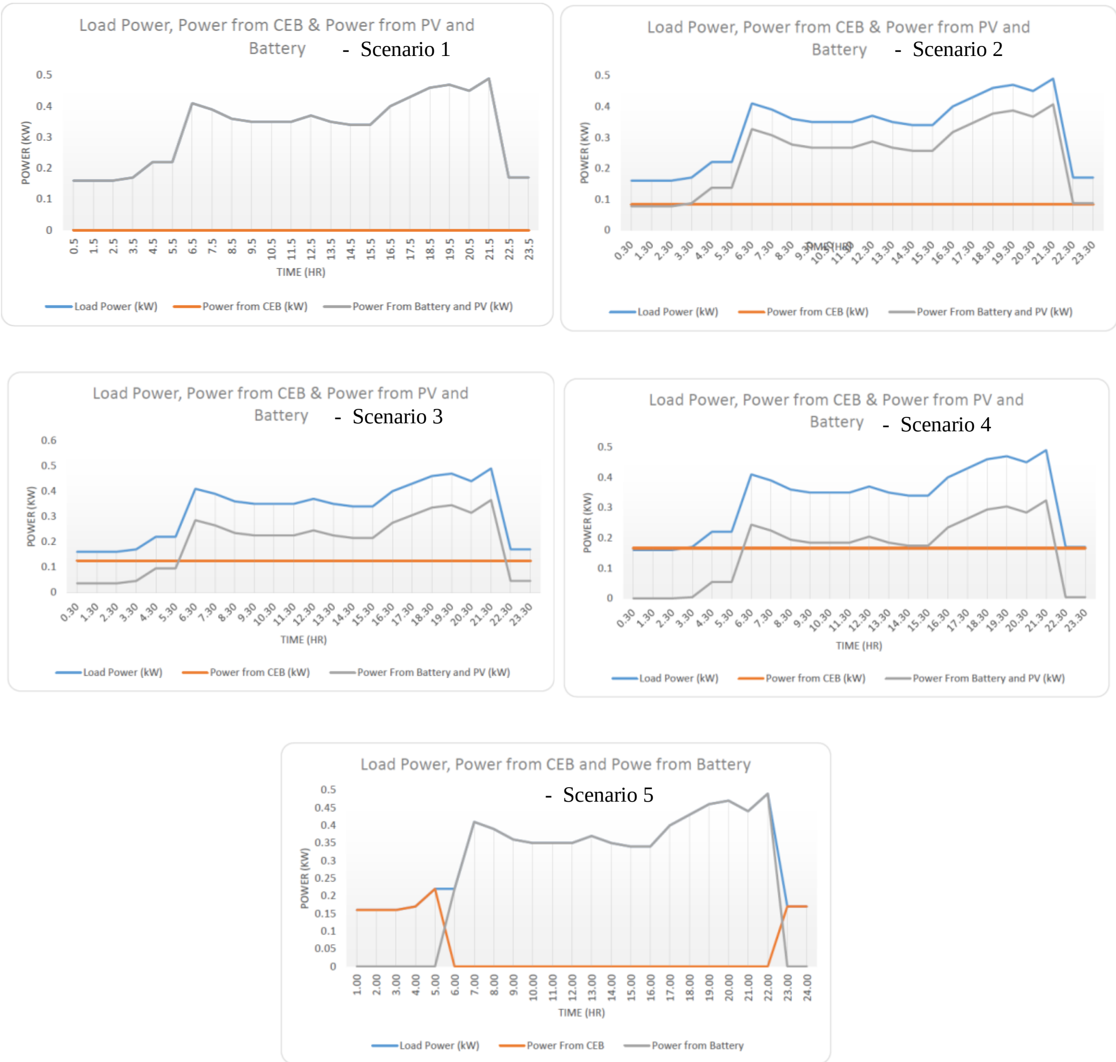

Figure 02: Power Distribution Curves for all five Scenarios

After obtaining all the capacities of the solar system and batteries, the installation cost was determined for all the scenarios. Hence, both the NPV and payback period were calculated while considering the cash inflows and different types of costs over the projected life span of the battery connected solar system. Figure 03 illustrates the comparison of various scenarios based on their NPV and payback period. Based on the table, under the block tariff scenario, solution 1 emerges as the optimal choice based on the payback period method, while solution 4 takes preference in terms of the NPV value. Conversely, when employing the TOU tariff, solution 5 ii is favoured both in terms of the payback period method and the NPV value.

Across all scenarios, scenario 5 ii consistently emerged as the optimal solution. Therefore, it is evident that scenario 5 ii is a viable recommendation for the mentioned household user.

		Pay Back period	NPV Value
Block Tariff	Scenario 1	8 years	Rs 362543.00
	Scenario 2	9 years	Rs 170854.00
	Scenario 3	9 years	Rs 156280.00
	Scenario 4	12 year	Rs (-277720.00)
TOU Tariff	Scenario 5 i	13 years	Rs(-133984.00)
	Scenario 5 ii	6 years	Rs 986738.00

Figure 03: Comparison of various scenarios based on their NPV and payback periods.

CONCLUSIONS/RECOMMENDATIONS

This project primarily focussed on analysing energy management in grid-connected solar systems integrated with battery storage across various scenarios, considering the different sizes of the solar systems and the Sri Lankan tariff structures. The comparison of these scenarios based on the NPV and payback period revealed that scenario 5 ii consistently emerged as the optimal choice in terms of both metrics.

Given that scenario 5 ii proves to be the best solution across all scenarios, it is evident that it can be recommended for household users. It's important to note that this analysis specifically targets household user data. However, in the future, this analysis could be extended to include commercial users as well.

Further enhancements to this analysis could involve implementing these scenarios into a MATLAB simulation for technical validation. Additionally, leveraging of various solar irradiation data and user data using AI methods could improve the accuracy and robustness of the analysis.

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