ASSESSMENT OF ECONOMIC FEASIBILITY OF BATTERY ENERGY STORAGE DEVICE INTEGRATION TO ROOFTOP SOLAR PV CONSUMERS

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Rooftop solar PVs are widely used at the distribution level. Most of these solar PV users are domestic customers and the main purpose is the reduction of the cost of energy. Integration of Battery Energy Storage Devices (BESD) to the solar PV in Sri Lanka is not frequent, and whether the integration of BESD to the solar PV brings the return of the investment is not certain. This study carries out the analysis of financial viability of use of BESD together with the solar PV for domestic consumers. The benefit of the study analysis is the charging of BESD using excess solar PV energy reducing export of the solar PV energy to the grid. The criterion for optimum BESD capacity has been identified. Furthermore, the formula for determining the BESD has been presented. The unit cost for solar PV energy and BESD cost formula is also given. Additional advantage of integration of BESD has been also discussed in this study. The proposed methodology has been used to determine the BESD capacity of the solar PV consumer. The results showed that BESD is not financially viable for any capacity of BESD. The optimum capacity of BESD and the cost saving has been presented at the end of the paper.

Keywords: Battery energy storage device, emergency power, peak shaving, solar photovoltaic

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INTRODUCTION

During the last decade, the use of rooftop solar photovoltaic (PV) has been rapidly increasing. Rooftop solar PV installation incurs capital investment for individual consumers. The rooftop solar PVs are used to meet the energy demand of domestic consumers. The excess energy of solar PV is exported to the grid under one of the schemes: net-metering, net-accounting and net-plus [09]. Other than meeting the daytime energy consumption, solar PV consumers are benefited by exporting excess solar PV energy to the grid. Utility organizations also are benefitted due to the reduction of energy generation during daytime, power quality improvement in the feeder, reduction of transmission losses, etc. [06]. The availability of energy from solar PV is limited to daytime. Due to recent planned power interruptions, Battery Energy Storage Devices (BESD) have been introduced to store daytime excess energy of the solar PV. The stored energy is utilized during grid interruptions. The cost of grid energy depends on the time of the day. Electricity tariff has also been increased. BESD technology has been advanced, and their cost has been reduced [08]. It is also advantageous for consumers to reduce the purchase of energy from the grid, especially during peak hours. Therefore, the correct selection of BESD capacity of solar PV can bring financial benefits to individual consumers. The main objective of this study was analysing the financial feasibility of the usage of BESD together with solar PV. Based on the capacity of BESD, the amount of energy export during daytime and energy storage in BESD for night peak vary. Therefore, the financial viability of the BESD depends on the cost-saving due to the reduction of grid energy during peak hours against the income due to the export of the solar PV energy to the grid. It is assumed that the time of the day tariff scheme is adopted by solar PV consumers. All solar PV consumers are paid under the net-accounting scheme.

METHODOLOGY

The criterion for the determination of BESD capacity is the maximum financial benefit for the solar PV consumer. During daytime, the BESD is charged from the excess power of solar PV. During the evening peak, energy stored in the BESD is discharged to meet part of the consumer's demand. Based on the BESD capacity, the amount of the energy purchased from the grid during the evening peak varies. The cost for peak energy is the cost of purchasing grid energy plus BESD energy cost. The minimum cost is determined by varying BESD energy.

The excess energy of solar PV (W_{Excess}) during daytime can be determined using equation (01).

$$W_{Excess} = W_{PV}(t) - W_{load}(t) \qquad (t = 7, 8, \ldots\ldots 18) \qquad (01)$$

Where,

$W_{PV(t)}$ - The energy of solar PV at the hour (t)

$W_{load(t)}$ - Consumer's energy consumption at the hour (t)

Solar PV energy (W_{PV}) per day is calculated using equation (02)

$$W_{PV} = \sum_{t=7}^{18} P_{PV}(t)\, \Delta T \qquad (02)$$

Where,

ΔT - time duration day in which solar power and load are taken as a constant value. (ΔT = 1h)

Consumer's daytime energy consumption is calculated using equation (03).

$$W_{load} = \sum_{t=7}^{18} P_{load}(t)\, \Delta T \qquad (03)$$

Part of the energy delivered by the BESD due to peak power shaving (W_{max}) is given in equation (04).

$$W_{max} = k \sum_{t=19}^{t=21} P_{load}(t) \Delta T \quad , k=0.2, 0.3, ... \quad (04)$$

Since energy discharged by the BESD is taken as a portion of peak power, the BESD capacity (W_{BESD}) can be expressed as given in equation (05).

$$W_{BESD} = \frac{k \sum_{t=19}^{t=21} P_{load}(t) \Delta T}{\text{Depth of Discharge} \times \text{Efficiency}} \quad (05)$$

Economical BESD capacity determination

To assess the economic feasibility, two main scenarios were analyzed.

i. The consumer has only solar PV. Under the net-accounting scheme, the consumer pays the monthly electric bill. For the export of excess solar PV to the grid, a consumer is paid at the approved rate.
ii. The consumer has solar PV with a BESD. The consumer need not pay for all the energy demand. This is because a part of the peak energy is taken from the BESD. The cost for that BESD energy is the cost of the BESD (capital cost plus operation and maintenance cost) plus the energy cost for charging the BESD. For the remaining energy, consumers pay the utility under the time-of-the-day tariff scheme.

The unit cost of solar energy is the total investment plus operation and maintenance cost divided by the energy of the solar PV over its lifetime. The reduction of solar PV efficiency during its lifetime is considered. The unit cost of energy of solar PV is calculated using equation (06)

$$C_{PV} = \frac{C_{kW} \times n}{W_1 + W_2} \quad (06)$$

Where,

C_{PV} - cost of energy of solar PV (Rs/kW)
C_{kW} - investment and maintenance costs for solar PV of 1 kW
n - number of kW units
W_1, W_2 - the energy of solar PV with higher and lover efficiency over the lifetime

The cost for a BESD is calculated using equation (07) [01]

$$C_{BESD}|_T = C_1 \times B_{rated} + C_{op} \times P_{rated} \times T + C_1 B_{rated} \times k1/100 \quad (07)$$

Where,

C_{BESD} - Total cost for BESD (Rs).
B_{rated} - Rated capacity of the BESD (kWh).
P_{rated} - BESD power (kW).
C_1 - Capital Cost per kWh (Rs).
C_{op} - Operation and maintenance cost per annum (Rs. per kW).
T - BESD lifetime (number of years).
$k1$ - Percentage of cost of associated equipment.

Unit cost for BESD energy is the cost of BESD divided by its lifetime plus the energy charging cost from solar PV. This is given in equation (08)

$$C_{PVBESD} = C_{PV} + C_{BESD} \quad (08)$$

Where,

C_{PVBESD} - Total cost for solar PV and BESD cost.

For the scenario (ii) cost of peak energy (C_T) is the cost of grid energy plus the cost of BESD energy. This is given in equation (09)

$$C_T = (W_{peak} - W_{BESD}) \times C_{peak} + W_{BESD} \times C_{BESD} \quad (09)$$

Where,
W_{peak} - Nighttime peak energy
C_{peak} - Cost for peak energy
The total income (C_{net}) of selling excess solar PV energy (W_{excess}) to the grid after charging the BESD and daytime consumption can be determined by the equation (10).

$$C_{net} = [W_{excess} - k \times W_{BESD}] \times \text{Solar PV selling unit price} \tag{10}$$

Total income revenue from the solar PV and BESD economic model ($C_{benefit}$) to the customer can be calculated using equation (11).

$$C_{benefit} = C_{net} - C_T \tag{11}$$

Emergency power

By considering the low voltage (LV) fault time duration, medium voltage (MV) fault duration, planned interruptions time duration, and scheduled maintenance time duration, the cost-benefit of the emergency power can be calculated. There is a higher probability of the fault occurring at nighttime rather than during daytime. MV fault and LV fault interruptions time duration is considered as 40% of the total fault time duration for the daytime and 60% of the total fault time duration for the nighttime. The charge for emergency (C_{emg}) power is taken as three times the peak hour charge according to the Time of Use (TOU) tariff rates.

RESULTS AND DISCUSSION

The proposed method was applied to a solar PV consumer in one of the LV distribution systems in a semi-urban area in the Colombo District. The consumer has installed 5 kW solar PV and the average monthly energy consumption is 373 kWh. Per month energy export to the grid without BESD is 422 kWh. Load and solar power variation is shown in Figure 1.

The BESD capacity has been determined by using the formula (05) for different values of k. The capacity of BESD and charging cost for different values of k are shown in Figure 2. The economic capacity of BESD for the given consumer is given in Table 1. As per the results, the particular consumer gets the financial benefit when the capacity of BESD equals the 60% of the energy of the peak power. The BESD capacity is 4.8 kWh. The results elaborate that the installation of BESD does not give financial benefit for any capacity of BESD. The most economical capacity of BESD depends on the amount and pattern of energy consumption. According to Figure 2 and Table 1, the most economical BESD capacity for nighttime peak shaving is 4.8 kWh. The payback period of this project is around 2 years when the selling emergency power income is the maximum possible income a customer can earn selling from emergency power.

CONCLUSION

This paper outlines the financial benefit due to the usage of BESD during peak hours. In the meantime, there are other advantages of having BESD. Solar PV cannot operate during daytime power interruptions in the LV distribution system. If BESD is connected to solar PV, it can be energized, and the energy of solar PV can be used. Therefore, consumers do have energy from solar PV irrespective of power interruptions in the LV system. Even during nighttime, BESD can provide electricity during unplanned power interruptions such as faults. In this work, the financial aspects of those advantages have not been analyzed. With the fast development of BESD technologies, the cost of BESD has been reduced. Therefore, in the future, integration of BESD to solar PV will be beneficial to both consumers and utility organizations.

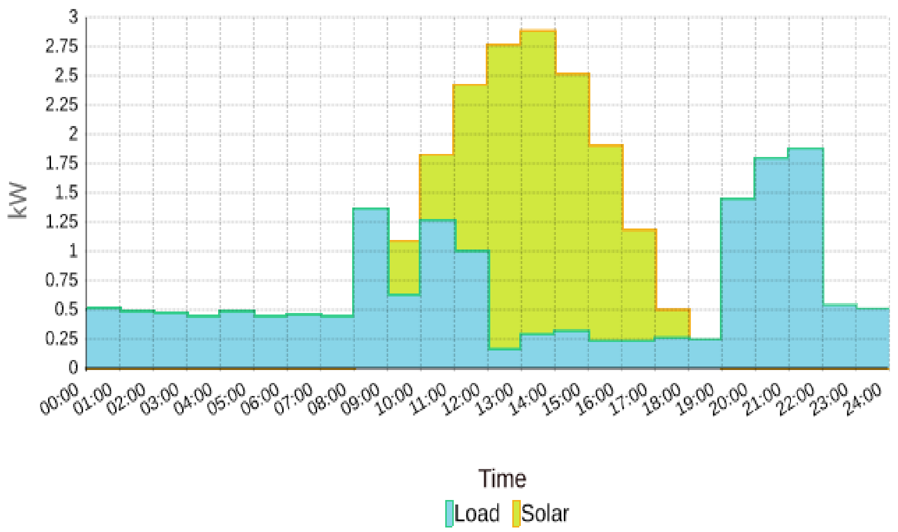

Figure 1:5 kWp solar generation with the load profile

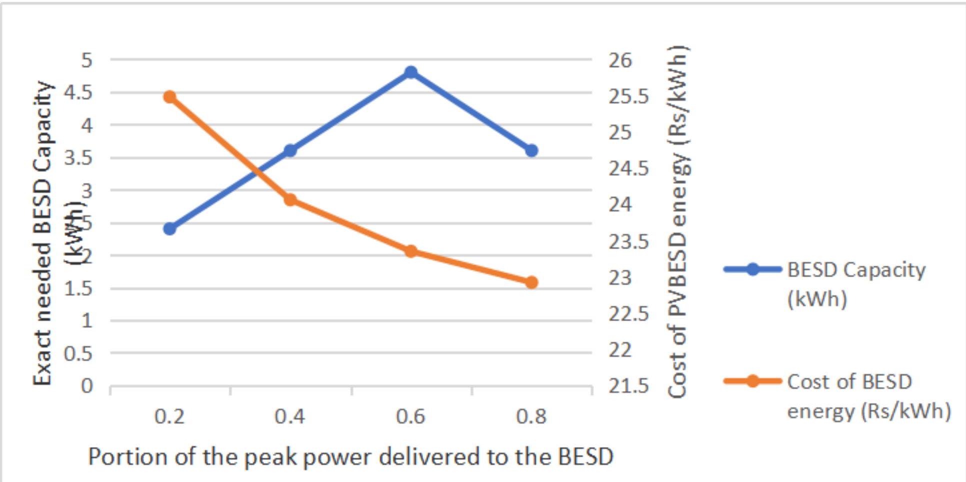

Figure 2: PVBESS Energy and unit costs

Table 1: PVBESD cost-benefit

	Total saving of peak energy for project lifetime (LKR)	Total expenditure of PVBESD for project lifetime (LKR)	Total cost benefit using PV+BESD (LKR)
BESD + 0.8 Grid	1486152	1292032.32	No benefit
0.4 BESD + 0.6 Grid	1202947.2	1138456.32	No benefit
0.6 BESD + 0.4 Grid	919728	984880.32	65152.32
0.8 BESD + 0.2 Grid	990144	452077.34	No benefit
Only Grid	1978992	1599184.32	No benefit

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