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Technoeconomic analysis of a grid-connected PV and battery energy storage system considering time of use pricing

Chinmay Kumar NAYAK[1,*], **Manas Ranjan NAYAK**[2]
[1]Department of Electrical Engineering, Indira Gandhi Institute of Technology, Sarang, Dhenkanal, Odisha, India
[2]Department of Electrical Engineering, Siksha 'O' Anusandhan University, Bhubaneswar, Odisha, India

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Abstract: This paper examines the technoeconomic optimization of the size of valve-regulated lead acid-type battery energy storage systems (BESSs) in order to minimize the total annual operating cost of a grid-connected photovoltaic BESS within the framework of system operational constraints, using the improved harmony search algorithm. The electricity cost is calculated using time of use pricing, where the price of energy varies according to the load demand. The concept of feed-in-tariff is discussed, where power can be bought from and sold back to the grid. A sensitivity analysis is performed for three cases: without storage, with storage and without peak load shaving, and with both storage and peak load shaving. The total annual operating cost of the system is calculated for all three cases and cost savings are compared. The simulations, performed with MATLAB, show a good optimization performance.

Key words: Battery energy storage system sizing, photovoltaic system, peak load shaving, time of use pricing, technoeconomic analysis

1. Introduction

Development of renewable energy techniques, such as solar photovoltaic (PV), integrated with the utility grid, allows the liberalization of the electricity market on a large scale [1]. The integration of photovoltaic systems and storage devices by domestic and commercial consumers receives much research attention [2]. Solar irradiance varies according to the time of day and different climatic conditions such as cloud cover, season, etc. [3]. Storage devices, such as battery energy storage systems (BESSs), help smooth out the PV power injection into the utility grid (capacity firming) [4], discharge and aid the PV output during peak load hours (peak load shaving) [5], store surplus PV and conventional energy from the grid when the price is low and sell energy to the grid when the price is comparatively higher (power arbitrage), and improve power quality. In a grid-connected PV system with storage, the utility grid supplies the demand in case of shortage of power generated at the consumer end. On the other hand, in the case of surplus generated power, the excess amount is sold back to the grid. The net cost of electricity is calculated with the help of a net metering system.

In this paper, the annualized replacement, operation, and maintenance costs of a BESS, as well as electricity price, load profile, and technical and economic constraints of the system, are considered for optimization of sizing of the BESS. Here, we adopt time of use (TOU), a dynamic pricing policy, where the buying and selling price of energy are assumed to be the same. The benefit of using a BESS under a TOU tariff is evaluated by referring to the optimal sizing of the battery [6].

*Correspondence: chinmaynayak009@gmail.com

Several research works have addressed different methods of optimizing the sizing of BESSs in grid-connected renewable energy systems. The modeling, control, and analysis of a grid-connected PV system and fuel cells were performed in [7]. A methodology was presented to optimize the design of a PV grid-connected system and analyze its economic feasibility [8]. The optimum energy dispatch schedule was designed by employing a storage system for peak load shaving [9]. Economic benefits were maximized by assigning suitable weight factors to the objective function by using the greedy-search heuristic algorithm [10]. An energy management system for a battery-backed grid-connected PV system was explored in order to maximize daily electricity benefit while reducing the power injection to the grid [11]. An energy management strategy was proposed to participate in the electricity market with sizing analysis [12,13]. A genetic algorithm (GA) was used to find the optimal location and sizing of grid-connected PV systems [14]. Particle swarm optimization (PSO) was used for optimal sizing of a stand-alone hybrid system, including PV and wind [15]. An iterative optimization technique was used to optimize the sizes of hybrid solar–wind power generation systems employing a battery bank [16].

In this paper, three cases are analyzed. In Case A, a grid-connected PV system without a storage system is analyzed. Cases B and C address a grid-connected PV system with a BESS, with and without peak load shaving, respectively. Finally, the total operating costs are compared to each other and with the existing conventional system. The improved harmony search algorithm (IHSA) [17,18] is used as the optimization tool. Initially, by using the IHSA, the optimum annual operating cost of the system is calculated. Then the corresponding number and size of the batteries are used to calculate the annual capital cost of the PV panel and inverter; the annual replacement cost of the BESS; the annual operation and maintenance cost of the PV panel, BESS, and the inverter; the net electricity cost; and the total annual operating cost (AOC).

Section 2 describes the modeling of the system and Section 3 presents the problem formulation. The simulation results and analysis are presented in Section 4, and Section 5 concludes the paper.

2. System modeling

The PV panel and BESS supply DC power through a unidirectional DC/DC PV converter and a bidirectional DC/DC battery converter, respectively. While the BESS is charging, the battery converter works as a charge controller. A bidirectional inverter is used to convert the DC power generated by the PV panel and the BESS into AC. The basic configuration of the system is shown in Figure 1.

2.1. Modeling of the photovoltaic system

The PV panel output DC power in kW is calculated as follows [19]:

$$P_{pv\_dc}(t) = A_{pv} \times \eta_{pv} \times \eta_{pt} \times N_{pv} \times f_{man} \times f_{dirt} \times f_{cell} \times \eta_{pv\_inv} \times E_{ir}(t) \times 10^{-3}, \tag{1}$$

where η_{pv} = PV generator reference efficiency = 15%, A_{pv} = area of the PV panel = 33 m^2 (for the PV panel of 5 kW rating), η_{pt} = efficiency for perfect maximum power point tracker = 100%, $E_{ir}(t)$ = global horizontal irradiance (GHI) at hour t in W/m^2, and N_{pv} = number of PV panels = 1. The derating factor due to temperature (f_{cell}) is given by:

$$f_{cell} = [1 - T_{co} \times (T_m - T_{ref})], \tag{2}$$

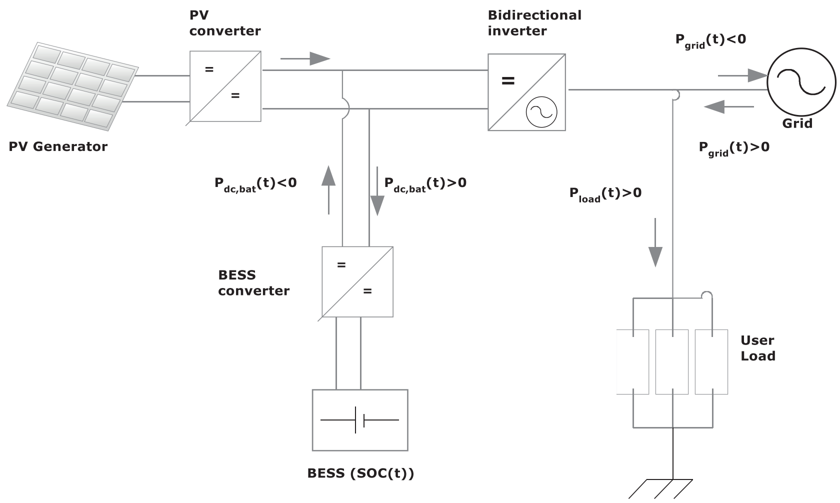


Figure 1. Basic configuration of the system.

where T_{co} = temperature coefficient = 0.005 (varies from 0.004 to 0.006 for silicon cells; the average value is taken) and T_{ref} = reference temperature = 25 °C. The module temperature (T_m) is calculated as follows:

$$T_m = T_{amb} + \left(\frac{NOC - 20}{800}\right) \times E_{ir}(t), \quad (3)$$

where nominal operating cell temperature (NOC) = 47.6 °C, T_{amb} = ambient temperature = 14.05 °C, f_{man} = 97% (derating factor for manufacture tolerance is 3%), f_{dirt} = 95% (derating due to dirt is 5%), and η_{pv_inv} = 97% (cable loss between the panel and inverter is 3%). AC output at the AC bus bar $P_{pv\_ac}(t)$ is calculated as follows:

$$P_{pv\_ac}(t) = P_{pv\_dc}(t) \times \eta_{inv} \times \eta_{inv\_sb}, \quad (4)$$

where η_{inv} = inverter efficiency = 97% and η_{inv_sb} = 99% (AC cable loss between the inverter and primary switch board, i.e. 1%).

The GHI data for the year 2015 were collected from the Indian Meteorological Department, Bhubaneswar, and are shown in Figure 2.

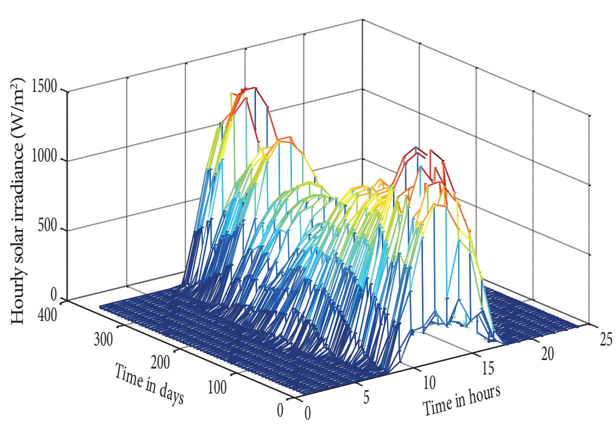


Figure 2. Average hourly solar irradiance in a year.

2.2. Modeling of battery energy storage system

In this paper, the battery bank selected is composed of gelled electrolyte sealed batteries, which are a type of valve-regulated lead acid (VRLA) battery. The status of the battery bank at hour t is related to its status at hour $t-1$, the output power of PV panel, and the load demand at time t. The available capacity of the battery bank at time t can be calculated as follows:

During peak hour,

$$C_{bat}(t) = \begin{cases} C_{bat}(t-1)\,(1-\sigma), & P_{pv\_ac} > P_{load} \\ C_{bat}(t-1)\,(1-\sigma) - \left[\,\frac{P_{load}(t)}{\eta_{inv}} - P_{pv\_ac}(t)\,\right] & P_{pv\_ac} < P_{load} \end{cases}; \tag{5}$$

During off-peak hour,

$$C_{bat}(t) = \begin{cases} C_{bat}(t-1)\,(1-\sigma), & P_{pv\_ac} < P_{load} \\ C_{bat}(t-1)\,(1-\sigma) + \left[\,P_{pv\_ac}(t) - \frac{P_{load}(t)}{\eta_{inv}}\right]\eta_{bat}, & P_{pv\_ac} > P_{load} \end{cases}, \tag{6}$$

where $C_{bat}(t)$ and $C_{bat}(t-1)$ are the capacity of the battery at hour t and $t-1$, respectively; P_{load} = load demand at hour t; and η_{bat} = battery round-trip efficiency.

Here, the battery bank consists of batteries connected in series and in parallel. The number of batteries connected in series (N_{ser}) to give system voltage (V_{sys}) is determined as follows:

$$N_{ser} = \frac{V_{sys}}{V}. \tag{7}$$

The number of parallel-connected branches, each of which has N_{ser} number of series-connected batteries to achieve the ampere-hour capacity, is calculated as follows:

$$N_{par} = \frac{\text{Battery bank capacity}}{\text{Individual battery capacity}}. \tag{8}$$

Total number of batteries (N_{bat}) is calculated as follows:

$$N_{bat} = N_{ser} \times N_{par}. \tag{9}$$

Four types of batteries, with ratings of 6 V/120 Ah, 6 V/150 Ah, 12 V/, 140 Ah, and 12 V/180 Ah, have been considered.

The state of battery charge is updated every hour with the charging and discharging of power to and from the battery.

Charging:

$$SOC(t) = SOC(t-1) \times (1-\sigma) + \eta_{ch\arg ing}\,\frac{P_{dc\_bat}(t)}{C_{bat}(t) \times V}; \tag{10}$$

Discharging:

$$SOC\,(t) = SOC\,(t-1) \times (1-\sigma) - \eta_{disch\arg ing}\,\frac{P_{dc\_bat}(t)}{C_{bat}(t) \times V}, \tag{11}$$

where $SOC(t)$ and $SOC(t-1)$ are the state of charge of the battery at hour t and $t-1$, respectively; σ = self-discharging factor = 2.5% per month; V = nominal battery voltage; $\eta_{ch\arg ing}$ = charging efficiency =

98%; $\eta_{disch\arg ing}$ = discharging efficiency = 95%; and $P_{dc,bat}(t)$ is the charging/discharging rate of the battery, which is defined by using Eq. (12):

$$P_{dc,bat}(t) \;=\; E_{bat}(t) \;-\; E_{bat}(t-1), \tag{12}$$

where $E_{bat}\,(t)$ and $E_{bat}\,(t-1)$ are the stored energy in the battery (kWh) at hours t and $t-1$, respectively.

2.3. Modeling of the load

The hourly load data of a typical residential customer at Bhubaneswar, Odisha, are taken for the year 2015, and the load profile is shown in Figure 3. Average daily energy consumption throughout the year is 27.31 kWh.

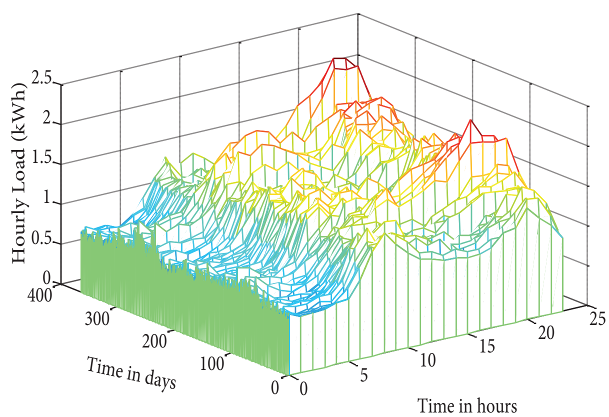


Figure 3. Average hourly load profile in a year for a typical residential customer at Bhubaneswar, Odisha.

3. Problem formulation

3.1. Objective function

The main objective of optimal sizing of a BESS is to obtain continuous power supply at minimum AOC for a grid-connected PV-BESS system within the framework of the system operation constraints.

The objective function is defined as:

$$f_{obj} = \min(AOC), \tag{13}$$

where AOC includes the net electricity cost, annualized capital cost of the PV panel and inverter, annualized replacement cost of the BESS, and annual maintenance cost of the PV panel, BESS, and inverter.

$$\begin{aligned} AOC \;=\; & \sum_{day=1}^{365}\sum_{t=1}^{24} E_{\cos t,benefit}(day,t) + ACC_{PV} + ARC_{bat} + ARC_{inv} + AOMC_{PV} + AOMC_{bat} \\ & + AOMC_{PV} + AOMC_{bat} + AOMC_{inv} + \text{ Total Penalty} \end{aligned} \tag{14}$$

The cost or benefit of electricity $(E_{\cos t,benefit}(day,t))$ can be calculated as follows:

$$E_{\cos t,benefit}(day,t) = E_{price}(day,t) \times P_{grid}(day,t), \tag{15}$$

where $E_{price}(day,t)$ is the instantaneous electricity tariff in rupees (Rs)/kWh and $P_{grid}(day,t)$ is the power transfer to and from the utility grid in kW.

When electricity is purchased from the grid, then $P_{grid}(day,t) > 0$, and when it is sold to the grid, then $P_{grid}(day,t) < 0$. The electricity tariff system is based on time of use. Peak hours are considered as 0700–1300 hours and 1600–2200 hours, when the electricity price is 12.20 Rs/kWh, whereas the remaining hours are considered as off-peak hours, when the electricity price is 5.00 Rs/kWh. The buying and selling rates are equal.

If the lifetime of the component is N years and i = annual real interest rate (a function of the nominal interest rate and annual inflation rate) = 4% per annum, the capital recovery factor (CRF) can be calculated as follows:

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1}. \tag{16}$$

The annualized capital cost of the PV panel (ACC_{PV}) is calculated as follows:

$$ACC_{PV} = C_{cap} \times P_{PV\_Rated} \times CRF(i,N), \tag{17}$$

where C_{cap} = capital cost of the PV panel = 150 Rs/kW$_p$, P_{PV_Rated} = rated power of the PV panel = 5 kW, and N= life time of the PV panel = 20 years.

The annualized replacement cost of the inverter (ARC_{inv}) is calculated as follows [20]:

$$ARC_{inv} = \text{ Inverter Capital cost} \times SFF_{inv}. \tag{18}$$

The inverter capital cost is 6000 Rs/kW.

SFF_{inv} is the sinking fund factor of the inverter and can be calculated as follows:

$$SFF_{inv} = \frac{i}{(1+i)^{N_{inv}} - 1}, \tag{19}$$

where N_{inv} = life time of the inverter = 10 years.

The annualized replacement cost of the BESS (ARC_{bat}) is calculated as follows:

$$ARC_{bat} = C_{rep} \times SFF_{bat}, \tag{20}$$

where C_{rep} is the replacement cost of the BESS, which can be calculated as follows:

$$C_{rep} = B_{invest\_\cos t} \times \text{Battery size in kWh}, \tag{21}$$

where $B_{invest\_\cos t}$ = investment cost of the BESS = 4000 Rs/kWh.

SFF_{bat} is the sinking fund factor of the BESS and can be calculated as follows:

$$SFF_{bat} = \frac{i}{(1+i)^{Y_{bat}} - 1}, \tag{22}$$

where Y_{bat} is the lifetime of the BESS and can be calculated as follows:

$$Y_{bat} = \frac{\text{Capacity of BESS in Ah} \times V}{C_{loss\_cumi\_year}}, \tag{23}$$

where $C_{loss\_cumi\_year}$ is the annual cumulative battery capacity loss, which can be calculated as follows:

$$C_{loss\_cumi\_year} = \sum_{day=1}^{365} \sum_{t=1}^{24} C_{loss}(day,t). \tag{24}$$

The hourly battery capacity loss $(C_{loss}(day,t))$ is calculated as follows:

$$C_{loss}(day,t) = C_{loss,cumi}(day,t) - C_{loss,cumi}(day,t-1), \tag{25}$$

where $C_{loss,cumi}(day,t)$ is the hourly cumulative battery capacity loss, which can be calculated as follows [21]:

$$C_{loss,cumi}(day,t) = \begin{cases} C_{loss,cumi}(day,t-1) - Z.\,P_{dc,bat}(day,t) & P_{dc,bat}(day,t) < 0 \\ C_{loss,cumi}(day,t-1) & P_{dc,bat}(day,t) \geq 0 \end{cases}, \tag{26}$$

where Z = aging coefficient = 5×10^{-4}, and $P_{dc,bat}(day,t)$ is the hourly DC output power of the BESS.

Annualized operation and maintenance cost of the PV panel $(AOMC_{PV})$ is calculated as follows:

$$AOMC_{PV} = \frac{(1-\lambda_{PV})}{N}. \tag{27}$$

Annualized operation and maintenance cost of the BESS $(AOMC_{bat})$ is calculated as follows:

$$AOMC_{bat} = \frac{(1-\lambda_{bat})}{N_{bat}}. \tag{28}$$

Annualized operation and maintenance cost of the inverter $(AOMC_{inv})$ is calculated as follows:

$$AOMC_{inv} = \frac{(1-\lambda_{inv})}{N_{inv}}, \tag{29}$$

where λ_{PV}, λ_{bat}, and λ_{inv} are the reliability of the PV panel, BESS, and inverter, respectively, and are assumed to be equal in magnitude, i.e. 0.98.

A penalty amount is imposed for not charging the BESS to benefit from the surplus energy that should be trimmed. Total penalty is calculated as follows:

$$Total\ Penalty = \left(\frac{SOC_{\max} - SOC\,(day,t)}{100}\right) \times C_{penalty}(day,t), \tag{30}$$

where $C_{penalty}(day,t)$ is the cost of the penalty, which is calculated as follows:

$$C_{penalty}(day,t) = E_{price}(day,t) \times 0.1. \tag{31}$$

3.2. System operational constraints

The objective function is subjected to the following equality and inequality constraints:

$$P_{Load}(day,t) = P_{pv\_ac}(day,t) + P_{ac,bat}(day,t) + P_{grid}(day,t), \tag{32}$$

$$SOC_{\min} \leq SOC(day,t) \leq SOC_{\max}, \tag{33}$$

$$P_{dc\_bat,\min} \leq P_{dc\_bat}(day,t) \leq P_{dc\_bat,\max}, \tag{34}$$

$$P_{grid,\min} \leq P_{grid}(day,t) \leq P_{grid,\max}, \tag{35}$$

where $SOC_{\min}$ (= 30%) and $SOC_{\max}$ (= 90%) are the minimum and maximum states of battery charge, respectively; $P_{dc\_bat,\min}$ and $P_{dc\_bat,\max}$ are the minimum and maximum DC outputs of the battery, respectively; and $P_{grid,\min}$ and $P_{grid,\max}$ are the minimum and maximum power obtained from the grid, respectively. The battery round-trip efficiency is 93.1%.

3.3. Operation of grid-connected PV-BESS system

In this paper, a suitable operation strategy for a grid-connected PV and BESS system has been developed for three different cases. These cases are explained in the following subsections.

3.3.1. Case A: grid-connected PV system without BESS

In this case, only the PV is integrated with the grid at the consumer end, without any storage system. When the PV power is available, it will supply to the load. When there is a positive net load $(P_{load}(day,t) - P_{pv\_ac}(day,t))$, this is fed by the utility grid. Otherwise, the net PV $(P_{pv\_ac}(day,t) - P_{load}(day,t))$ is sold back to the utility grid.

3.3.2. Case B: grid-connected PV-BESS system without peak load shaving

In Case B, the BESS and the PV panel are introduced at the consumer end in a grid-connected system. The operation strategy of the system is classified into four scenarios.

- Scenario 1, $P_{pv\_ac}(day,t) > P_{load}(day,t)$ and during peak hours of the day: Net PV power is sold to the grid as the cost is higher during peak hours. If the state of charge of the BESS is greater than $SOC_{\min}$, then the BESS discharges to sell power to the grid; otherwise, it remains idle.
- Scenario 2, $P_{pv\_ac}(day,t) < P_{load}(day,t)$ and during peak hours of the day: If the SOC of the BESS is more than $SOC_{\min}$, the BESS discharges to supply the net load. If the net load is less than the maximum discharging rate of the BESS, the latter will discharge to cover the net load. Otherwise, it will discharge at its maximum rate. If both PV and BESS are unable to meet the load, it will be fed by the grid.
- Scenario 3, $P_{pv\_ac}(day,t) > P_{load}(day,t)$ and during off-peak hours: The net PV power will charge the BESS, provided that its SOC is less than $SOC_{\max}$. In this case, if net PV is less than the maximum charging rate of the BESS, then the battery charges at a rate that is equal to the net PV; otherwise, it will charge at its maximum rate. If the BESS is at its $SOC_{\max}$, then the net PV will be sold to the grid.
- Scenario 4, $P_{pv\_ac}(day,t) < P_{load}(day,t)$ and during off-peak hours of the day: In this scenario, the net load is fed by the utility grid only. The BESS is not allowed to discharge during this period because the stored energy gives better economic profitability if sold to the grid during peak hours.

3.3.3. Case C: grid-connected PV-BESS system with peak load shaving

This case is similar in operation strategy to Case B; however, here the main consideration is to reduce the electricity purchase from the grid during peak time. The battery is allowed to discharge only up to a predefined value of SOC during peak hours, when the PV output power is sufficient to meet the load demand. The remaining capacity is reserved to feed the peak load when the PV power is not sufficient to feed the load.

4. Simulation results and analysis

To process this simulation, the hourly GHI and load data for 1 year have been given as input. The IHSA optimization technique has been implemented in the MATLAB environment (release 2010a, version 7.10) with Intel Core i5 and 4 GB RAM. The IHSA parameters used in the simulation of the network are $hms = 30$, $hmcr = 0.85$, $par = 0.3$, and $T_{\max} = 100$. The objective function (min (AOC)) variation of the system is shown in Figure 4. It can be observed that the AOC value converges at a value of Rs. 58701.20 for the system operating with peak load shaving, and at a value of Rs. 61232.00 for the system operating without peak load shaving.

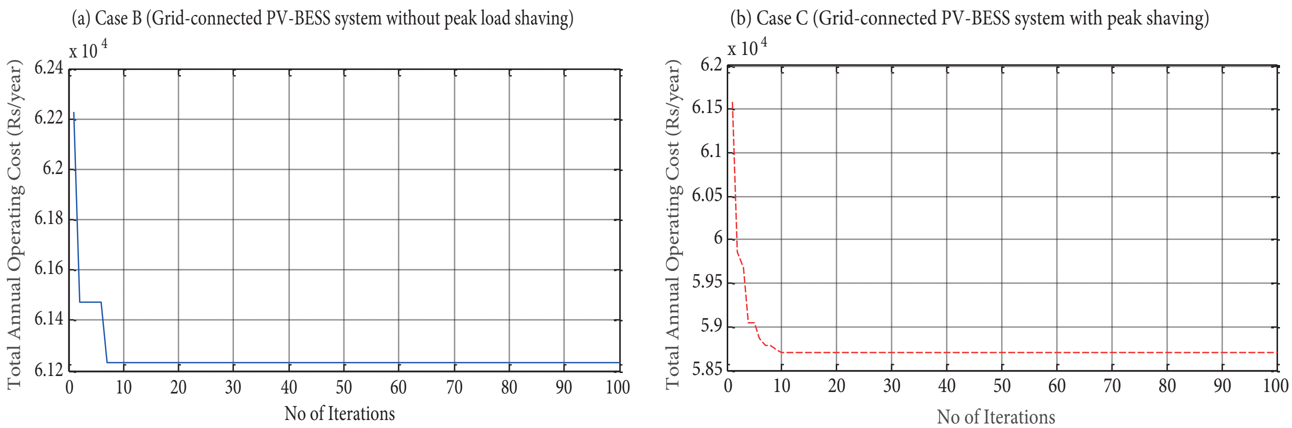


Figure 4. Variation of the objective function (f_{obj}) of the system: (a) Case B; (b) Case C.

Figure 5 compares total AOC in all four cases compared. It can be inferred that the AOC is minimum in Case C, where the concept of peak load shaving is incorporated. Cost savings for Cases A, B, and C are 27.43%, 38.6%, and 41.13%, respectively.

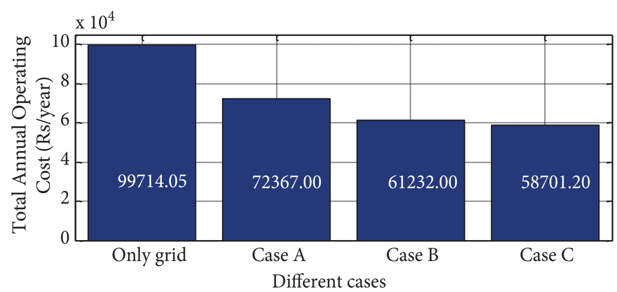


Figure 5. Comparison of total annual operating cost in different cases.

In the Table, the simulated size of the battery is calculated for all the cases, and the results are compared with a case of the conventional method of buying power only from the utility grid.

The active power variation of the PV system output, load, grid, and battery on a typical day in all three cases is shown in Figure 6. In Case A, the load is compensated by PV power only when it is available. The surplus power generated by the PV panel is sold to the grid. In the absence of PV power, the utility grid supplies the load. In Cases B and C, the charging and discharging pattern of the BESS is shown depending on time. Furthermore, the variation of PV power, grid power, and load is shown for both peak and off-peak hours.

Figure 7 shows the variation of state of charge and cumulative battery capacity loss in a day for Cases B and C. The BESS charges and discharges during the off-peak and peak hours, respectively. In Case B, i.e. without considering peak load shaving, there is no restriction on the discharging of the BESS during peak hours. However, in Case C, i.e. considering peak load shaving, the BESS is not allowed to discharge beyond a certain limit during peak hours when the PV power is sufficient to meet the load. This limit is optimized and subjected to the objective of minimum AOC and is found to be 50.12%. The energy of the BESS is shown in Figure 7.

Table. Optimization results.

Name of parameter	Grid only	Without storage (Case A)	Without peak load shaving (Case B)	With peak load shaving (Case C)
Individual battery size (Ah)	-	-	120	150
Number of batteries in series	-	-	2	2
Number of batteries in parallel	-	-	19	19
Total number of batteries	-	-	$2 \times 19 = 38$	$2 \times 19 = 38$
Annual electricity cost (Rs)	99,714.05	16,431.00	–2177.40	–5705.10
ARC_{bat} (Rs)	-	-	3955.00	4943.80
ARC_{inv} (Rs)	-	-	1148.60	1435.70
ACC_{PV} (Rs)	-	55,186.00	55,186.00	55,186.00
$AOMC_{PV}$ (Rs)	-	750.00	750.00	750.00
$AOMC_{bat}$ (Rs)	-	-	168.37	195.43
$AOMC_{inv}$ (Rs)	-	-	27.58	34.47
Total penalty (Rs)	-	-	2173.60	1860.50
Total AOC (Rs)	99,714.05	72,367.00	61,232.00	58,701.20

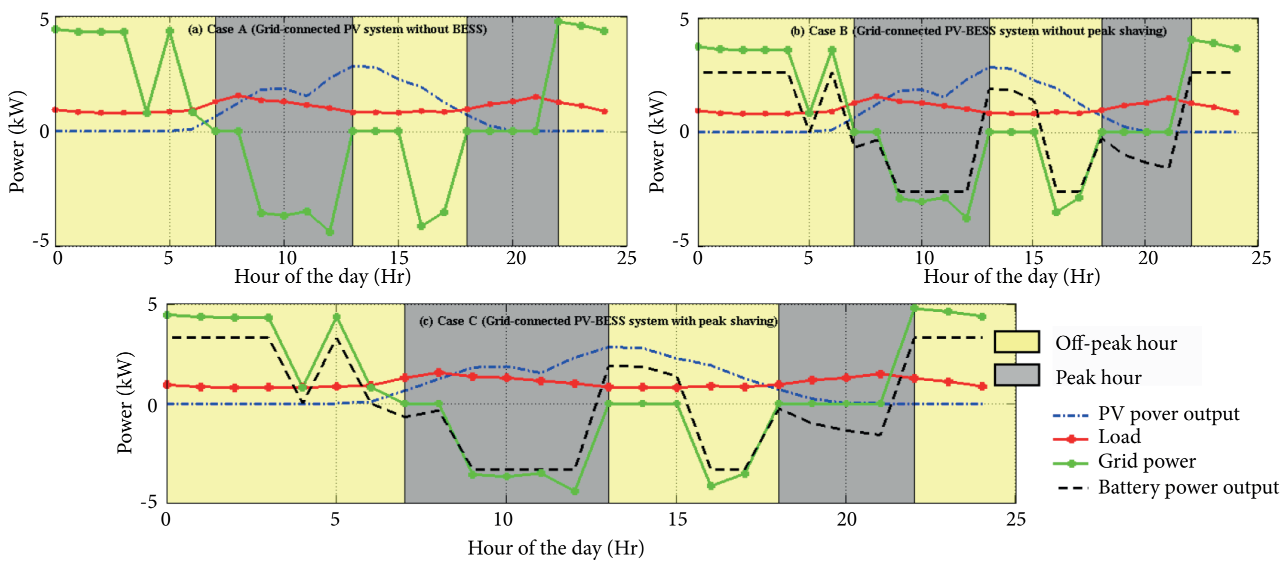
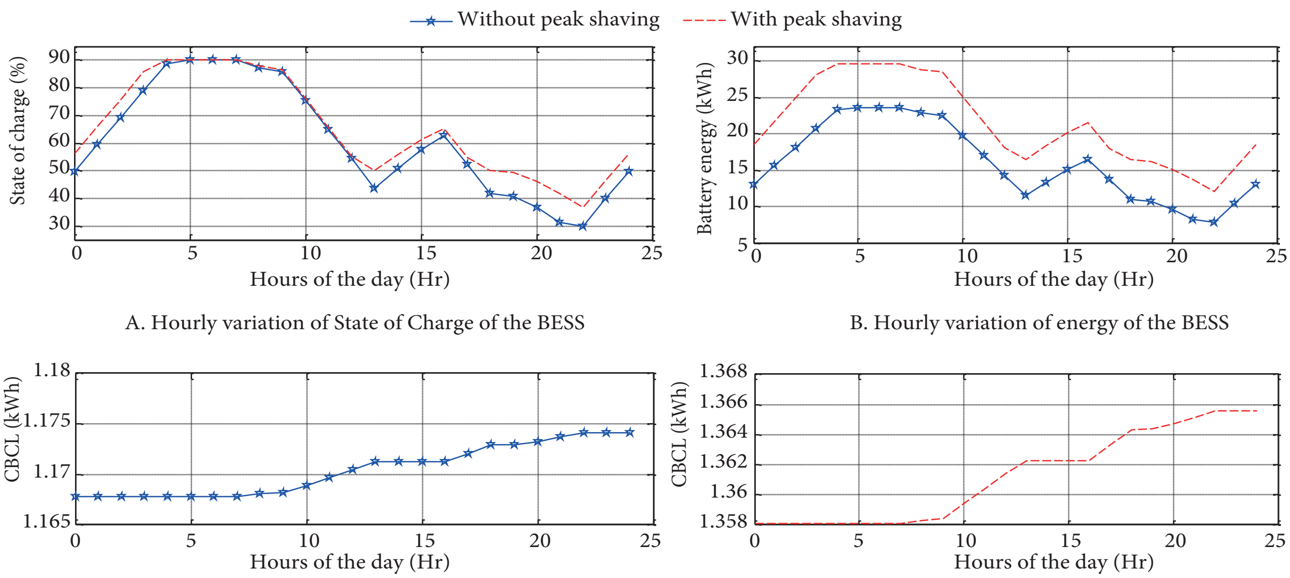


Figure 6. Active power variation of PV system, load, grid, and the BESS in a day: (a) Case A; (b) Case B; (c) Case C.

From Figure 7, the variation of cumulative battery capacity loss is found to be 6 and 8 Wh in Cases B (without peak shaving) and C (with peak shaving), respectively. It can be observed from the figure that battery capacity loss is prominent during the discharging hours of the BESS and constant during the remaining hours, when the BESS either charges or remains idle.

5. Conclusion

This paper performed a technoeconomic analysis for a grid-connected PV-BESS system with the objective of obtaining minimum annual operating costs for three different cases, i.e. a system without BESS, with BESS and without peak load shaving, and with both BESS and peak load shaving. The integration of PV-BESS units has the advantage of demand charge management, renewable energy time shift, and capacity farming. The cost



A. Hourly variation of State of Charge of the BESS
B. Hourly variation of energy of the BESS
C. Hourly variation of CBCL (Without Peak Shaving)
D. Hourly variation of CBCL (With Peak Shaving)

Figure 7. Hourly variation of SOC, energy, and CBCL of the BESS for Cases B and C in a day, and BESS capacity loss variation in a day.

saving is found to be improved through the proposed optimum energy flow strategy with peak load shaving. A new efficient technique was proposed that uses the BESS for storing and selling energy to the utility grid. This system considers the TOU tariff and defines SOC for each hour for a year in order to minimize the total AOC of the system. The result is highly economical and more suitable for practical applications, as different factors affecting the performance of a PV panel are considered. The IHSA, a metaheuristic optimization technique, is used to find the optimal size of the BESS, which proves to be fast, reliable, and aptly accurate. The cost analysis is performed in an Indian scenario considering actual historical data. Hence, the result is more suitable for practical applications in a rapidly developing country like India with ample renewable energy sources.

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