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Analysis of Photovoltaic & Battery Energy Storage System Impacts on Electric Distribution System Efficacy

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Abstract: Uncertain nature of renewable energy sources like solar irradiation poses a serious concern of loss of power supply reliability. Battery energy storage (BES) system helps in improving system reliability by storing surplus energy generated and supplying the load in case of energy deficit. Thus BES allows improvement of microgrid performance and reduces operational cost by increasing the utilization of renewable energy sources. This paper presents an energy management strategy (EMS) to dictate the power flow among photovoltaic (PV) panels, BES and the load considering a proposed time-of-use (TOU) pricing as the control factor. Its efficacy in improving power supply reliability as well as power quality issues of a 69-bus radial distribution system (RDS) is evaluated from technical performance indices like power loss, voltage deviation index and security margin and economic performance considering costs of power import from the grid and active power loss and financial benefit from battery discharge. Grasshopper Optimization Algorithm (GOA), is used to optimize the sizes and placements of three PV-BES units to minimize an objective function aptly formulated combining the technical performance indices using weighted sum method. The results are contrasted against another two cases of with only PV and without PV and BES integration. Finally, the proposed system is analysed from economic perspective and the benefits obtained are compared. The results are evident of both technical and economic advantages of integrating both PV and BES units at optimal locations (load bus). The optimization results obtained from GOA have been compared with that from Genetic Algorithm (GA). GOA proves to be fast, effective and reliable in resolving power flow optimization problem.

Keywords: solar photovoltaic; battery energy storage system; radial distribution system; grasshopper optimization algorithm (GOA); techno-economic analysis.

1. Introduction

Alarming increase in energy consumption, environment pollution, change in climate and depletion of fossil fuel reserves motivate the contemporary researchers to facilitate the renewable energy harvest. The introduction of PV systems into conventional power distribution systems has been proven fertile in this scenario [1]. But factors like solar radiation, cloud cover, daylight hours, and ambient temperature adversely affect the reliability of PV power output and overall power quality which can be solved by installing battery energy storage (BES) with PV systems [2]. High PV power penetration may induce drastic voltage fluctuations which can also be smoothened by using BES [3]. PV with controllable BES system also ensures economical benefit to consumers by peak load shaving [4].

The integration of BES with PV system has been studied extensively in recent years. In [5], a procedure for sizing components of a standalone hydro kinetic turbine-PV-battery system is explained. In [6], the optimal capacity of a solar photovoltaic and battery energy storage system for a grid connected domestic load is determined to minimize the net present cost of electricity. In [7], a novel control strategy is devised to integrate battery and supercapacitors in order to increase the energy and power density. In [8], a new control strategy, namely, Fractional Order Proportional Integral (FOPI) has been proposed for a hybrid PV-wind-battery system for three

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phase integration. In [9], a novel method for control and scheduling of renewable energy sources for cost savings in a multi-microgrid system. In [10], the optimal sites and sizes of the DGs have been found out to minimize the total active power loss, for test systems such as IEEE 33, IEEE 69 and IEEE 118 bus radial distribution system with the help of different optimization techniques such as Grey wolf optimization, modified one by one search algorithm, Moth-flame optimization, Whale optimization and Salp swarm optimization. In Yanzhi et al.[11], a fuzzy multi-objective function consisting of reliability, electricity generation cost, grid loss and voltage profile was optimized with smart generation dispatching. To improve the dynamic behaviour of a solid oxide fuel cell a new control strategy was proposed and tested in Meghdad et al. [12]. In Mahdi et al.[13], a hybrid genetic algorithm was employed to improve the reliability of a utility grid.

In this paper a PV-BES system connected to a 69-bus RDS is designed taking PV power fluctuations, uncertainty in power demand, TOU pricing into account for different modes of operation for a location on the coast of eastern India. A new energy management strategy (EMS) is devised to regulate the charging and discharging of the BES along with charging time while minimizing the proposed objective function. This EMS shifts the peak load demand to off peak hours. A systematic view of a single objective Grasshopper Optimization Algorithm (GOA) is presented as an optimization tool to determine locations and capacities of PV-BES unit which is not yet tested in solving optimal sizing and placement problems of renewable energy sources in RDS. Techno-economic benefits of the power supply operators are also evaluated for the specific location using a proposed TOU tariff plan.

The remainder of the paper is sorted out in the subsequent way. In section 2, the modelling of the system is defined. Section 3 offers the energy management strategy. In Section 4, the problem formulation is deliberated and the GOA is pronounced in Section 5. The simulation and result analysis are presented in Section 6. Finally, conclusion is submitted in Section 7of the paper.

2. Modelling of the system

A. Modelling of components used in the PV-BES unit

The PV-BES unit, utility grid, and load are associated to a common AC bus bar. The PV and BES are connected to a DC bus first through a regulated DC–DC boost converter and then via a bidirectional charge controller. A bidirectional 6-pulse inverter is connected in between AC bus and DC bus to facilitate power conversion from AC to DC and vice versa as per the instructions of the EMS. Gelled electrolyte valve-regulated lead-acid batteries are used since they support deep cycle charging, enabling the BES to charge and discharge frequently without affecting its lifespan drastically. The system overview along with power flow of the PV-BES unit is presented in figure. 1. $P_{grid}(t)$ is the power transfer to and from the utility grid in kW. Positive value of $P_{grid}(t)$ implies power export to the grid whereas negative value implies power import from the grid.

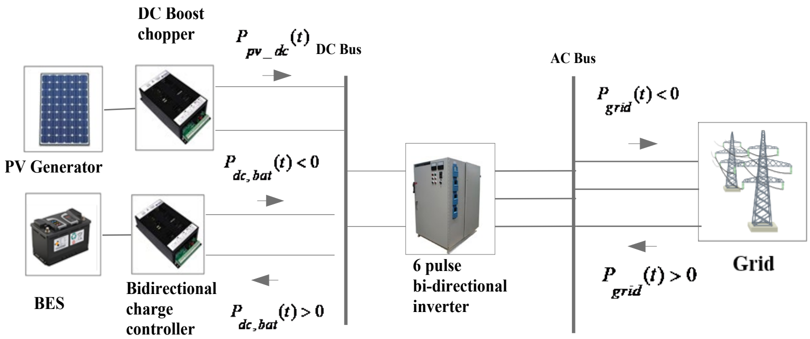

Figure 1. Modelling of PV-BES unit

A.1. Modelling of PV system

Solar PV modules are able to extract the energy encapsulated in photons and transform it into electrical energy. But the PV power output is dependent on PV module efficiency, inverter efficiency, ambient conditions like temperature, cloud cover, solar irradiance etc, and technical limitations of power electronics components like inverter efficiency, maximum power point tracker (MPPT) efficiency, power loss in connecting cables etc. The net PV power output at the AC bus can be computed as discussed in [14].

The hourly global horizontal irradiance (GHI) data considered for calculation of output power has been collected for a day in the year of 2015[15] for Bhubaneswar, India. It is shown in figure. 2.

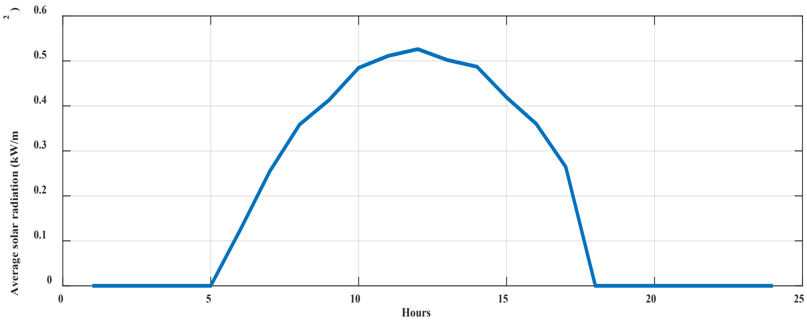

Figure 2 Hourly average of solar insolation

A.2. Modeling of battery energy storage (BES) system

In this paper, Gelled electrolyte valve regulated lead acid battery with carbon enhanced electrodes is used to design the BES. This kind of battery is selected for its capability of withstanding deep cycle charging and longer life span. The oxygen produced on the positive plates of a VRLA battery gets absorbed on the negative electrode inhibiting the production of hydrogen at the cathode, rather water is produced in the cell maintaining the pH of the electrolyte. Hence it doesn't need frequent watering, thus it proves to require less maintenance. It can be used in wet environment. As most part of India receives rainfall due to monsoon for almost 4 to 5 months a year, its utility is appreciated. Not having liquid electrolyte enhances its portability. It shows greater resistance to extreme temperature which is most likely at the location under study and mechanical stress and turmoil.

The hourly BES capacity and its state of charge (SOC) are dependent on the charging and discharging schedule and rates. The SOC must remain within its permissible limits to ensure healthy operating condition of the BES. The detail modelling of the BES is given in [14].

A.3 Modeling of the load

Three load buses are selected to place three PV-BES units. The selection is performed using GOA optimization technique. The IEEE reliability test system load profile [16]is considered for framing a 24-hr profile of load demand factors. The estimated loads are calculated at bus *i* as follows:

$$P_{Load,i}(t) = w_h(t) \times P_i \tag{1}$$

where $w_h(t)$ = hourly weight factor as shown in figure. 3 and P_i = peak load at bus i. The load demand and power output from PV-BES units are balanced throughout the three phases.

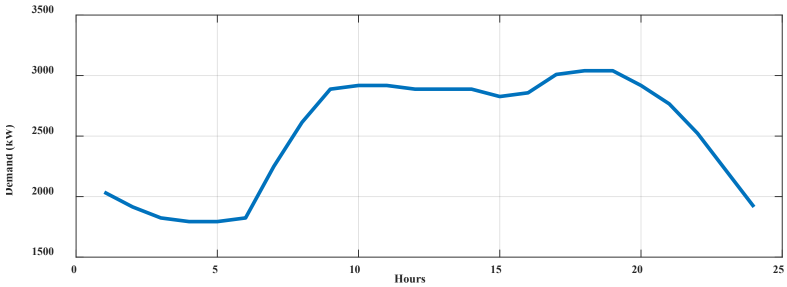

Figure 3. Demandin a day

B. Distribution system and load flow

A 69-bus large-scale RDS is studied as the test system [17]. The total active loads on this system are 3802.19 kW. The load-flow analysis of the distribution system under study is carried out using Backward and forward sweep-based algorithms [18] because of their high computational efficiency and robust convergence characteristics. The parameters which are considered for power flow studies are given in Table 1. Integration of PV-BES units in RDS is shown in figure 4.

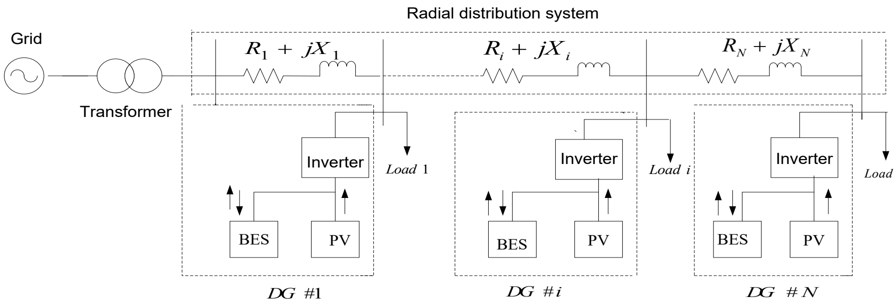

Figure 4. Radial distribution system with multiple buses

Table 1. Parameters used in power flow studies

Base kV	Base MVA	Current carrying capacity of branches
12.66kV	100 MVA	Branches 1-9 : 400A Branches 46–49 & 52–64: 300A Remaining Branches: 200A

3. Energy management strategy (EMS) for PV-BES unit

The operation strategy of the system is explained in figure 5.

In figure. 5 P_{pv} is the PV power output, $P_{ac,bat}$ is the AC power supplied by the BES, $P_{bat,\max}$ is the maximum allowable limit of $P_{ac,bat}$, $SOC^{\min}$ and $SOC^{\max}$ are the minimum and maximum limit of the SOC of the BES respectively,

4. Problem formulation

The proposed PV-BES unit is incorporated into the RDS for reducing power loss, confirming secure operation and maintain the voltage within tolerance limits. The hourly total power loss of each branch in the RDS is found from the Backward-Forward sweep method. The point of the proposed strategy is to decide the optimal allocation of the PV-BES unit.

A. Objective functions

The problem addresses three objective functions such as power loss $(f_{obj,1})$, voltage offset $(f_{obj,2})$, and security margin $(f_{obj,3})$.

$$Minimize \quad (F_T = k_1 \ f_{obj,1} + \ k_2 \ f_{obj,2} + k_3 \ f_{obj,3}) \tag{2}$$

where k_1, k_2, and k_3 are the weights for the objective functions $f_{obj,1}$, $f_{obj,2}$, and $f_{obj,3}$, respectively. These coefficients reflect the degree of importance of the objective functions, k_1 = 0.5, k_2 = 0.3, and k_3 = 0.2. Each objective function is converted into their respective per unit values.

The mathematical modelling of each objective function is described as follows:

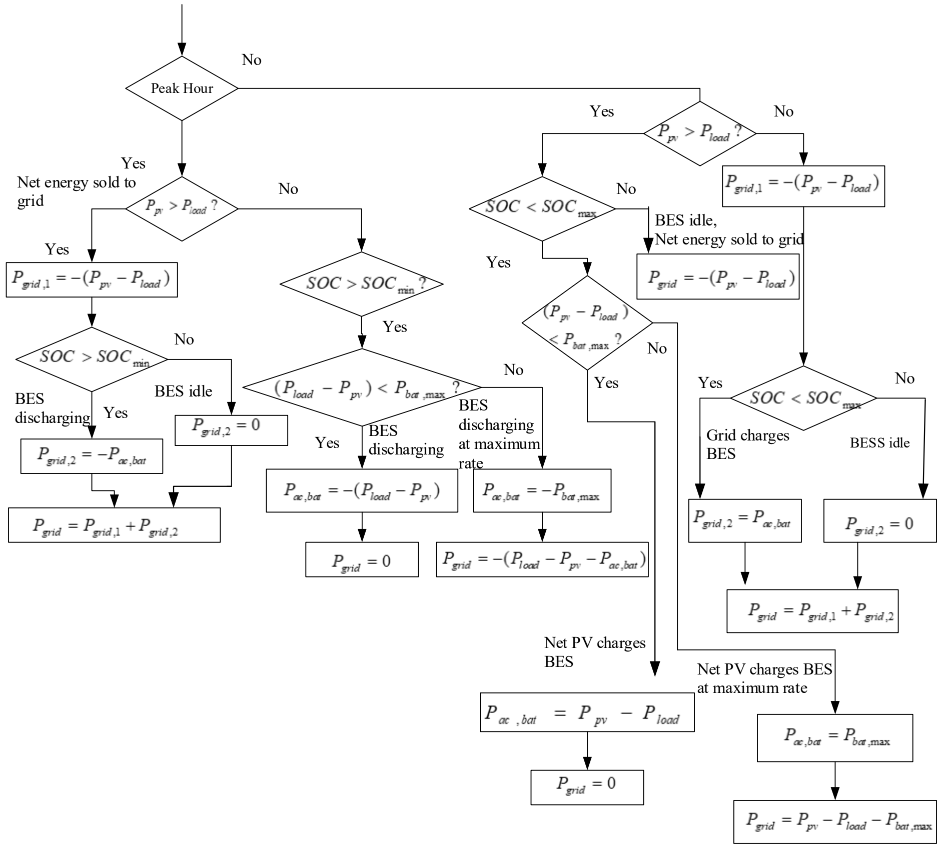

Figure 5. Flow chart of EMS

A.1. Power loss minimization

$$f_{obj,1} = \frac{1}{n_t} \sum_{t=1}^{n_t} P_{Loss,i}(t) \tag{3}$$

$$P_{Loss,i}(t) = R_i I_i^2(t) \tag{4}$$

where R_i = resistance of the i^{th} branch, $I_i(t)$ = current at i^{th} branch at time t , n_t is the total time slot=24hours and $P_{Loss,i}(t)$ = power loss of i^{th} branch at time t. This will improves performance of RDS.

A.2. Voltage deviation index:

$$f_{obj,2} = \max\left(\frac{1}{n_t} \sum_{t=1}^{n_t} \left| V_j(t) - 1 \right| \right) \text{for } j = 1,2,3.......N \tag{5}$$

where $V_j(t)$ = voltage at bus ‘ j ’ at time t and N = number of buses. Here, the voltage deviation index determines how close the daily average value of actual voltage obtained at the bus is to the rated value i.e. 1 p.u. The maximum value of the voltage deviation index must be minimized to limit the voltage to be deviated from the rated value up to an allowable threshold of 5% of it.

A.3. Security margin:

$$f_{obj,3} = \frac{1}{n_t} \sum_{t=1}^{n_t} \left(1 - \min_i \left| \frac{I_i(t) - I_i^r}{I_i^r} \right| \right) \tag{6}$$

where $I_i(t)$ = current at i^{th} branch at time t and I_i^r = rated current. The security margin is a measure of allowable currents through the branches of the RDS. It quantifies the relative deviation of the branch currents with respect to their rated current capacities. Under unpredictable loads and system discrepancies the security margin ensures that there is current carrying capacity reserved. Hence it improves the utility of the existing distribution system rather than upgrading it by changing the conductors and components like transformers, protection devices etc. which saves a great deal of expenditure for the utility company.

B. Economic analysis

Integration of PV units along with BES reduces the power requirement of the RDS hence reducing the power loss hence the cost associated with it. Also the RDS needs to buy less power from the supply substation. Discharging of the BES also increases the financial benefits of the consumer as well as the utility company. Hence the cost associated with the system involves three different components. They are detailed below.

The cost of active power bought from upstream grid can be intended as

$$C_{pur} = \left[\sum_{t=1}^{n_t} (P_{pur}(t) \times P_{price}(t)) \right] \times 365 \tag{7}$$

where $P_{pur}(t)$ and $P_{price}(t)$ are the active power purchased from the upstream grid and the price of the electricity at time *‘t’* respectively and n_t is no. of time slots in a day. The daily cost of energy throughout a year is assumed to be constant. The active power purchased from the upstream grid can be calculated as

$$P_{pur}(t) = real(V_{sub}(t) \times I^{*}_{sub,inj}(t)) \tag{8}$$

where $V_{sub}(t)$ and $I_{sub,inj}(t)$ are the voltage at the substation and the current at the substation flowing into the RDS at time *‘t’* respectively.

The cost associated with the power loss can be calculated as

$$C_{loss} = \left[\sum_{t=1}^{n_t} (P_{Loss}(t) \times P_{price}(t)) \right] \times 365 \quad (9)$$

The daily power loss throughout the year is assumed constant.

The benefits obtained from discharging BES can be calculated as

$$C_{BES,disch} = \left[\sum_{t=1}^{n_t} (P_{bat,ac}^{disch}(t) \times P_{price}(t)) \right] \times 365 \quad (10)$$

where $P_{bat,ac}^{disch}(t)$ is the ac power discharged from the BES and penetrates into the distribution system.

C. System Operational Constraints

The system operates within some constraints which are given below:

$$P_{sub}(t) \pm P_{grid}(t) = P_{Load}(t) + P_{Loss}(t) \quad (11)$$

$$V_j^{\min} \le V_j(t) \le V_j^{\max} \quad (12)$$

$$I_i(t) \le I_i^r \quad (13)$$

$$P_{pv}^{\min} \le P_{pv}(t) \le P_{pv}^{\max} \quad (14)$$

$$P_{dc,bat}^{\min} \le P_{dc,bat}(t) \le P_{dc,bat}^{\max} \quad (15)$$

$$SOC^{\min} \le SOC(t) \le SOC^{\max} \quad (16)$$

where $P_{sub}(t)$ is the active power injected by the substation at time t, $P_{Load}(t)$ is the predicted active load at time t, $V_j^{\min}$ and $V_j^{\max}$ are the minimum and maximum voltage of bus j, $I_i^{\max}$ is the maximum current at i^{th} branch, $P_{pv}^{\min}$ and $P_{pv}^{\max}$ are the minimum and maximum output power of the PV units respectively, $P_{dc,bat}^{\min}$ and $P_{dc,bat}^{\max}$ are the lower and upper limit of DC power supplied or absorbed by the BES respectively.

5. Grasshopper Optimization Algorithm (GOA)

GOA is a kind of natural heuristic algorithm. Its design inspiration comes from the social behavior of grasshoppers in nature. A grasshopper swarm moves slowly in its infancy and has a wide range of activities in its adulthood. These two characteristics make two trends in the search process of natural heuristic algorithm: exploration and exploitation [19]. Exploration and exploitation, as well as target search, are naturally accomplished by grasshoppers. The swarming flora of grasshoppers is presented by following mathematical model [20]:

$$x^i = s^i + g^i + a^i \quad (17)$$

Where x^i is the i^{th} grasshopper position, s^i is the social interface, g^i is the force of gravity on the i^{th} grasshopper, and a^i shows the wind advection. To give arbitrary conduct of the grasshopper, equation (17) can be rewritten as

$$x^i = r^1 s^i + r^2 g^i + r^3 a^i \quad (18)$$

$$S(r) = f e^{\frac{-r}{l}} - e^{-r} \quad (19)$$

Where f is the intensity of attraction and l is the attractive length scale. Using Eq. (18) grasshopper quickly reaches to the comfort zone and it does not converge globally. Hence a modification is needed. An altered form of this equation is given as follows:

$$X_d^i = c\left(\sum_{\substack{j=1\\ j\neq i}}^{N} c\,\frac{ub^d - lb^d}{2}\, s\left(\left|x_d^j - x_d^i\right|\right)\frac{x^j - x^i}{d_{ij}}\right) + \hat{T}_d \tag{20}$$

Where, ub^d is the higher bound in the d^{th} dimension, lb^d is the lower bound in the d^{th} dimension. $\hat{T}_d$ is the value of d^{th} dimension in the target and c is a decreasing coefficient to shrink the comfort area, repulsion area, and attraction area.

Equation (20) cleverly simulates the interaction between grasshoppers in a swarm. The next position of grasshoppers is determined by their current position, target position, and the position of all other grasshoppers. The first component of the equation takes into account the position of grasshoppers relative to other grasshoppers, and the second component simulates the trend of grasshoppers transferring to food sources, the parameter c simulates the deceleration of grasshoppers approaching food sources and slowing down to eat.

As per the iteration number , the parameter c is updated to reduce exploration and increase exploitation as follows:

$$c = c^{\max} - l\,\frac{c^{\max} - c^{\min}}{L} \tag{21}$$

where c^{max} is the maximum value, c^{min} is the minimum value, l indicates the current iteration, and L is the maximum number of iterations. In this work, we use 1and 0.00001 values for c^{max} and c^{min}, respectively.

The mathematical model of the GOA requires grasshoppers to move towards the target gradually during the iteration process, avoiding convergence to the target too quickly, so as to fall into local optimum. GOA saves the most promising target in the search space in each iteration and requires grasshoppers to move towards it gradually. This is to find a better and more accurate target as the best approximation of the real global optimum in the search space. Like other evolutionary algorithms, GOA uses fitness function to guide grasshoppers to search their optimal location in D-dimensional space in order to meet the requirements of objective function. At each stage of the algorithm, the position vector corresponding to the optimal fitness value is taken as the global optimal position vector, and this information is transmitted to other grasshoppers around, so that grasshoppers can adjust their steps and position vectors accordingly until they reach the target position of food. The main optimization process of GOA algorithm is shown in figure 6 and pseudo code of GOA to solve the proposed problem is shown in figure 7.

```
Initialize the swarm i .e. location and size of PV -BES units as pre the lower and higher limits .
Set the values as  cmax = 1 , cmin =0.00001  and L =200.
Calculate the fitness (F T) of each search agent. T=best search agent
while l<L
    Update the value of c as Eq . 21
    for each search agent
        Normalize the distance between grasshoppers.
        Update the position of current search agent as Eq . 20.
        Bring the current search agent back if it goes outside the boundaries .
    end for
    Update T if there is a better solution.
    l=l+1
end while
Return T.
```

Figure 7. Pseudo code of GOA to solve the proposed problem

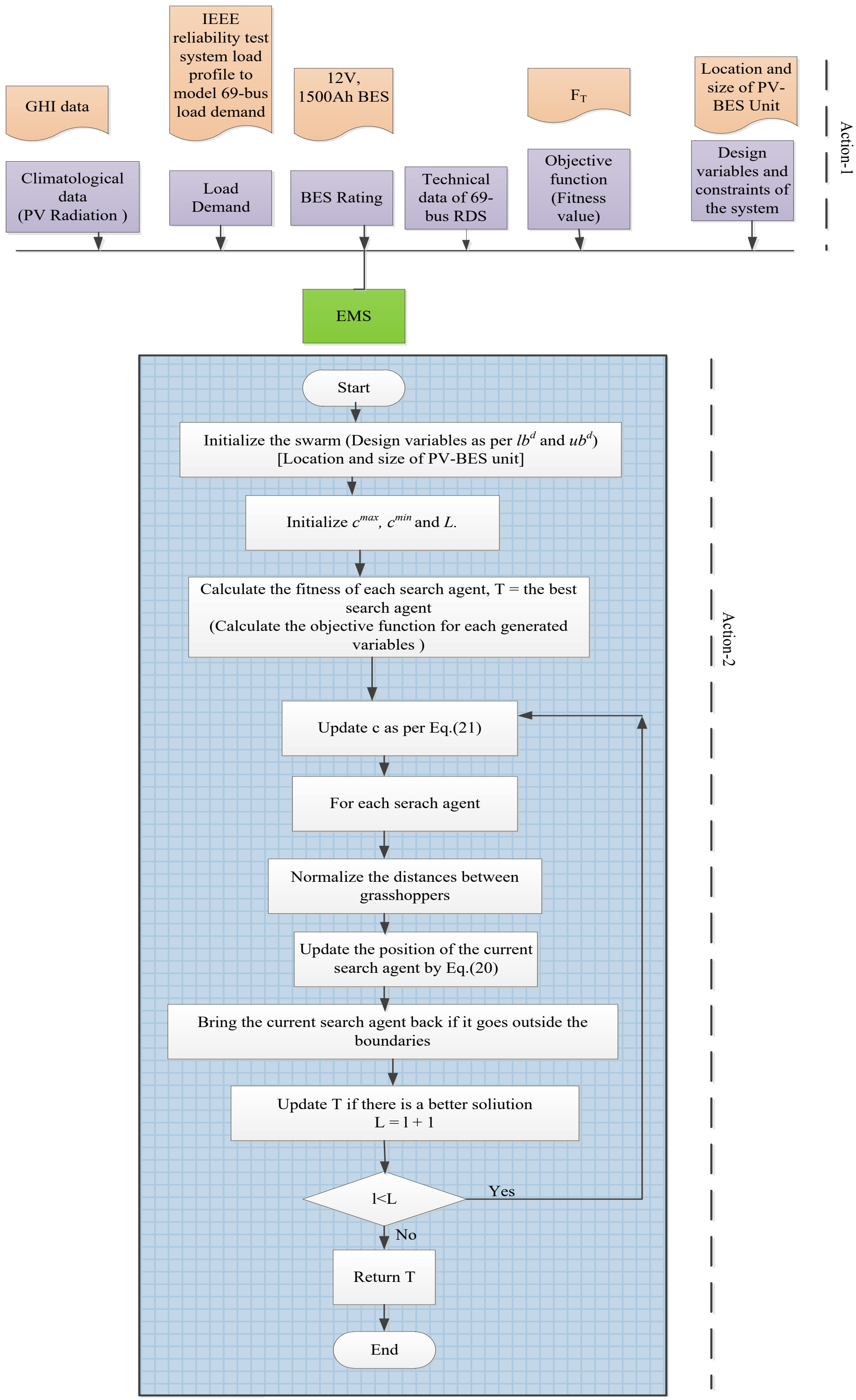

Figure 6. The flowchart of the overall GOA computational procedure

6. Simulation and result analysis

The proposed algorithm for allocation of three PV-BES units in 69-bus RDS is analyzed using three case studies:

Case #0 (Base Case): Without installing PV-BES units

Case #1: Installing three PV units without any BES systems.

Case #2: Installing three PV units along-with BES systems.

The load bus is considered as the location for integration of the PV units and PV-BES units for case#1 and case#2 respectively. The three PV-BES units are assumed to be of same ratings and specifications. Moreover, the hourly insulation data for the locations of all the load buses are assumed to be same. The bus voltage is limited to 0.95–1.05 p.u. 7 a.m. to 1 p.m. and 4 p.m. to 10 p.m. are considered as the peak load hours of a day and the rest of the hours are considered as off-peak hours.

Table 2. Optimization results

		Case #0	Case #1		Case #2	
			GA	GOA	GA	GOA
Functions	Power Loss ($f_{obj,1}$)	97.74	61.13	50.09	49.83	48.69
	Voltage deviation ($f_{obj,2}$)	0.0583	0.0421	0.0346	0.0347	0.0338
	Security Margin ($f_{obj,3}$)	0.6319	0.4786	0.4728	0.4686	0.4607
Variable	Location : PV of Unit 1 PV of Unit 2 PV of Unit 3	-	13 69 64	17 61 64	13 69 64	17 61 64
	No. of PV: PV of Unit 1 PV of Unit 2 PV of Unit 3	-	350 350 350	350 350 350	350 350 350	350 350 350
	No. of Battery: BES of Unit 1 BES of Unit 2 BES of Unit 3	-	0 0 0	0 0 0	20 164 30	28 174 2

The proposed Grasshopper Optimization Algorithm is used to optimize the location and size of three PV-BES units in the 69-bus RDS in order to minimalize the proposed objective function. Here the size of each PV panel is fixed at 1750 kW. The optimization results are illustrated in Table 2. All the values shown in the table are the average values for a day. The results reveal that PV units integrated with BES yield the best solutions as compared to other cases.

Figure 8 shows the hourly variation of voltage at bus 65 for one day. Bus 65 is chosen for illustration as it is the weakest bus in the RDS under study. TheFigureure ensures that the voltage at the weakest bus is envelopped within the prespecified allowable limit of ± 5% of its rated value. In case 2 i.e. when the system is integrated with both PV and BES units, the voltage does not exceed the specified limit and improves to a great extent in comparison to the other two cases. In case # 0, with neither any renewable energy sources nor any energy storage units included in the system, the voltage starts declining as the peak hour starts at 7 a.m. as the huge load demand drags down the voltage at bus 65. It slightly improves at the starting of the off-peak hours. Again it goes down at 4 p.m. with the load surging up. With the PV units installed in case # 1, the voltage increases as the PV units start generating power and injecting it to the RDS. During the hours when the PV power is unavilable, the voltage profile follows the path traced in case # 0. In case # 2, from 7 a.m. onwards the BES discharges to supply power to the grid along with the PV units increases the voltage beyond that of case # 1. After 1 p.m., during off-peak hours the BES starts charging dragging the voltage down. Hence there is a dip in the voltage curve during these hours. Otherwise the voltage profile of case # 2 follows that of case #1 with a slight improvement. After 10 p.m. again the BES starts charging reducing the voltage down a bit.

Figure 9 shows the hourly average voltage at all 69 bus of the RDS. It is observed from theFigureure that in case # 2 the voltages at almost all buses improve in comparison to the other cases. The minimum voltage level for Case #0, Case #1 &Case #2 are 0.9419 p.u., 0.9691 p.u. & 0.9709 p.u. respectively. It is observed that significant amount of improvement in minimum voltage level can be accomplished in Case #2.

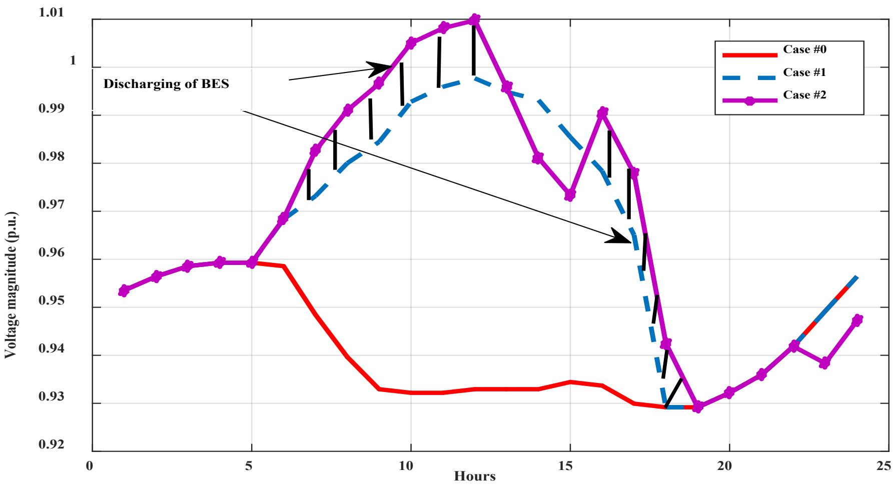

Figure 8. Voltage profile of bus 65

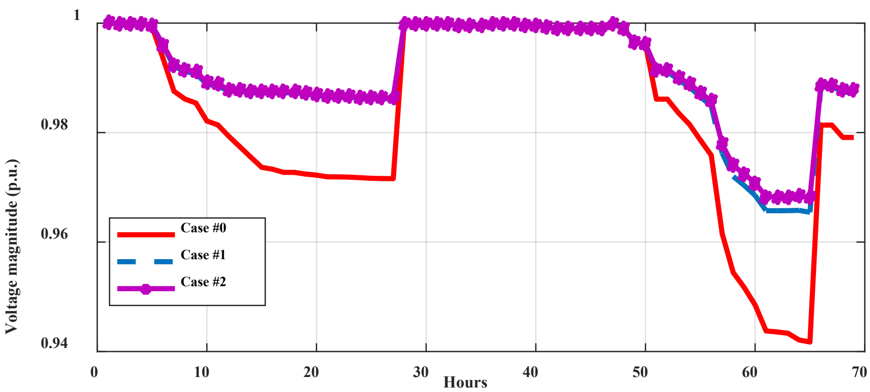

Figure 9. Voltage profile of 69-bus network

Figure 10 shows the power drawn from the HV grid at the substation.It is evident that considerable improvementsare obtained in terms of the leveling power in Case #2. The integrated PV-BES units supply the loads during peak hours hence reducing the power imported from the upstream grid.The BES units discharge during peak hours and charge otherwise to reduce power flowovercrowding by supplying power downstream which discourge transmission–distribution system upgrade, facilitate demand charge management, renewable energy time shift, and renewable capacity firming. Peak hour load shifts resulting in reduction of power burden on the HV grid and distribution line. It is evident from theFigureure that in presence of PV generated power i.e. from 6 a.m. to 6 p.m. (in case #1 & case #2) the dependance on HV grid to meet the load demand reduces drastically. During 1 p.m. to 4 p.m. (off-peak hour) the BES charges consuming power from the grid behaving like a load. So in case #2 the power curve shifts upward during this interval.

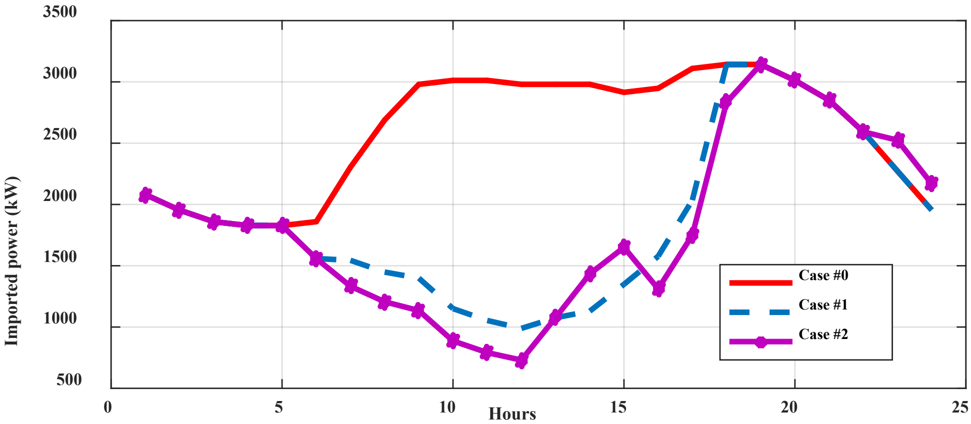

Figure 10. Active power imported from the HV grid

Discharging power of BES can support the power grid during peak hours due to which ripples in the load profile can be eliminated and peak load shaving can be attained. Figure. 11 demonstrates the assessment of load for three cases. And it can be noticed that, power from the BESs and the PV arrays, supply enough energy not only to shave off the peak load but also to create a dip in energy demand. The system with PV-BES units promises maximum profit. The stress on components of RDS is also reduced during peak hours.

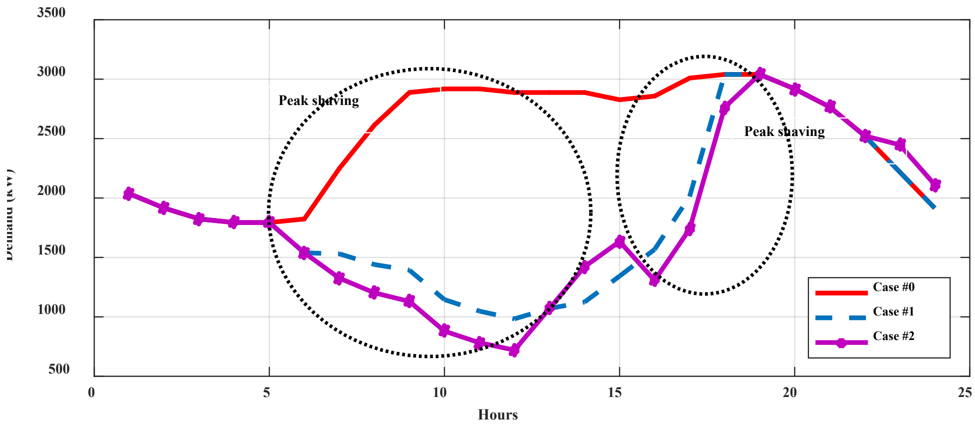

Figure 11. Hourly variation of the load in a day

Figure 12 shows the variation of state of charge of BES. It is seen that the BES stays inactive from the beginning of the day to 7 a.m. as the SOC is at its allowable maximum value of 90%.

As the peak hour begins after 7 a.m. the BES discharges to supply the load until 1 p.m. when the SOC becomes its allowable minimum value of 30%. Then, BES starts charging until 4 p.m. as these hours are off-peak hours. After 4 p.m. it discharges until its SOC reaches to 30% i.e. up to 7 p.m. At that point, it stays inactive and again begins charging at 11 p.m. as the off-peak hour begins. Same kind of BES is utilized in all PV-BES units so the SOC bends are same for each of the three locations.

Table 3. Economic analysis

Cases	Cost of power losses (INR)	Benefit of discharging power of BES (INR)	Power purchased from upstream grid (INR)
Case #0	8690297	-	220953397
Case #1	5628211	-	151626499
Case #2	5532500	133930	143415628

From economic viewpoint, the advantages of the proposed technique are recorded in Table 3 based on the TOU pricing. Electricity is purchased at a rate of INR12.20/kWh for peak hour and INR5.00/kWh for off-peak hours. The table presents financial benefit obtained by using the proposed energy management strategy. The revenue increases with a decrease in the cost of power loss.

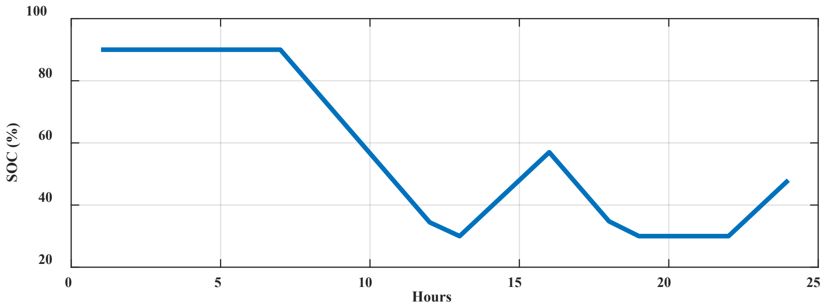

Figure 12. Variation of SOC of BES at optimal locations

7. Conclusion

In this study, a novel strategy for energy management among PV panels, BES units and the utility grid for a grid connected distribution system are proposed. The optimal size and placement of PV-BES units are determined with the help of a bio-inspired evolutionary algorithm, namely GOA. Here, the objective function is uniquely formulated by combining total active power loss, voltage deviation index (VDI) and security margin (SM) using weighted sum method. The optimization technique minimizes the maximum value of VDI in order to avoid power quality issues like voltage sag or swell. Minimizing SM ensures the fact that the maximum current that flows in a branch must fall within the rated capacity of the same branch. The results obtained have ensured these objectives. The EMS also proves its worth in maximizing the economic benefits considering different cost components. The proposed scheme is evaluated in a widely appreciated, standard IEEE 69-bus RDS to authenticate the results. The simulation results demonstrate the efficiency and swiftness of convergence of GOA. The integration of PV-BES units with the distribution system is a profitable approach and offers many techno-economic benefits.

8. References

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