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Optimal sizing of Battery Energy Storage System in Microgrid by using Particle Swarm Optimization Technique

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ABSTRACT

The power generation from Renewable Energy Sources (RES) is intermittent in nature, therefore a 'generation - demand' mismatch always exists, which leads to reliability and energy management issues which can be solved by introducing Energy Storage Systems (ESS). This paper proposes a sizing methodology to optimize the components of microgrid which includes Photovoltaic System (PV) and Battery Energy Storage System (BESS).The aim is to minimize the Total Annual Cost (TAC) of the system which includes annual capital cost, annual maintenance cost and replacement cost over a 20 year life of project. The optimization problem is subject to economic parameters and technical constraints. The technical constraint related to system reliability is expressed by Loss of Power Supply Probability (LPSP). In this study, Particle Swarm Optimization (PSO) algorithm is used for optimal sizing of PV system and BESS. The obtained simulation results are optimum PV panel number, battery number, inverter capacity and Diesel Generator (DG) capacity for backup purpose. The simulation results of the PSO algorithm is verified with Iterative Search Based (ISB) algorithm. It is observed, simulation time of PSO is faster than ISB algorithm.To optimise system, meteorological data such as solar radiation and typical load curve is considered. A real time case study of Symbiosis Campus Pune India is reported to show the efficacy of the developed algorithm.

Keywords: Microgrid, Battery, Energy Storage System, Loss of Power, Supply Probability, Particle Swarm Optimization

INTRODUCTION

With the pressure from environment pollution and energy depletion, more emphasis on use of Renewable Energy Sources (RES) such as Solar and Wind is increasing day by day. Also as per the vision of an Indian Government of installing 175 GW of RES by 2020, promoting RES has become an inevitable reality. In the meanwhile, conventional power plants are overloading the atmosphere with CO_2 and other heat trapping gases which substantially contribute to global warming and these emissions significantly affect human health and climate. The RES emit very little of global gas emissions as compared to other energy sources like coal and natural gas. In the RES, PV system is considered as quite reliable and secure source as compared to other sources.[1] Currently, grid connected PV systems are widely used as distributed generation units in power system. However, the PV system satisfies the load demand in day time and if power needed in day time, grid supply power to load. The power generation from PV system is intermittent in nature, therefore a 'generation - demand' mismatch always exists, which leads to reliability and energy management issues which can be solved by introducing BESS.[11] In this paper, microgrid is considered which is grid connected in nature. It includes PV system with BESS and DG.[2]

The sizing of each component in microgrid is most challenging task. Now a day's optimization technique plays a vital role in sizing a microgrid. During a past few decades, people were using conventional methods to size microgrid but these methods have limitations such as reliability constraints, computational constraint etc. Recently People move towards new optimization techniques such as Artificial Intelligence (AI), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Simulated Annealing (SA) etc. to overcome limitation of Iterative Search Based (ISB) conventional method.[8]

This paper proposes a sizing methodology to optimize the components of microgrid which includes PV andBESS.The aim is to minimize the TAC of the system which includes annual capital cost, annual maintenance cost and replacement cost over a 20 year life of project. The optimisation problem subject to economic parameters and technical constraints. In the system operation

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strategy, LPSP reliability index is used to balance the mismatch between demand and generation.

In this study, PSO algorithm is used for optimal sizing of PV system and BESS. The obtained simulation results are optimum PV panel number, PV Capacity, battery number, battery capacity, inverter capacity and DG capacity for backup purpose. The simulation results of the PSO algorithm is verified with ISB algorithm. It is observed, simulation time of PSO is faster than ISB algorithm. To optimise system, meteorological data such as solar radiation and typical load curve is considered.[15] A real time case study of Symbiosis Campus Pune India is reported to show the efficacy of the developed algorithm.

System Configuration

The topology of microgrid is illustrated by Figure 1.It is a set of PV panels, BESS, DG, load demand with other electronic devices connected with grid.

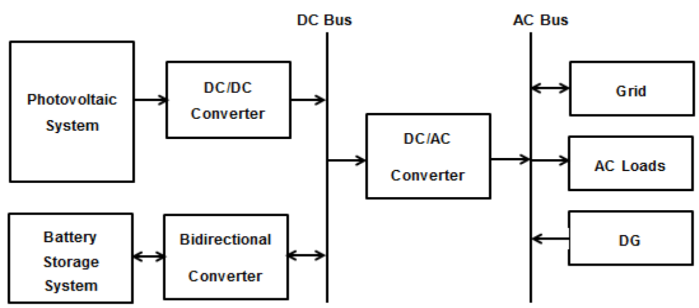

Figure 1 Schematic of the microgrid system

A. PV System

The output power of each photovoltaic panel can be calculated as follows:

$$P_{PV-Each} = \begin{cases} P_{Rs}\left(\frac{r^2}{R_{SRS}R_{CR}}\right) & if \quad 0 \le r \le R_{CR} \\ P_{Rs}\left(\frac{r}{R_{SRS}}\right) & if \quad R_{CR} \le r \le R_{SRS} \\ P_{Rs} & if \quad R_{SRS} \le r \end{cases} \qquad (1)$$

Where, $P_{PV-Each}$is the power generated by each panel,P_{Rs} is the PV rated solar power, r is the solar radiation factor, R_{CR} is a certain radiation point and $R_{SRS}$is the solar radiation in the standard environment set usually 1000 (W/m^2). The assumption is that PV panels have maximum power point tracking (MPPT). The temperature effect on the PV panels is ignored.[4]

The total power and energy generated by the PV panels at time t are obtained by.

$$P_{PV} = N_{PV} \times P_{PV-Each} \quad (2)$$

B. Battery Bank Modeling

BESS units to be strategically integrated into a microgrid so that it will balance the shortage of power when local renewable resource is not sufficient to operate the PV systems. The output power of PV systems at a particular time and location determines the stateof charge (SOC) of the battery storage.

The battery serves a reliable platform to the system by stores the renewable energy whenever the supply from the PV panels exceeds the load demand and discharges when load demand exceeds the PV generation. So need to optimize properly sized battery bank.[4,9,10,16]

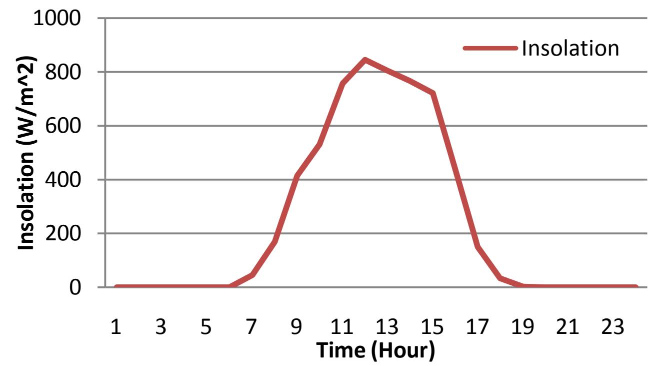

Figure 2. Hourly average solar insolation

The following constraint must be satisfied, when determining the state of charge (SOC) of battery energy storage system.

$$SOC_{min} \le SOC \le SOC_{max}$$

Where, SOC_{min} and SOC_{max} are the minimum and maximum state of charge respectively and these terms are varies as technology changes.

When the total output generation of PV panels is greater than the demand, the battery bank is in charging mode.[4,10,11] The charge quantity of the battery bank at time t can be obtained by following equation,

$$E_{Batt}(t) = E_{Batt}(t-1) \times (1-\sigma) + [E_{pv}(t) - \frac{E_{load}(t)}{n_{inv}}]n_{BC} (3)$$

Where, $E_{Batt}(t)$ *and* $E_{Batt}(t-1)$ is the charge quantity of battery bank at time t and t-1, σ is the hourly self-discharge rate, n_{inv} is the inverter efficiency, E_{load} represents load demand and n_{Batt} is the charge efficiency of battery bank.

When the total output generation of PV panels is less than the demand, the battery bank is in discharging mode. Hence the charge quantity of the battery bank at time t can be obtained by following equation,

$$E_{Batt}(t) = E_{Batt}(t-1) \times (1-\sigma) - [\frac{E_{load}(t)}{n_{inv}} - E_{pv}(t)] \times n_{BF}$$
(4)

When the total output generation of PV panels is equal to the load demand, then the battery bank is discharges with its self-discharge rate only. The charge quantity of the battery bank at time t can be obtained by,

$$E_{Batt}(t) = E_{Batt}(t-1) \times (1-\sigma) \qquad (5)$$

C. Load Model:

The load profile of the site is depicted in Fig.3 which is average of one year.The average daily load is 1.868MWh.

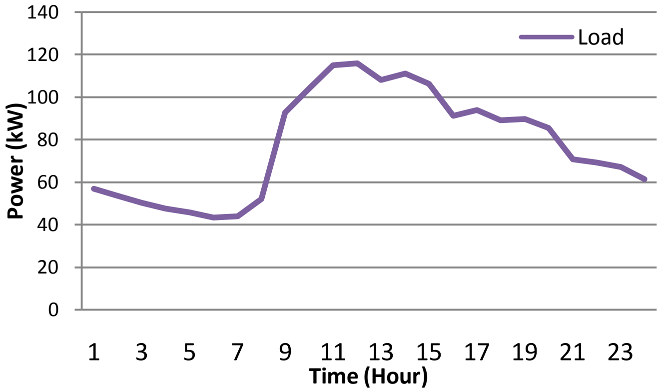

Figure 3 Hourly average load

OBJECTIVE FUNCTION AND CONSTRAINTS

The objective function of the optimum design problem is the minimization of the total annual cost (TAC). The TAC consists of the annual capital cost (C_{Cap}) and the annual maintenance cost (C_{Man}). To optimally design the hybrid generation system, the optimization problem defined by Eq. 7should be solved using an optimization method.

$$Minimize\, TAC = C_{Cap} + C_{Man} \quad (7)$$

Capital cost occurs at the beginning of a project while maintenance cost occurs during the project life.

In order to convert the initial capital cost (P) to the annual capital cost (A), capital recovery factor (CRF), defined by Eq. (8), is used[4].

$$CRF = \frac{A}{P} = \frac{j(1+j)^n}{(1+j)^n - 1} \quad (8)$$

In this equation, n denotes the life span and$n = 20$, $j = 0.06$ is the interest rate of the system.

Some components of PV/battery system need to be replaced several times over the project's lifetime. In this paper, the lifetime of battery is assumed to be 5 years. By using the single payment present worth factor, we have

$$C_{Batt} = P_{Batt} \times \left(1 + \frac{1}{(1+i)^5} + \frac{1}{(1+i)^{10}} + \frac{1}{(1+i)^{15}}\right) \quad (9)$$

Where,C_{Batt} is the present worth of battery, and $P_{Batt}$is the battery price.

In the same way, the lifetime of converter/inverter is assumed to be 20 years. By using the single payment present worth factor, we have

$$C_{Conv/Inv} = P_{Conv/Inv} \quad (10)$$

Where, $C_{Conv/Inv}$ is the present worth of converter/inverter components and $P_{Conv/Inv}$ is the converter/inverter price.

By breaking up the capital cost into the annual costs of the photovoltaic panels, converter/inverter, battery, and backup generator, Eq. (11) is obtained.

$$C_{Cap} = CRF \times [N_{PV} \times C_{PV} + N_{Batt} \times C_{Batt} + N_{Conv/Inv} \times C_{Conv/Inv} + C_{Backup}] \quad (11)$$

In this equation,N_{PV} is the number of photovoltaic panels,$C_{PV}$is the unit cost of photovoltaic panels, which is defined as the sum of panel price (P_{pr}) and panel installationfee (P_{inf}), N_{Batt} is the number of batteries,$N_{Conv/Inv}$ is the number of converter/inverter systems and C_{Backup} is the cost of the backup generator.

For the annual maintenance cost, Eq. (12) is obtained.

$$C_{Man} = [C_{Mnt} \times \textstyle\sum_{t=1}^{24} P_{PV} \times \Delta t] \times 365 \quad (12)$$

In this equation, Δt denotes the time between the samples, and C_{Mnt} is the PV panel's maintenance cost per kW h.

The maintenance costs of inverter, battery bank and diesel generator are ignored.

The total annual cost of the project is,

$$TAC = C_{Cap} + C_{Man} \quad (13)$$

Equality Constraint:

$$\Delta P = P_{Gen} - P_{Dmd} = 0 \quad (14)$$

The difference between the generated power and demand must be minimum. At any time, the charge quantity of battery bank should satisfy the constraint of

$$E_{Batt-min} \le E_{Batt} \le E_{Batt-max} \quad (15)$$

$$E_{Batt-min} = (1 - DOD) \times S_{Batt} \quad (16)$$

Where, $E_{Batt-max}$ is the maximum charge quantity of battery bank, $E_{Batt-min}$is the minimum charge quantity of the battery bank, DOD is the obtained by maximum depth of discharge battery bank, and $S_{Batt}$is the value of nominal capacity of battery bank[4].

Reliability Index:

Loss of power supply probability (LPSP) is defined as the percentage of power supply that is not able to satisfy the load demand. It indicates the reliability of power supply to load. LPSP is given by the ratio of summation of all power supply, LPS(t) at a specific time period (t) over the summation of load demand, $E_{load}(t)$ at the same time period (t).[13] LPSP is defined as:

$$LPSP = \frac{\sum_{t-1}^{N} LPS(t)}{\sum_{t-1}^{N} E_{load}(t)} \quad (17)$$

In which,

$$LPS(t) = E_{load}(t) - E_{sys}(t) \quad (18)$$

Where, $E_{sys}(t)$ is the total energy generated from the system. Meanwhile, if LPSP is equal to 0, it means that the load demand is totally satisfied at a specific time period (t). On the other hand , if LPSP is not equal to 0, it means that the load demand is not totally satisfied. For LPSP between 0 and 1, it means that the supplied power cannot fully recover the load demand because of insufficient solar radiation and the battery storage capacity.[13]

SIZE OPTIMIZATION ALGORITHM

Particle Swarm Optimization

Particle swarm optimization was originally invented by Kennedy and Eberhart in 1995; PSO is a population-based metaheuristic algorithm attempting to discover the global solution of an optimization problem by simulating the animals' social behaviour such as fish schooling, bird flocking, etc. In PSO algorithm, each feasible solution of the problem is called a particle which is specified by a vector containing the problem variables. Particles have memory and thus retain parts of their previous state. There is no restriction for particles to share the same point in belief space, although their individuality is protected. Each particle's movement is the composition of two randomly weighted influences and an initial random velocity: sociality, the tendency to move towards the neighbourhood's best previous position; and individuality, the tendency to return to the particle's best previous location.

The standard PSO algorithm utilizes a real-valued multidimensional space as belief space, and evolves. The particles fly through the n dimensional domain space of the function to be optimized. The state of each particle is represented by its position $x_i = (x_{i1}, x_{i2}, x_{i3}, \dots\dots x_{in})$ and velocity $v_i = (v_{i1}, v_{i2}, \dots . v_{in})$. The states of the particles are updated. The three key parameters to particle swarm optimization algorithm are in the velocity update equation. First is the momentum component, which is the cognitive component. Here the acceleration constant C_1 controls how much the particle heads toward its personal best position. The second component is the inertial constant ω, which controls how much the particle remembers its previous velocity. The third component, referred to as the social component, draws the particle toward swarm's best ever position; the acceleration constant C_2 controls this tendency. At the beginning of the algorithm, a group of particles is randomly initialized in the search space.[14] Each particle makes use of its memory and flies through the search space for obtaining a better position than its current one. In its memory, a particle memorizes the best experience found by itself (P_{best}) as well as the group's best experience (G_{best}).[4] The position of each particle in that space is achieved using the following equations:

$$v_{i+1} = w \cdot v_i + c_1 r_1 (P_{best} - x_i) + c_2 r_2 (G_{best} - x_i) \tag{19}$$

$$x_{i+1} = v_{i+1} + x_i \tag{20}$$

where v_i is the component in dimension d of the i^{th} particle velocity in iteration k, is the component in dimension d of the i^{th}particle position in iteration k, C_1 and C_2 are constant weight factors, P_{best} is the best position achieved so far by particle i, G_{best} is the best position found by the neighbours of particle i, r_1 and r_2 are random factors in between 0 and 1 interval, and w is inertia weight which is started from a positive initial value (w_0) and decreases during the iterations by $w_{k+1} = \beta \times w_k$.(This study consider the $C_1 = C_2 = 2$,$w_0 = 1$, $\beta = 0.99$).

The procedure of standard PSO is described in steps 1to 9:

1. A population is randomly generated in the search space.
2. The initial velocity of each particle is randomly generated.
3. Objective function value for each particle is calculated.
4. The initial position of each particle is selected as its $pbest$, and the best particle among the population is chosen as $gbest$.
5. Particles move to new positions based on Eqs. (19) and (20).
6. If a particle exceeds the allowed range it is replaced by its previous Position.
7. Objective function value for each particle is calculated.
8. $P_{best}$and$G_{best}$are updated.
9. The stopping criterion is checked. If it is satisfied, the algorithm is terminated and G_{best} is selected as the optimal solution. Otherwise, Steps 5 to 8 are repeated.

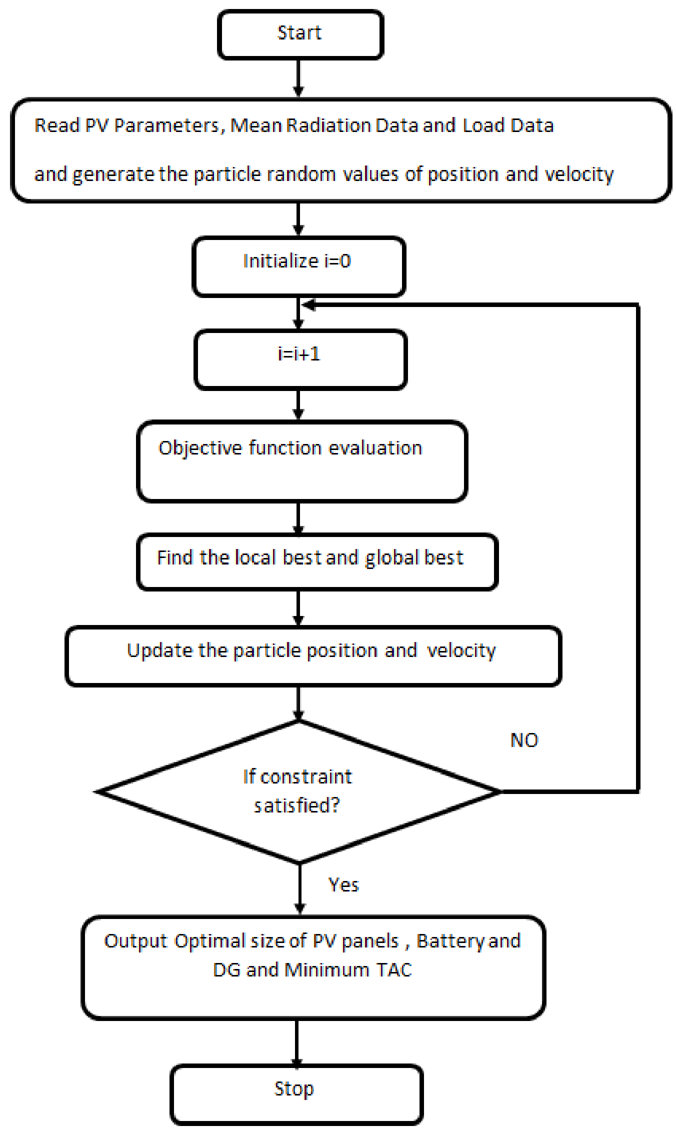

Figure 4 Flowchart of PSO algorithm

Iterative Search Based(ISB) Algorithm

The iterative search based optimization procedure is adopted for selecting the number of PV panels need for an optimal sizing of microgrid components to meet a specific load is as follows,[3]

1. Select commercially available unit size for PV panel and battery storage
2. Increase the number of PV panel until the system becomes balance that is the curve of the ΔP verses time for the system has an average of zero over a given period of time
3. Stop when the reliability criteria meet that is PV generation equal to the load demand
4. Obtain the required storage capacity and number of batteries.

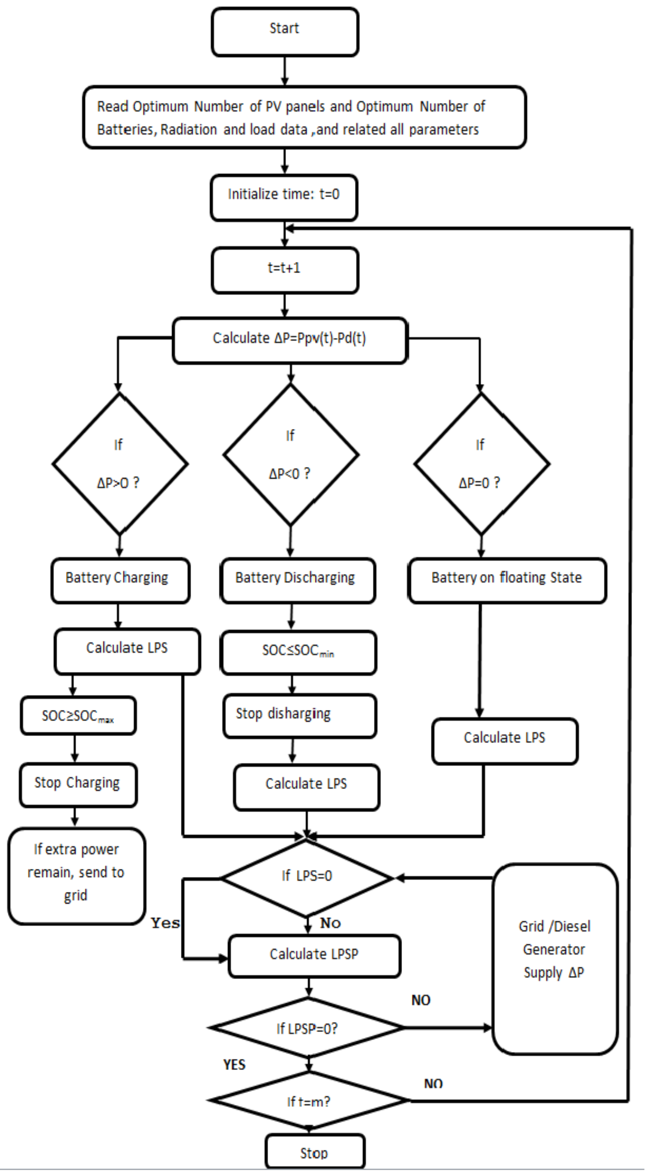

Figure 5 Flowchart of Microgrid operation

Table I. PV, Battery, inverter and other parameters

P_{Rs}	0.315 kW
P_{pr}	227.94 $
P_{inf}	$0.5 \times P_{pr}$
C_{Mnt}	0.005$/kWh
LS_{PV}	20 years
S_{Batt}	2.1 kWh
η_{BC}	95%
η_{BF}	100%
P_{Batt}	357$
LS_{Batt}	5
DOD	0.8
σ	0.0002
Voltage	12V
Inverter Rated Power	30kVA
η_{inv}	80%
P_{inv}/Conv	2894.58$
LS_{inv}	20 years

RESULTS AND DISCUSSION

The optimization techniques has been applied to size a grid connected microgrid components for optimal energy management of an AC load and to meet its requirement and constraints. The hourly data of the solar radiation in the location under study which is illustrated in Figure 2. The average PV power generated is illustrated in Figure 6.

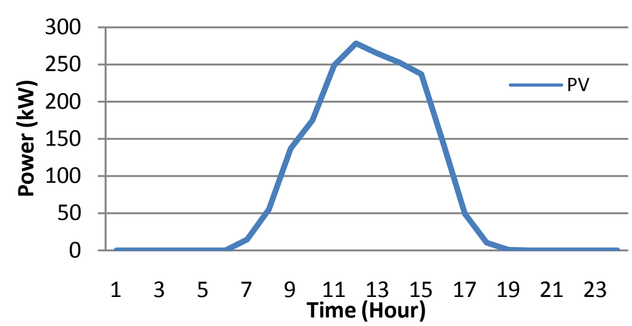

Figure 6 Average PV power output

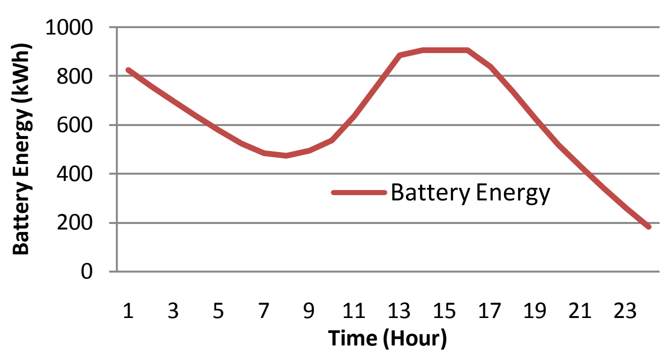

Figure 7 Battery energy output

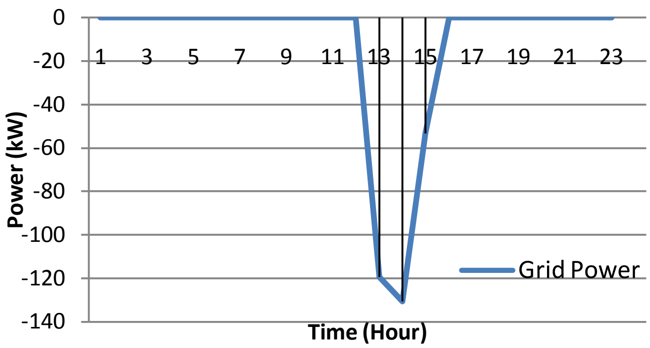

Figure 8 Power export to grid

In the operation, initial state of charge (SOC) of the battery is 100%.The battery will charge and discharge between 20% SOC to 100% SOC. The BESS charging and discharging power curve is illustrated in Figure 7. In Figure 8 excess power is exported to grid by satisfying the load and battery maximum SOC. In this paper, BESS is only charging through the excess generated PV power not via grid.

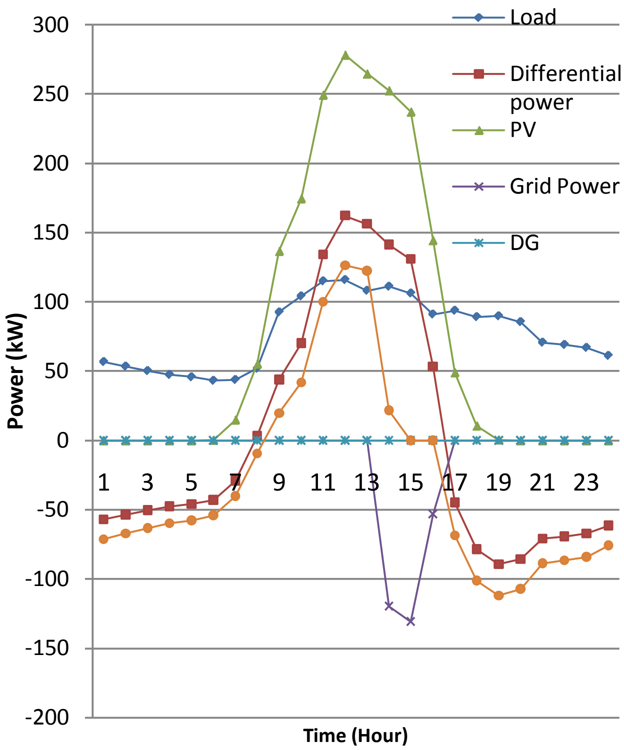

Figure 9 Power flow by Microgrid sources

The Total annual cost of system is obtained by PSO which is illustrated by Figure 10. Table II shows that the obtained simulation results which compare two methods that is PSO and ISB. The results by both the method is same but computational time of PSO is less as compared to ISB.

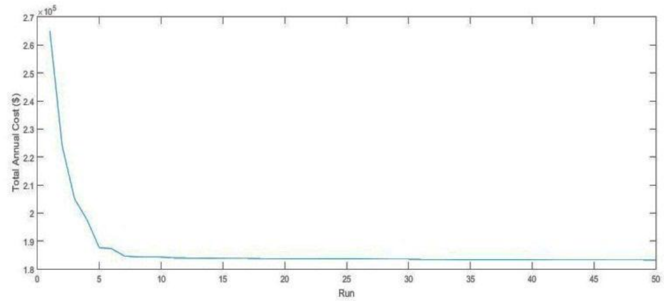

Figure 10 TAC by PSO algorithm

Table II Simulation results

Sr.No	Parameters	PSO	ISB
1	N_{PV}	1045	1045
2	$PV_{Capacity}$	278.26 kW-p	278.26 kW-p
3	N_{BATT}	1724	1724
4	$Battery_{Capacity}$	905.23 kWh	905.23 kWh
5	N_{INV}	10	10
6	N_{DG}	1	1
7	$DG_{Capacity}$	210.6 kVA	210.6 kVA
8	LPSP	0	0
9	TAC	183140$	183140$
10	Computational Time	1.0325 sec	2.389 sec

The obtained results done by programming in MATLAB-15a software. The total average power generated by PV is 1.868 MWh and the BESS capacity is 905.23 kWh.

Conclusion

This paper presents a method to determine optimal sizing of microgrid component by PSO method. The simulation results of the PSO algorithm is verified with Iterative Search Based (ISB) algorithm. It is observed, simulation time of PSO is faster than ISB algorithm. Obtained BESS capacity satisfies the average deficit load. Also, these algorithms can be extended to BESS sizingat remote locations.

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