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Multi-Objective Optimization of Hybrid Power System using Magnetotactic Bacteria Moment Migration Optimization Algorithm

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Abstract: ***Alternative energy sources are more attractive now a day because of the vanishing of conventional sources in the next few decades, energy crisis and environmental effects. Solar PV and wind are the two emerging sources among the existing renewable energy sources. However intermittent nature and system cost are the two main limitations of renewable sources. Therefore hybridization of photovoltaic, wind with battery can overcome this drawback and improves the reliability as well as efficiency to some extent. The objectives considered in this work are to minimize the hybrid system cost and maximize the energy generation from PV and Wind with a new constraint of Grid Dependency Ratio (GDR). A new multi-objective optimization method is suggested in this work to achieve the aforementioned objectives. The proposed algorithm shows the quick convergence, improved accuracy and minimum processing time compared to the Particle Swarm Optimization algorithm.***

Keywords **:** ***Photovoltaic, Wind, Battery, Hybrid Power System, multi-objective optimization, Magnetotactic Bacteria and Particle Swarm Optimization***

I. .INTRODUCTION

India is one of the major economic countries in the world but still starving for electricity demand. India's energy demand is increasing rapidly and generating energy capability has to increase to encounter the present demand, because of economic and population growth [1]. The Indian government has recognized the significance of sustainable energy sources to reserve conventional sources and bring feasible resolutions to decrease the global warming effect.

Wind and solar are the most prominent among the different available sustainable energy sources, because of its complementary nature. But intermittent nature of these sources, reliability of the power system decreases. Thus hybrid power system (HPS) including battery is used to alleviate the variations in energy generation as well as increases the reliability and efficiency. Hybrid power system is generally assembled to design of the system with optimal cost and maximum energy generation at increased reliability.

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Therefore optimization methods are required to design an optimal configuration of HPS [2].

Existed literature indicates that many authors proposed the different optimization methods to design the HPS. Swarnkar et. al [3] utilized the HOMER optimization tool to design the hybrid renewable energy system. Optimal configuration and power management of HPS is highly complex and non-linear optimization problem, therefore an efficient and effective optimization method is required. The optimization strategies dependent on artificial intelligence, population search, and swarm intelligence is extensively applied to determine the optimal configuration of HPS [4]. Adel et.al [5] developed ANN-GA hybrid algorithm to generate the sizing curve of the selected sites in Algeria using LLP. Rajparthiban et. al [6] suggested the ANFIS optimization method to design PV and Wind resources with the reliability constraint of LPSP. The optimization results are better than those results achieved by HOGA and HOMER software's.

The objective of the proposed system is a multiobjective optimization problem with contradictory objectives of reliability and cost. Probabilistic analysis methods are required to compute the reliability, due to variations in solar, wind and load demand. Maheri et.al [7] considered two design scenarios based on cost and reliability to model hybrid system with the help of margin of safety parameter using a robust genetic algorithm. Luo et al. [8] presented GA and comprehended a sequential simulation to obtain the optimal sizing of the storage system for the hybrid system. Same studies have been presented in [9–11].

Masoud et al [12] presented the PSO method for the hybrid renewable system to solve multi-objective optimization problem. Akbar et al. [13] designed an optimal configuration of Wind/PV/FC with the constraint of LPSP using Artificial Bee Colony Optimization technique. Alireza [14] has presented a Discrete Harmony Search Algorithm (DHSA) for the hybrid energy system to achieve the optimal sizing.

Most of the work in the literature is about the sizing of wind/PV/battery hybrid power system for isolated systems. Few studies only are there on grid-connected hybrid systems. In grid-connected hybrid systems, deficit load is procured from the grid, therefore it is always reliable. This work proposes a novel Magnetotactic Bacteria Moment Migration Algorithm for optimal configuration and power management of a considered hybrid power system. The objectives of this algorithm are to decrease the cost and maximize the energy generation from renewable sources with the constraint of GDR.

II. MODELING OF GRID CONNECTED HYBRID POWER SYSTEM

The proposed system consisting of the PV and Wind are the sustainable energy sources. These are the two main sources of energy generation. The integration of these sources is a major challenging issue because of the intermittent characteristics. As a result, it is very important for the proposed system to enhance the reliability and efficiency. Therefore a battery is introduced into the system can increase reliability. Fig.1 shows the considered hybrid renewable power system. Wind and PV are the many energy generation sources to encounter the load. When insufficient energy generated from the main sources, the battery system can supply the energy to the load and battery system will be charged through the excess energy generated by main sources. If the battery SOC limits are minimum or maximum then the grid will inject or absorb the energy.

A. PV panel modeling

The output power produced through the PV source is calculated using the solar irradiance and ambient temperature of the location moreover the panel characteristics itself. The output power of photovoltaic is given by the below equations [15]

$$T_c = T_a + I_s\left(\frac{T_O - 20}{0.8}\right) \quad (1)$$

$$I = I_s(I_{sc} + K_I(T_c - 25)) \quad (2)$$

$$V = V_{oc} - K_V \times T_c \quad (3)$$

$$P_{PV} = N \times FF \times V \times I \quad (4)$$

$$FF = \frac{V_{MPP} I_{MPP}}{V_{OC} I_{SC}} \quad (5)$$

Where T_c=Temperature of cell (°C), T_a=Ambient Temperature (°C), T_O=Operating Temperature (°C), I_S=Solar Insolation, I=solar current (Amps), V=solar voltage (Volts) I_{sc}=SC Current (Amps), V_{oc}=OC Voltage (Volts), K_I=Current Temp. Coefficient (A/ °C), K_V=Voltage Temp. Coefficient (V/°C), FF=Fill Factor.

B. Wind Turbine modeling

The wind kinetic energy can be transforms into electric energy by wind turbine. The power generated from wind turbine based on the wind speed and also the parameters of the power performance curve. The wind output power is determined using the equation (6) [15]

$$P_{WT}(v) = \begin{cases} 0, & 0 < v_a < v_{ci} \\ P_r \frac{(v_a - v_{ci})}{(v_r - v_{ci})}, & v_c \le v_a \le v_r \\ P_r, & v_r \le v_a \le v_{co} \\ 0, & v_{co} \le v_a \end{cases} \quad (6)$$

From the above equation, P_{WT} is the wind power is a function of wind velocity. V_a, V_r, V_{ci} and V_{co} are the average wind velocity, rated wind velocity, cut-in wind velocity and cut-off wind velocity respectively. The Range of 10 to 30 number of wind turbines is considered for optimal size each of 50 kW.

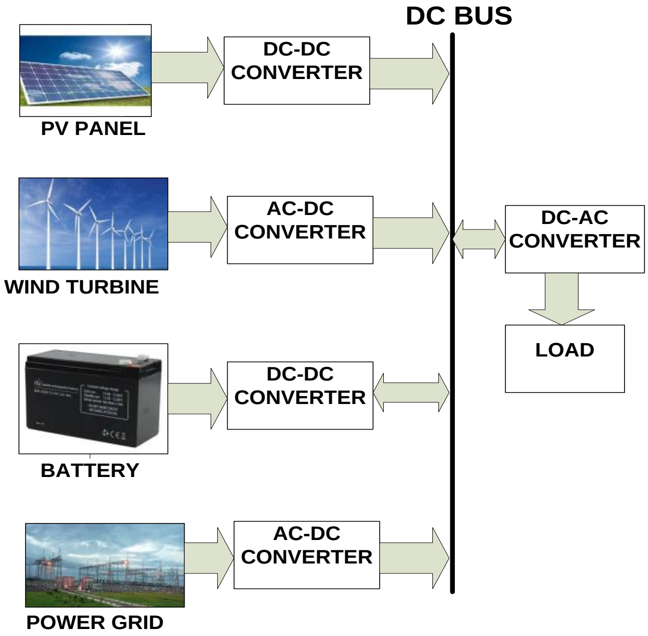

Fig. 1. Hybrid Power System

c. Battery Energy System Modeling

The battery SOC for charging and discharging operations can be determined [16] relies upon the energy generated through the renewable energy sources and load demand by using following equations (7) and (8)

$$SOC(t) = SOC(t-1) + \frac{E_{bat}(t)\eta_{cbat}}{P_{bat}}.100 \quad (7)$$

$$SOC(t) = SOC(t-1) - \frac{E_{bat}(t)\eta_{dbat}}{P_{bat}}.100 \quad (8)$$

Where η_{cbat} is the charging efficiency, η_{dbat} is the discharging efficiency. P_{bat} is battery nominal capacity. SOC (t) is the state of charge at time t and E_{bat} is the power exchange during the time Δt.

Table I system component characteristics

S.No.	Parameter	PV Size(kW)	Wind Size (kW)	Battery Size (kW)
1	Range	[100 1500]	[10 20]	[1 33]
2	Initial Cost	3500 $/kW	181035 $	475 $
3	Maintenance Cost	20($/year)	50($/year)	30($/year)
4	replacement cost	--	1600	140

III. PROBLEM STATEMENT

The proposed objectives of this work are minimization of the cost and maximize the availability of energy generation. The power generated from photovoltaic and wind sources have the main precedence to supply the load, and if the power produced is insufficient, the energy storage system can feed the load. If there is still inadequate power a definite amount of power can be procured from the power grid to supply the demand. Therefore, imported power from the grid has a lowermost priority.

A. System Cost

The total cost of the considered system consists of the cost of PV, wind, and battery system. The total cost of the system ($/year) comprises initial cost and operational & maintenance cost, it is expressed as [17]

Total system cost = C_{wind}+ C_{PV} +$C_{Battery}$+C_{Grid} (9)

$$C_{PV} = \text{PV power cost} = \frac{I_{PV} + OM_{PV}}{N} \quad (10)$$

The initial and O&M cost of PV system, expressed as

$$I_{PV} = L_{PV} \times N_{PV} \quad (11)$$

$$OM_{PV} = OM_{yearly} \times N_{PV} \times \sum_{i=1}^{N} \left(\frac{1+\vartheta}{1+y}\right)^{i} \quad (12)$$

$$C_{wind} = \text{wind power cost} = \frac{I_{wind} + OM_{wind}}{N} \quad (13)$$

The initial and O&M cost of wind turbine system, similarly expressed as

$$I_{wind} = L_{wind} \times N_{wind} \quad (14)$$

$$OM_{wind} = OM_{yearly} \times N_{wind} \times \sum_{i=1}^{N} \left(\frac{1+\vartheta}{1+y}\right)^{i} \quad (15)$$

$$C_{Battery} = \text{battery power cost} = \frac{I_{Battery} + OM_{Battery}}{N} \quad (16)$$

The battery bank initial cost and O&M cost expressed as

$$I_{Battery} = L_{Battery} \times P_{CB} \quad (17)$$

$$OM_{Bttery} = OM_{yearly\_Batt} \times P_{yaerly\_Batt} \times \sum_{i=1}^{T_b} \left(\frac{1+\vartheta}{1+b}\right)^{(i-1)N_{Batt}} \quad (18)$$

The objective function of cost minimization can be expressed as

$$\underset{cost}{Minimize}(N_{PV}, N_{wind}, P_{CB}, \rho) \quad (19)$$

The power imported cost from the power grid, expressed as

$$Cost_{grid} = \sum_{i=1}^{T} P_{grid,t} \times L_{grid} \quad (20)$$

B. Energy Availability

The total power produced by the both renewable energy sources is given by [22] following equation no. (21)

$$P_{RES}(t) = P_{PV}(t) + P_{wind}(t)$$

Where

$$P_{wind} = P_{WT} \times N_{wind} \times \eta_{wind} \quad (22)$$

$$P_{PV} = I_S \times N_{PV} \times \eta_{PV} \quad (23)$$

The battery system supplies the energy to load when insufficient energy generated through the main sources and excess energy generated by main sources will be charge the battery. If the battery SOC limits are minimum or maximum then the grid will inject or absorb the energy.

$$P_{Execess}(t) = P_{RES}(t) - P_D(t) \quad (24)$$

In equation (24), P_{Excess} is the excess power generated through the renewable sources is used to charge up to battery reaches maximum SOC.

$$P_{Surplus}(t) = P_{Excess}(t) - P_{Batt}(t) \quad (25)$$

In equation (25), $P_{surplus}$ is the power injected to the grid and P_{Batt} is the battery power required to reach SOC_{max} specified in equation (7).

The power imported from the power grid, calculated using equation (26)

$$P_{PG}(t) = P_D(t) - P_{Batt}(t) \quad (26)$$

Where $P_D(t)$ is the power demand, P_{PG} is the purchased power from the grid and P_{Batt} is the battery power supplied to the load before SOC_{min} is reached is specified in equation (8)

The hybrid power system in this work is completely reliable for any size of system constituents because it is grid-connected. But, the optimum size of the proposed system includes the constraint of grid energy utilization by the demand. Grid Dependency Ratio (GDR) is a new constraint proposed in this system. The GDR is defined as the ratio of the system requires procuring energy from the grid when the hybrid system is incapable to feed the load demand.

The GDR can be determined, using equation (27)

$$GDR(\rho) = \frac{\sum_{i=1}^{T} P_{PG}(t)}{\sum_{i=1}^{T} P_{D}(t)} \quad (27)$$

Energy Availability is the energy is available from PV and Wind for the fraction of time. It can be expressed for the duration of T as [17]

$$E_A = 1 - \rho \quad (28)$$

$$P_{PG}(t) = \rho \times (P_D(t) - P_{RES}(t) - P_{Batt}(t)) \quad (29)$$

The maximization of energy availability objective function can be expressed as

$$\underset{Availability}{Maximize}(N_{PV}, N_{wind}, P_{CB}, \rho) \quad (30)$$

C. Constraints

The design constraints of the optimization algorithm are:

N_{wind} , N_{PV}, P_{bc} and ρ

$N_{windmin} < N_{wind} < N_{windmax}$ (31)

$N_{PVmin,} < N_{PV} < N_{PVmax}$ (32)

$P_{bcmin} < P_{bc} < P_{bcmax}$ (33)

$0 < \rho < 1$ (34)

The total power generated must not go beyond the load demand to avoid the hybrid power system oversize and adding excessive cost. It is expressed as:

$$P_{PV}(t) + P_{wind}(t) + P_{Batt}(t) + P_{grid}(t) \leq P_D(t) \quad (35)$$

IV. MAGNETOTACTIC BACTERIA MOMENT MIGRATION ALGORITHM

(21)

A novel optimization algorithm called Magnetotactic Bacteria Moment Migration Algorithm (MBMMA) is suggested in this work [18]. MBMMA is motivated by Magnetotactic bacteria (MTB) is a sort of polyphyletic set of prokaryotes through the features of magnetotaxis which causes them to orientate and move along the fields of geomagnetic lines. In this algorithm, the magnetosomes moments are considered as solutions.

The moments of qualified better solutions migrate each other to expand the diversity.

The basic operators and the important steps of MBMMA are described in the following. MBMMA primarily has three main operators together with moment generation, moment migration, and moment replacement.

Initialize population. The initial population includes a randomly generated N number of -dimensional real vectors. The initial population will generate as follows:

$$x_{ij}^{0} = x_{\min j} + rand(0,1) \times (x_{\max j} - x_{\min j}) \quad (36)$$

Let $X_i^0 = (x_{i1}^0, x_{i2}^0, \ldots, x_{in}^0)$ signifies the randomly initialized i_{th} cell.

Where, i=1, 2,…N and j=1, 2,…n. $x_{\max j}$ and $x_{\min j}$ are upper and lower limits for the dimension j, respectively.

Interaction distance calculation. In this algorithm, each solution is a cell comprising a magnetosome chain. Interaction distance is used to calculate the interaction energy for generating the magnetosomes. The distance of two cells X_i and X_r, $D_i^t = (d_{i1}^t, \ldots, d_{in}^t)$ is calculated as follows:

$$D_i^t = X_i^t - X_r^t \quad (37)$$

Thus, we can get Nxn distance matrix

$$D^t = (D_1^t, D_2^t, \cdots D_i^t, \ldots D_N^t)' = \begin{bmatrix} d_{11}^t\ d_{12}^t \cdots d_{1n}^t \\ d_{21}^t\ d_{22}^t \cdots d_{2n}^t \\ \vdots \quad \vdots \quad \cdots \quad \vdots \\ d_{N1}^t\ d_{N2}^t \cdots d_{Nn}^t \end{bmatrix} \quad (38)$$

Where i and r represents different integers from {1, 2, . . . ,N}, and r is randomly selected. N is the population size.

MTSs Generation.

The interaction energy $E_i^t = (e_{i1}^t, \ldots, e_{in}^t)$ between two cells depends on the distances among cells, is defined as

$$e_{ij}^t = \left(\frac{d_{ij}^t}{1 + c_1 \times norm(D_i^t) + c_2 \times d_{pq}^t}\right)^3 \quad (39)$$

Where, norm (D_i^t) is the Euclidean length of vector D_i^t. d_{pq}^t is randomly chosen from D_p^t. p is randomly selected integer from{1,2. . .,N}.q is random integer index from{1,2. . .,n}.

The moments $M_i^t = (m_{i1}^t, \ldots, m_{in}^t)$ are generated rendering to (40) after attaining interaction energy. B represents the magnetic field of the magnetosome.

$$M_i^t = \frac{E_i^t}{B} \quad (40)$$

moment vector matrix can be obtained as

$$M^t = (M_1^t, M_2^t, \cdots M_i^t, \ldots M_N^t)' = \begin{bmatrix} m_{11}^t\ m_{12}^t \cdots m_{1n}^t \\ m_{21}^t\ m_{22}^t \cdots m_{2n}^t \\ \vdots \quad \vdots \quad \cdots \quad \vdots \\ m_{N1}^t\ m_{N2}^t \cdots m_{Nn}^t \end{bmatrix} \quad (41)$$

Total moments of a cell then regulated as :

$$\vartheta_{ij}^t = x_{ij}^t + m_{ls}^t \times rand \quad (42)$$

Where m_{ls}^t is randomly selected from M_l^t . l is randomly selected integer index from{1,2,...,i}. s ∈ {1,2,...,n}.

MTSs Regulation. After MTSs generation assess the population rendering to cells fitness, then the moments are regulated as:

If rand > mp

$$u_{ij}^t = \vartheta_{rIj}^t \quad (43)$$

Otherwise

$$u_{ij}^t = \vartheta_{iqI}^t + (\vartheta_{cbestqI}^t - \vartheta_{iqI}^t) \times rand \quad (44)$$

MTSs replacement. Evaluate the population according to cells' fitness after the moments migration. Few cells with worse moments are substituted rendering to (44) with the probability 0.5.

$$X_t^{i+1} = m_{l's'}^t \times ((rand(1,n) - 1) \times rand(1,n)) \quad (45)$$

Then the moments of remained cells are replaced by using:

$$X_t^{i+1} = u_{ij}^t \quad (46)$$

V. RESULTS AND DISCUSSION

A. Case study description

In this work, MBMMA is suggested to design a PV/wind/battery grid-connected hybrid power system for a selected location of Hyderabad is considered as a case study.

B. Load Profile

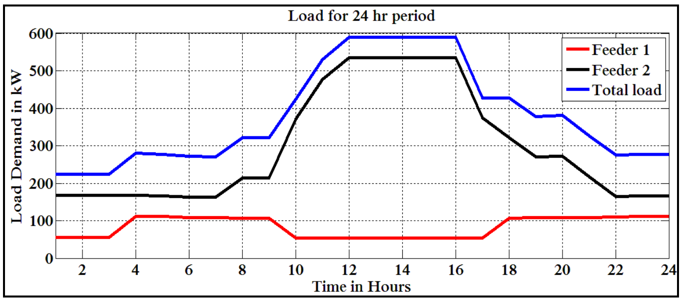

Fig.2. Daily Load Profile

The daily load curve of the considered case study is shown in figure 2. From the load data, daily average energy consumption is 3300 kWh/day. Peak load demand is 600 kW. Two feeders each 11 kV rating from distribution substation are feeding selected site buildings.

C. Resources of Solar and Wind

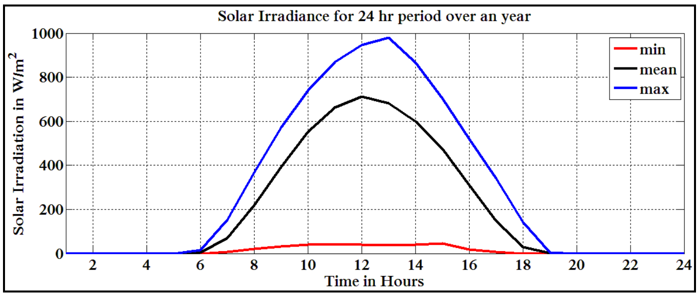

Fig. 3. Solar Irradiation

The selected site is placed at latitude of 17.3850^0 N, longitude of 78.4867^0 E, and an altitude of around 500 m.

The selected place is sanctified with 5.35 kWh/m^2 annual average daily solar radiations and the average speed of wind in a year is 4.54 m/s. The solar and wind data can be found from the NASA database [19].

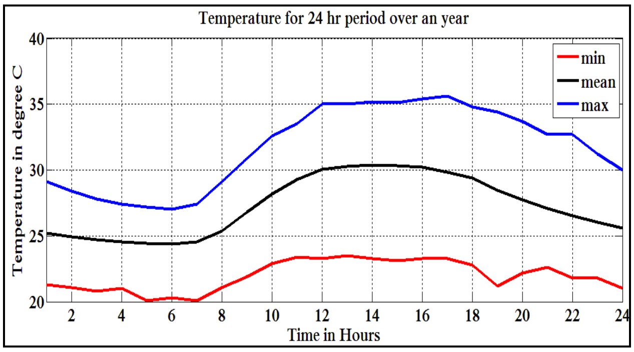

Fig. 4. Temperature

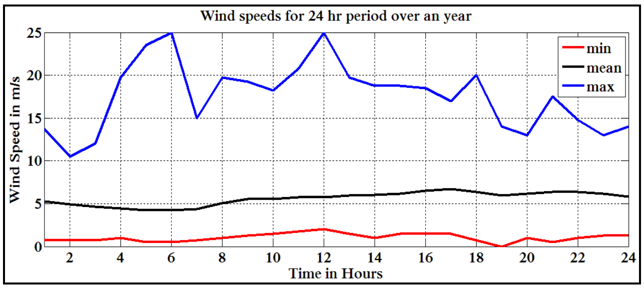

Fig. 5. Wind Speed

The suggested algorithm is implemented in MATLAB to design an optimal configuration and power management of PV/Wind/Battery grid integrated hybrid system for a selected location and compared with the Particle Swarm Optimization (PSO). The input data for simulation consists of annual hourly information of solar radiation, temperature, and wind speed and load data as shown in fig 2 to fig 5. The power produced from each source shown in figures 8 to 11. Table 2 shows the parameters of MBMMA and PSO algorithm and table 3 shows the parameters used to run the simulation. The MBMMA algorithm attempts to decide the optimal size of PV, wind, and battery of the proposed hybrid system to minimalize the total system cost and the GDR at the same time. Simulation results of optimization under MBMMA algorithm are compared with the PSO and comparison of results shown in table 4 and table 5.

Table 2: Algorithm parameters

S.No.	MBMMA	PSO
1.	Maximum Iteration = 1000	Maximum Iteration = 1000
2.	Population = 30	Population = 30
3.	C_1=20, C_2=0.003	C_1=2.5
4.	MP=0.6	C_2=1.5
5.	Magnetic Field Constant B=1	Inertia Weight W=0.3

Table 3: Simulation parameters

S. No	Parameter	Value
1	Life Cycle (N)	20 years
2	Battery Life Cycle	5 years
3	Inflation Rate β	0.08
4	Interest Rate γ	0.12
5	Escalation rate	0.12
6	Cost per unit grid power (1 kWh)	0.11$

Table 4: Optimal configuration of the proposed HPS using MBMMA

	PSO	MBMMA
No. of Solar Panels	2135	2015
No. of Wind Turbines	26	24
No. of Batteries	34	32

Table 5: Comparison of proposed hybrid power system optimization results

Size & Cost	PSO	MBMMA
PV(kW)	694	655
WT(kW)	642	594
Battery	79.9	71
Grid(kWh)	509410	503580
Total Cost($)	776609.67	727817.12
COE($/kWh)	0.10	0.095

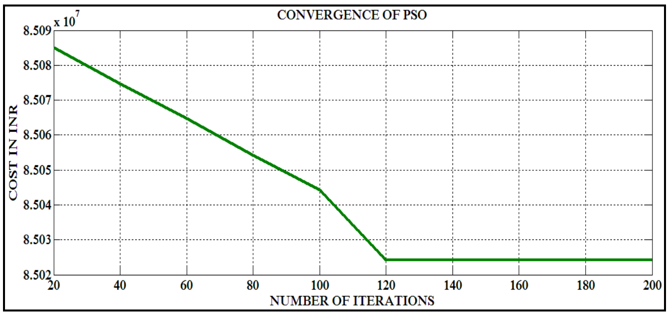

Fig. 6 Convergence of PSO

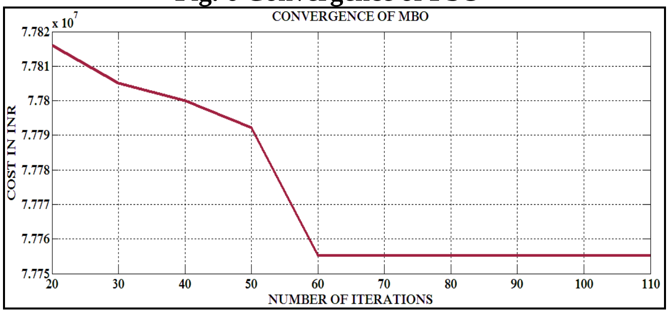

Fig.7 Convergence of MBMMA

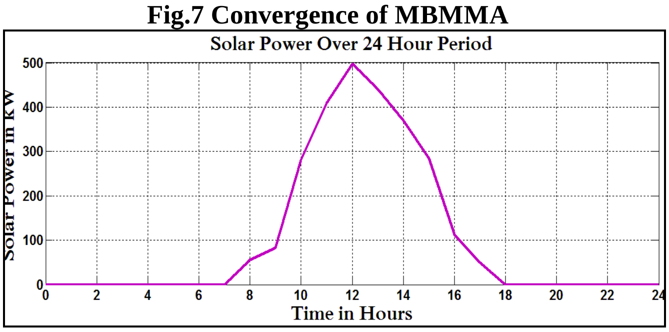

Figure 8 Solar Power output

Convergence characteristics of MBMMA are compared with the PSO and are shown in fig 6. & fig.7. The result shows the quick convergence of MBMMA compared to PSO. The MBMMA algorithm converges to the optimum value at the iteration of 60 but the PSO requires 120 iterations to converge.

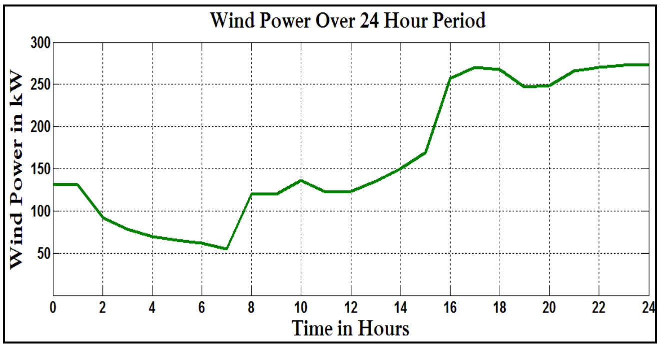

Figure 9 Wind Power Output

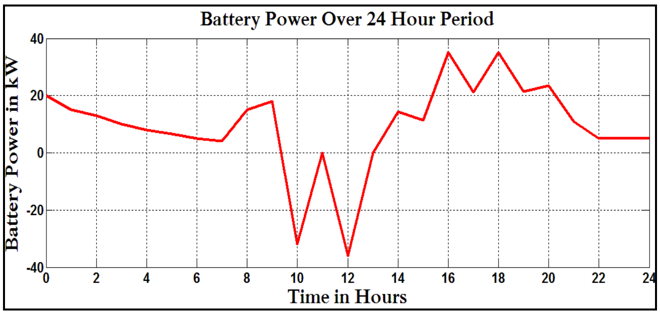

Figure 10 Battery Power

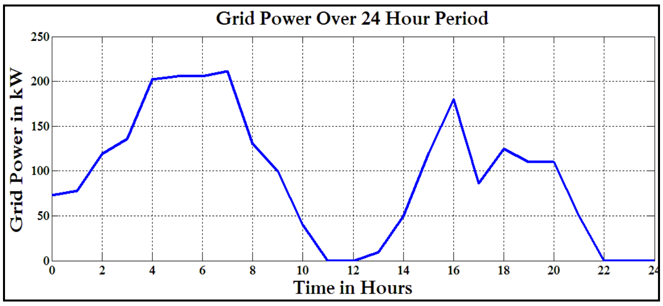

Figure 11 Grid Power

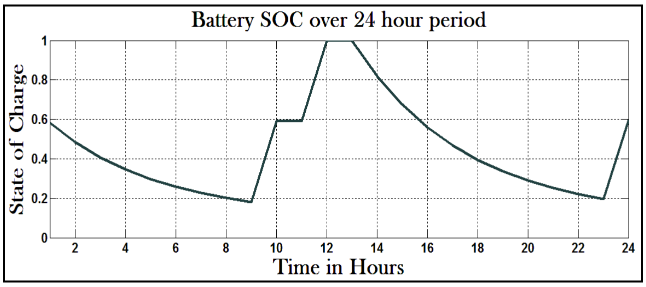

Figure 12 Battery SOC

VI. CONCLUSION

A new optimization method of Magnetotactic Bacteria Moment Migration Algorithm (MBMMA) is used in this work to obtain the optimal configuration and power management of the proposed system. The primary contribution in this work is the minimization of cost and maximization of energy with the new constraint of GDR is achieved by using MBMMA technique. This optimization method relies upon the utilization of long term information of the solar irradiation, wind speed, and load profile of the selected location. From the optimization results, it observes that MBMMA converges to the optimal solution quicker than PSO and it is more accurate in identifying the optimal system size.

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