Hybrid Energy Scheduling in a Renewable Micro Grid

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***Abstract*: *In the present days, the society has been facing a lot of challenges in the energy scenario, as their dependency increases in that crisis that is to be given greater concern. As fossil fuels are turned out to be too expensive or it may be phased out, in spite of large investments, researchers suggest the renewable energy sources as a supplement for this issue. A microgrid which connects the generation units with the electrical power network and also the utility area results in the efficient utilization. The efficiency and flexibility of the power system can be optimized by installing microgrid. It combines the sources of heat and power (CHP) with renewable energy which includes wind and photovoltaic power that implies a reliable and controllable power supply. As power storage equipment's and electric vehicles (EV) enhances the bidirectional power flow, the optimization of scheduling is needed for the EV and demand side management (DSM).In this work, with the CHP microgrid, an optimal scheduling model of the network is proposed with EV and DSM.The minimum operation cost is considered as an objective function and the optimization variable is the output of each source. A simulation study which improves the capability global search using hybrid Artificial Immune algorithm is put forward for higher feasibility*.**

I. INTRODUCTION

For the optimum scheduling of the operation, various researches have been encountered with different objectives and the load conditions. In the work [1], intelligent energy management system (IEMS) was suggested which identifies the optimal set points in storage systems, combined heat and power and renewable units. In the paper [2], CLS (chaotic local search) based hybrid PSO algorithm with configuration of fuzzy self-adaptive was recommended for the optimization of scheduling. In the work [3] and [4], a distributed energy resources customer adoption model in first and the later used a dispatch model for the cost reduction. In [5] and [6], an optimum management of energy in microgrid was carried on EV in first and the later recommends the scheduling of uncertain departure times of EV's.From [7, 8] DSM was recommended to equate the power and demand. Following [9], [10] the DSM is utilized to elevate the constraints and reserve operation is suggested. With [11, 12], particle swarm optimization (PSO) is made use of to optimize scheduling in the demand and generation part.

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In this paper a multi-dimensional network is revised with Monte Carlo simulation with Artificial Immune System (AIS). With all the results of the prescribed works, a case study is done in this paper to establish the performance of Hybrid AIS over AIS in optimum scheduling in micro grids.

II. MODELING OF THERMAL SYSTEM

Power load and heat load are the two models operated in the micro gas turbine (MT) CHP.power model offers higher concern to the demand of power load while the heat model prefers for the demand of heat load. If there are any occurrences of changes in load, the MT concerns strongly to the changes in the operation with the power load model. The below equation shows the mathematical model of this combination of MT and CHP.

$$\begin{cases} R_{MT}(u) = Q_e(u)\left(1-\eta_e(u)\right) - \eta_1/\eta_e(u) \\ R_{he}(u) = R_{MT}(u)L_{he} \\ W_{MT} = \sum(Q_e(u)\Delta u/\eta_e(u)M) \end{cases} \quad (1)$$

Where the parameters are explained as η_1=loss coefficient of heat of gas turbine, $R_{MT}(u)$is the exhausted heat in time u, $\eta_e(u)$ is the efficiency of the power generation of turbine at u time. $Q_e(u)$=power output in time$u$, $R_{he}(u)$ denotes the capacity of heat in time$u$, L_{he}=coefficient of heat exchanger, W_{MT}=weight of natural gas utilization, finally Δu and M specifies the running period and colorific value of the gas taken as 9.7 kWh/m^3.

Depending upon the size of the thermal load $Q_{heat-load}$ and the boiler's thermal efficiency η_{boiler} ,the gas turbine consumes the gas .In the economical point of view, the thermal efficiency is the major factor in design consideration and boiler operation .This decides the technology enhancement in boiler operation. Considering the η_{boiler} as 0.88 and M as the gas calorific term, the W_{boiler} can be computed with the following equation

$$W_{boiler} = \frac{Q_{heat-load}}{\eta_{boiler} \cdot M} \quad (2)$$

A. *Modeling of renewable generation*

Solar energy generation depends on the illumination level of the light radiation from the sun. The photovoltaic panel absorbs the ray of light as photons and it is converted into electrical energy in terms of electrons. It consists of array of PV panels and attract the photons. The output of the PV array is of DC current which is fed to the DC to DC converters for enhancing the DC level and further it is converted to AC current using inverters. The output of the silicon PV module depends on the material type, temperature and the radiation imposed on the PV plane. It is related by the following equation.

$$P_{PV} = P_{STC}\left[1 + k\left(T_c - T_{ref}\right)\right]G_T/G_{STC} \qquad (3)$$

Where $P_{PV}$the output power of panel is, P_{STC} is the test power in standard conditions (considering the temperature T_{ref} as 25°C and G_{STC} with 1000W/m^2 as intensity of light and $-0.47\%/K$ as temperature coefficient of power).Tc is termed as solar panel temperature.

$$T_C = T_a + \frac{(NOCT-20)}{0.8}G \qquad (4)$$

T_a Denotes the ambient temperature and G is the light absorbed in the plane, $NOCT$ defines the operating temperature. Similarly, the wind power depends on the speed of the wind and it may vary with the environmental conditions related to air. An aerodynamic machine converts the kinetic energy of the wind into electrical energy that mainly depends on parameters like turbine blade area, speed of the wind and density of air. The relation can be expressed as

$$P_w(v) = \begin{cases} 0 & 0 \le v \le v_{ci} \\ P_{rated} \times \dfrac{(v^3 - v_{ci}^3)}{(v_r^3 - v_{ci}^3)} & v_{ci} \le v \le v_r \\ P_{rated} v_r \le v \le v_{co} & \end{cases} \qquad (5)$$

Whereas $v_{ci}$and v_{co} is the cut-in and cut-off speed and rated speed as v_r.

B. Modeling of storage battery

The battery is a device that is used to store the energy in any network. The bidirectional power flow and faster response to the variations has been utilized for frequency alteration and the real time balance can be achieved. The power quality has been improved resulting in stable operation of the micro grid. In this study, lead acid battery is applied for energy storing. The charging state of the battery is a major parameter to indicate the balance power The SOC value at time t and t + Δt is related and the charging, discharging can be expressed as

$$S_{t+\Delta t} = S_t + \frac{P_{bat}-t^{\Delta t}}{C_{bat}} \qquad (6)$$

In which SOC is defined using the values of S_t in t and$t + \Delta t$. $P_{bat} - t$ Is the power of the device, and C_{bat} is the capacity of accumulator. The time lost cost is also to be considered. The effects on duration may vary according to the charging and discharging depths. Considering the battery loss of duration, charging and discharging can be equated as:

$$C_{storage} = \frac{C_{init}}{N} \qquad (7)$$

$$N = a_1 e^{a_2 D_N} + a_3 e^{a_4 D_4} \qquad (8)$$

The equation 8 relates cycle time and discharge depth. N is the cycle number, D_N is the depth of the discharge, where, a_1, a_2, a_3, and a_4 are coefficient factors of correlation with values −16.27, 2.679, 4110 and −1.85.

C. Modeling of Electric Vehicle

Relating to the conventional vehicles, electric vehicles hold greater advantages in conservation of energy, environmental prospects and minimizing the usage of fossil fuels to the mankind. It persists the power and load characteristics with a battery connected to the grid. The energy manager assigns the scheduling of demand management using EV's in the grid. The periodic charging cycle can be explained with a relation

$$CC_{Ey} = M \times ec / M_d \qquad (9)$$

CC_{EV} is the cycle of charge, M and M_d gives the mileage and daily mileage of the EV and ec prescribes the coefficient of efficiency? Similar to the conventional batteries, charging and discharging characteristics are assumed.

D. Modeling of Response in Load Demand

On dynamic pricing, the demand side resource has been covered by the load demand management from the load control side to responsive demand. In the recent investigations and advancements in smart grid, the demand management plays a major role in the technology feasibility and economic factors.

In this work, the tariff of electricity is considered in the demand end with time of use (TOU). With the different measures of power demand management, a "cross elasticity of demand "is initiated in the power load that is transferable. The model of the load can be expressed as

$$d(i) = \left\{ d_0(i) + \sum_{i=0}^{23} E_0(i,j) \times \frac{d_0(i)}{p_0(i)} \times [p(j) - P_0(j)] + A(j) \right\} \times \left\{ 1 + \frac{E(i) \times [p(i) - p_0(i) + A(i)]}{p_0(i)} \right\} \qquad (10)$$

Where $i = 0, 1, 2, .. 23$ refers the 24 hours in a day, $d(i)$ is the user power demand and $P(j)$is the price of the power $A(i)$ is allowances as incentive and $E(i)$defines cross price elasticity.

III. MODELING OF OPTIMAL SCHEDULING

In the modeling of optimum scheduling, the objective functions and the limitations or constraints were explained with the parameters and equations relating each of them.

A. *Objective Functions*

The operation cost of the hybrid system in CHP comprises of turbine and fuel cost, initial power acquiring cost and the duration loss cost of charging and discharging in storage batteries. During the erection of wind and solar plants, it creates an impact on the running output. The maintenance and operating costs have included in the objective function designed as:

$$C = \min\left(C_{gs} + C_{ep} + C_{om} + C_{so}\right) \qquad (11)$$

C defines the overall operating cost, C_{ep} and C_{gs} are the purchasing cost of gas and electricity C_{om} and C_{so} illustrates the costs of operating and maintenance of generator and storage cost for EV's. The electricity acquiring charge can be

$$C_{ep} = \sum_1^H \left(C_{ec}^t P_{grid}^t \Delta t\right) \qquad (12)$$

Here, H is the dispatch cycle time number, P_{grid}^t is the quantity of purchased power from grid with respect to time. This will be a negative parameter if the supply is transferred from system to grid. C_{ec}^t describes the price of power at t time. The cost of gas is:

$$C_{gs} = C_{gs} \sum_1^H \left(W_{MT}^t + W_{boiler}^t\right) \qquad (13)$$

$$C_{om} = C_m \frac{\gamma(1+\gamma)^m}{(1+\gamma)^{m-1}} - C_s \frac{\gamma}{(1+\gamma)^{m-1}} + C_{op} \qquad (14)$$

$$C_{SO} = C_{storage} + C_{ev} \qquad (15)$$

C_m is the overall preliminary investment in generators, C_{ss} is cost on sunk, C_{op} is the operating cost, finally $C_{storage}$ and C_{ev} is the battery storage and EV cost that can be intended from equation 7

B. *Constraints*

(a) The constraints of electric power balance:

The constraints for balancing electric power are framed as per the rule the power demand should be satisfied from the power generation. In considering all the power from the generating side to delivery (load) side, the relationship has illustrated.

$$P_D(t) = P_G(t) + P_{st}(t) + P_{EV}(t) + P_{Grid}(t) \qquad (16)$$

All the power constraints are taken with respect to time period $P_D(t)$ is the total load demand in the grid, $P_G(t)$ gives the power from the renewable sources like wind, PV arrays (solar cells) and gas turbines. $P_{st}(t)$ and $P_{EV}(t)$ are the storage battery and EV charging and discharging powers at time t. $P_{Grid}(t)$ is the power output or consumption to the micro grid with respect to time t.

b) Constraints of Distributed generation:

The generator constraints are given with the following equation

$$P_{Gi,min} \le P_{Gi}(t) \le P_{Gi,max} \qquad (17)$$

The constraints of ramping can be scheduled as

$$-R_i^{down} \le P_{Gi}(t) - P_{Gi}(t-1) \le R_i^{up} \qquad (18)$$

The time constraints to staff off is given by

$$\begin{cases} P_{ch}(t) \le P_{ch,max} \\ P_{dis}(t) \le P_{dis,max} \end{cases} \qquad (19)$$

$P_{Gi}(t)$ is the power output of generator I in t time. $P_{Gi,min}$, $P_{Gi,max}$ are the minimum and maximum output power of generator I, similarly R_i^{down}, R_i^{up} defines the speeds of the generator i, when ramping up and down.

Constraints of Storage battery:

Constraints on Capacity:

$$E_{st,min} \le E_{st}(t) \le E_{st,max} \qquad (20)$$

Constraints on power:

$$\begin{cases} P_{ch}(t) \le P_{ch,max} \\ P_{dis}(t) \le P_{dis,max} \end{cases} \qquad (21)$$

$E_{st,max}$, $E_{st,min}$ are the upper capacity and lower capacity of the storage battery $P_{ch}(t)$, $P_{dis}(t)$ are the charging power and discharging power of the battery and $P_{dis,max}$ and $P_{ch,max}$ are the maximum and minimum limits of the same.

Constraints of Thermal energy:

The power balance on thermal system can be illustrated in

$$Q_{bl}(t) + Q_{MT}(t) = Q_D(t) \qquad (22)$$

$Q_D(t)$ defines the demand of load in time t and $Q_{bl}(t)$ and $Q_{MT}(t)$ are the heat rate output of gas boiler and turbine in grid.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The above given expressions are implemented in MATLAB software using HAIS algorithm and the results are verified. In order to do that a case study is prepared and it is described below.

A. *Case study*

A micro grid that consists of a mini factory, vegetable market and residential area in Coimbatore district, India is taken for this case study. The components of the micro grid are stated below:

- Electric loads.
- Thermal loads.
- Micro gas turbine.
- Storage battery.
- Polycrystalline silicon PV array.
- Micro wind turbine.
- Gas boiler.

Table- I: The values of the components of the micro grid

COMPONENTS	VALUES
Electrical loads	265 kW
Thermal loads	313 kW
Micro gas turbine	C65
Storage battery	12-V/200-Ah
Electron vehicles (EVs)	20
Polycrystalline silicon PV array	100km
Gas boiler	300kw

The distance per charge of the EVs is 252Km and its efficiency coefficient is 0.67. The minimum distance travelled per day is 25km. The EVs charges for every 7 days. The gas boiler balances the thermal loads that is not met by the grid.

The operating cost of the grid is very much smaller when compared to the original investment. This case study mainly focuses upon the operational cost difference between the five operating modes.

B. *Mode1(Separate supplies for Electrical and thermal power)*

The micro grid system in this mode supplies the residual and the gas boiler supplies the heat load separately. Supply loads are given higher priority by the wind and solar power. The estimated operational cost of this system per day is 3200RS. The system's power consumption is 1732 kWh and PV power generation of 722 KWh. The wind capacity of the system is 1788 KWh. The system consumes a power of 1732 KWh. The cost of this system is 1700RS. The volume of gas purchased is 500 m^3 and this costs 1501RS. Table1 given below gives the optimal output of mode1.

C. *Mode2(Hybrid Energy Supply, excluding Storage, EVs and DSM)*

The micro gas turbine and the gas boiler simultaneously provides the required heat load for the system and the power load that the system requires is provided by the wind and solar power. In Mode2, Operational cost per day is 2835RS. At a cost of 176 RS, the electricity purchased from the system will be 142 KWh and for a cost of 2660RS, the purchased natural gas is 1064m^3.

D. *Mode3(Hybrid energy supply with storage batteries, excluding EVs and demand response)*

The heat load supply of Mode3 is similar to that of Mode2 also, the power load to the system is supplied by wind and solar power. The energy storage and power grids provide the residual in Mode3.The operational cost per day is 2672RS. The electricity purchased is 15 KWh from the micro grid that cost 18RS. 2527Rs is used for purchasing 1012 m^3 volume of gas which cost 2526RS. 126RS is spent for the charging and discharging of the battery.

E. *Mode4(Hybrid energy supply with storage batteries and EVs, excluding demand response)*

Mode4 has the same heat load as that of Mode2. Also, the power load is provided by wind and solar power in Mode3. The energy storage, EVs and power grid system provides the residual. The electricity purchased from the micro grid is excluded and the operational cost per day 2672RS. At a cost of 2625m^3, a gas volume of 1008 is purchased. The charging and discharging of the battery cost 126RS. EV is charged and discharged at a cost of 26RS. The total load of the system is increased due to the connection of electric vehicles and the micro grid which in turn leads to a rise in operational cost of the system. Hence the operational cost of Mode4 is higher than that of Mode3.

F. *Mode5(Hybrid energy supply including all factors)*

In mode5, the heat load supplied to the system is similar to that of Mode2. The power load to the grid is provided by the wind and solar power, whereas the energy storage, EVs and the power grid provides the residual. the operational cost per day is 2624Rs. The charging and discharging cost of EV and the battery is 26Rs and 126Rs respectively. The electricity purchased for the system is excluded. As a result of adopting DSM, the operational cost of the system is lowered and the load of the system is transferred slightly. Table-2 shows the output of the system. From the table it can be seen that, in the grid system the mode of operation and the cost of operation does not depend upon each other in which the construction of wind turbine and PV array is also taken into account.

Table- II: Output of mode1

	P_{wt}	P_{pv}	P_{gt1}	P_{gs2}	P_{st}	P_{ev}	P_{gd}	$Price_{In}$	$Price_{Out}$	P_{load}
1	71.4	0	62.8	62.8	−20	−15	0	0.4	0.36	130.3
2	71.5	0	56.8	56.8	−20	−15	0	0.4	0.36	100
3	66.8	0	52.6	52.6	−20	−15	0	0.4	0.36	90.2
4	68.1	0	40.5	40.5	−20	−15	0	0.4	0.36	86.4
5	67.9	0	47.5	47.5	−20	−15	0	0.4	0.36	96.9
6	82.1	0	41.4	41.4	−20	−15	0	0.4	0.36	98.4
7	62.1	3.2	51.4	51.4	−20	−15	0	0.4	0.36	100.8
8	62.3	3.8	53.4	53.4	−20	−15	0	0.8	0.72	116.6
9	71.9	18.9	48.7	48.7	−20	−15	0	0.8	0.72	145.5
10	70	67.2	15.8	15.8	0	0	0	1.2	1.08	172.7
11	69.5	95	10.0	10.0	0	0	0	1.2	1.08	198.8
12	60.8	96.9	10.0	10.0	0	0	0	1.2	1.08	203.9
13	71.5	96.7	10.0	10.0	0	0	0	1.2	1.08	204.7
14	70.1	95.8	10.1	10.1	0	0	0	1.2	1.08	216.1
15	87.7	89.5	10.3	10.3	0	0	0	1.2	1.08	218.7
16	94.9	64.9	20.1	20.1	0	0	0	1.2	1.08	222.1
17	71.1	49.7	45.2	45.2	0	0	0	1.2	1.08	232.2
18	76.4	34.4	45.7	45.7	20	6	0	1.2	1.08	243.3
19	82.3	3.7	50.6	50.6	40	12	0	1.4	1.26	255.8
20	80.4	0	56.5	56.5	40	12	0	1.4	1.26	265.6
21	86.4	0	46.2	46.2	40	12	0	1.4	1.26	248.9
22	78.2	0	41.1	41.1	40	12	0	1.2	1.08	221.2
23	91.2	0	49.6	49.6	0	0	0	0.8	0.72	200.9
24	72.2	0	50.2	50.2	0	0	0	0.8	0.72	170.5

A better economic efficiency is seen in the previous mode of operation when the total operational cost of the cogeneration mode and the separate supply mode is compared whereas the efficiency is increased by 11% in the hybrid system supply.

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By the installation of energy-storing devices, the operational cost can be reduced to a greater extent. Therefore, an integrated combination of both economic efficiency and reliability is needed for the energy storing device capacity construction. The schedulable and the non-schedulable once are classified into storage batteries and EVs respectively, EVs are considered as electric loads when connected to micro grid. The operational cost increases by 8Rs by using a micro grid with EV connections in Mode4. With the addition of three non-schedulable EVs to the grid, the electric demand increases by 27KWh whereas the power supply cost is lowered to 0.60 Rs/KWh from 0.64 RS/KWh along with 1.7% decrease in ratio. The usage of DSM leads to the transfer of a part of the peak load to valley load. There is a reduction in the peak valley difference from 178 KW to 126.5 KW. When compared to Mode4 the operational cost is lowered to 2624Rs along with 2.2% decrease. The fig3 given below show the operational cost of all modes.

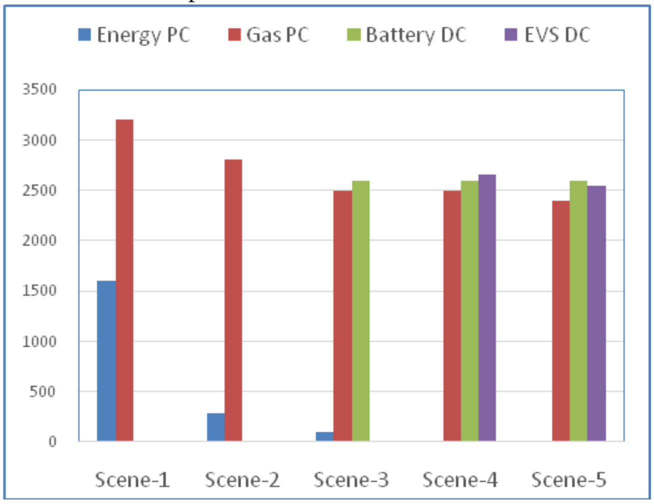

Fig. 3. The micro grid operation costs in different modes

The total operation costs are calculated for energy PC, gas, battery and EVS and the results is given in Fig.3. From the Fig.3, it is identified that gas-based operation cost is higher than the other sources. Fig.4 shows the difference in operational profit of the power supplier in different modes of operation in the micro grid system. It is seen that Mode2 profit is higher than that of Mode1 which is from 2760RS to 3272RS. Due to the addition of storage batteries to the system that helps in the adjustment of load ratios of the peak valley, the operational cost of the system is reduced and the profit is raised by 80 RS there by attaining 3352RS along with 2.46% growth rate. The profit of the system is raised to 29RS and the rate of decrease in the operational cost is also lowered in Mode4 as the system load capacity is higher than that of EVs. The operational cost is lowered to a lager extent in Mode-5 as there is an effective transfer in system load due to the adoption of DSM. Also, the supplier profit is lowered as a result of reduction in peak load. Therefore, the electricity bill of the users is lowered from 4425RS to 4214RS benefiting them to a larger extent. This means that there is no gain for the suppliers in the micro grid in terms of operation due to the adaptation of DSM. As the load is transferred with higher efficiency, the storage device investment is saved. Fig.5 shows the profileof the load including and excluding DSM.

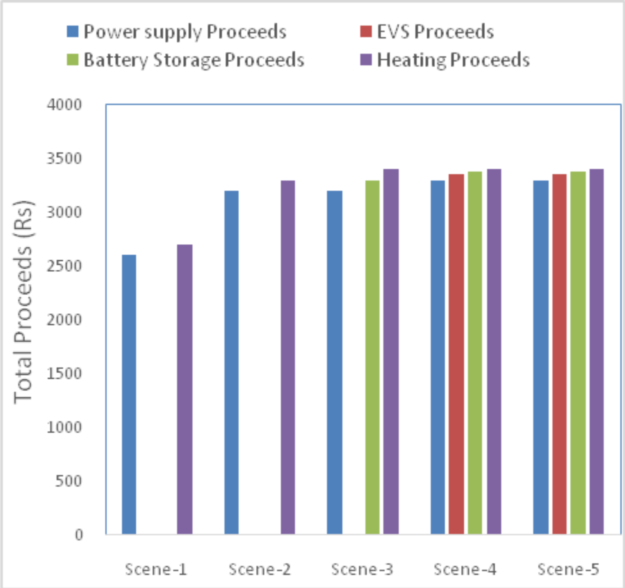

Fig. 4. The micro grid profits in different modes

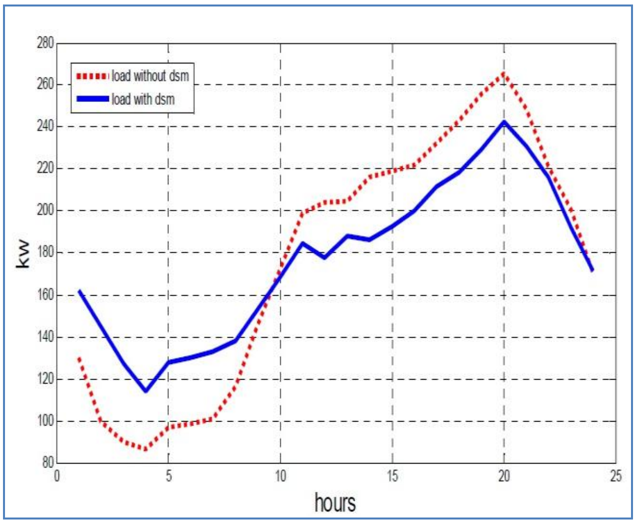

Fig. 5. Load profile with and without demand side management (DSM).

In this paper, the algorithm of HAIS is used for giving higher performance in optimizing capability than the normal PSO algorithm. The maximum iteration and the particle amount are assigned a value of 100 and 50 respectively for calculation purpose. Fig.6 shows the similarity in characteristics and speed of evolution curves among the two algorithms for the first 20 iterations. For the iterations that are more than 20 and less than 50, there is an optimizing capacity enhancement and higher performance along with increased optimum information of the group when HAIS algorithm is used. Among the two algorithms HAIS needs additional step for calculation but has the same speed of calculation. It is observed that the global optimum solution for each algorithm consisting of same population group (50) and maximum number of iterations is 68 and 88 respectively were the test is carried out 100 times. Even though the HAIS is not able to achieve 100% *favorable* outcome, it is more obvious that it has enhanced global convergence ability.

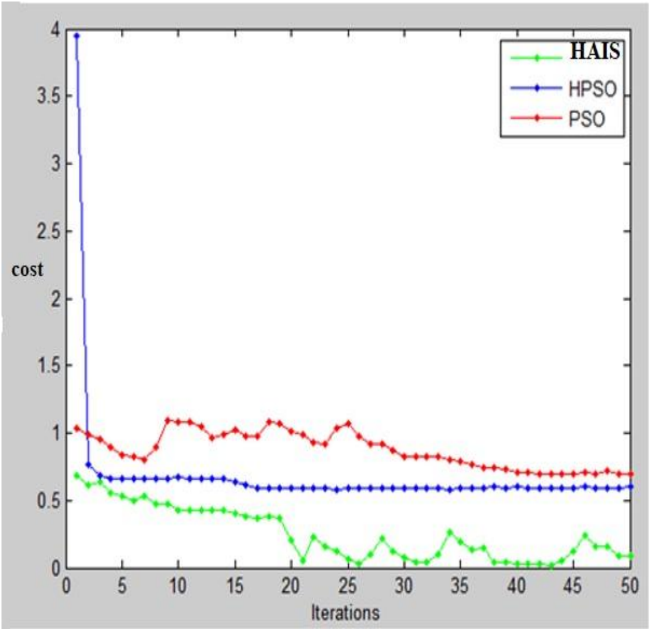

Fig. 6. Convergence characteristics of PSO and multi-team PSO (MTPSO).

From the above figures it is noticed that the proposed approach is better and the overall performance is summarised here. Initially the cost of the renewable energy system is calculated and verified. Cost in terms of energy, gas, battery, and EVS are calculated. Comparing with all, the cost of the EVS is reduced as much as possible. The cost of each individual energy model affects the entire micro grid. The total cost is obtained by finding the summation of all the energy system costs connected in the grid. Also, the operation cost is calculated for different scenarios. For Scene-5, the operation cost is less, and it can be followed in the real time experiment. Similarly, the operational profit of various scene is calculated. The operation cost of the scene-1 is less than the others. Overall comparison, for all the scenarios, the profit of the power supply is high for heating proceedings. Finally, when comparing the load, the load without DSM is high. Up to 20hours the load is increasing gradually, after 21^{st} hour the load is decreases. To evaluate the performance of the proposed approach it is found that the HAIS is better, is noticed from the convergence rate.

V. CONCLUSION

The main objective of this paper is to achieve minimum operational cost. For this purpose, a thermo-electric mixed micro grid with solar, wind and storage with optimal scheduling model is set up. In order to solve such a problem, a Hybrid Artificial Immune System algorithm is put forward. The global optima searching ability of HAIS is made higher than that of existing PSO by increasing particle search information using organization global optimal solution. In running mode, the CHP uses energy cascade. When compared with individual power and heat supply mode, the operational cost of CHP is decreased. By introducing energy storage battery and EV integration in the grid, the peak and load valley can be regulated to a higher extant and the operational cost of the system can be lowered. The purchasing power cost and the operational cost of the system is lowered for the users by using DSM.

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