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https://doi.org/10.5109/7151691

出版情報：Evergreen. 10 (3), pp.1422-1429, 2023-09. Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Japan
バージョン：
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Multi Objective Scheduling of CHP based Microgrid Using Manta Ray Optimization Technique

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(Received June 7, 2023; Revised July 27, 2023; accepted August 18, 2023).

Abstract: With the introduction of concept of sustainable development for different applications, combined heat and power system became very important due to reliability, economical aspects, saving in energy and saving of environment. Here a model is taken for economic load scheduling, CHP system with a micro grid fuel cell, wind energy, solar energy, heat boiler (waste heat), and loads which includes thermal and electrical. An optimal model with nonlinearity is taken which deals with the economical operating condition of all the power sources used and formulate the heat demand along with the electrical demand for one day (24 hours) forecasted values of all the types of power generating sources is taken in to consideration. Manta Ray foraging optimization technique is suggested for the optimization and compared with other techniques also. This Model is tested without peak valley pricing for different type of optimization algorithm. After comparing the results of different optimization method, it is clear that the result produced by MRFO are better than other method and the costing of the system is improved. From convergence graph, it can be seen that the MRFO technique demonstrates a faster convergence rate towards reaching the minimum cost of the objective function compared to other optimization techniques. As it iteratively progresses through the optimization process, MRFO efficiently approaches the optimal solution, which is the desired minimum cost. This efficiency translates to the technique requiring fewer iterations to achieve the desired outcome. Since MRFO achieves the desired outcome with fewer iterations, it reduces the overall computational workload and resource requirements compared to slower converging optimization methods.

Keywords: CHP Micro Grid, PSO, IPSO, MRFO, Economic Load Dispatch

1. Introduction

Globalization, Digitalization and continuous infrastructure development has increased the energy demand and with increasing demand of supply the environment is degrading continuously. With the larger cost and heavy emission of pollutants through the conventional energy sources the renewable energy sources has become very crucial aspect in the field of energy. The microgrid is defined as a solution for different type of energy resources specially distributed energy resources having number of energy storage units and different load condition with RES[1-7].

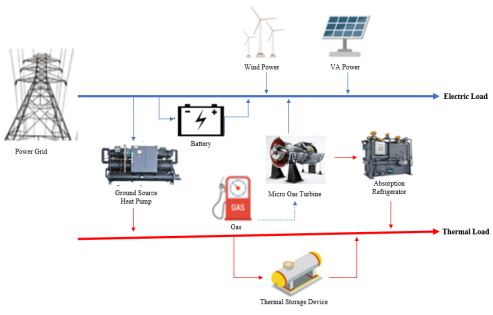

Fig. 1: The CHP microgrid structure

By satisfying all the constraints, ELD is a method to provide economic and best solution to the load demand with the committed generator units[8]. ELD is defined as important feature of power system Network with number of comparison techniques[9]. Sometimes the load may be fixed or may be variable so depending upon the load ELD may be static or dynamic ELD[10]. While only one load level can be managed by Static economic dispatch at any

instant because of the limitation of ramp rate and it can fail to deal with variation in the load at the other end dynamic dispatch can deal with large variation in load demand so optimal dynamic dispatch is very important[11].In any power system the load plays very important role for the efficient functioning of all the parameters, If the load demand increases the power generated by the plant increase or vice versa so its most important to optimize the generation of the different units in the system i.e Dynamic Economic load dispatch[8].

A system with the wind and solar energy sources was introduced for the optimal solution[12]. Different type of Power generating unit with renewable energy sources evolved till the date for the analysis of dynamic load Problems[12]. The equipment and their connection are in a CHP microgrid is shown in Fig. 1. It provided a system with wind system connected to the conventional power. On the other hand, number of researchers modeled a micro grid system with different sources to calculate risk and optimization of cost, fuel cost and emission was also done. operation and maintenance and installation costs as well as the emission costs.

A model for economic dispatch for microgrid in which few uncertainties which can impact the economic operation of system as electrical energy demand, the cost of electricity with different aspects of environment was incorporated and energy demand, and environmental factors was considered and single-objective optimal technique was presented for the optimal solution[13-15]. The economic dispatch problem was studied and the solution was proposed using PSO[16]. All the nonlinear characteristics of generator were also taken in to consideration. PSO has the main advantage of simplicity, the implantation of PSO is easy, for large number of variables it provides best results and computational efficiency is good[17]. The PSO has advantage but few disadvantages also due to which the result get deviated due to local solution and it also has a limitation in handling problems with number of constraints[18]. Therefore, to overcome the issues with the PSO it is required to improve the PSO and new techniques should be implemented to get best the result[19-20].

The authors[21-25] have used CVR technique in a smart grid (SG) and conducted experimental work along with simulation. Jia et al.[25] have quantified the uncertainty with the conditional CVR of relative disturbance and proposed a multi-objective optimal scheduling model.

In the formulated model the performance of CHP grid is investigated, it is also known as co generative or distributed generation. In CHP micro grid simultaneously two types of energies are developed Electrical energy and heat energy. The ability to create two forms of energy from a single source offers low cost, low losses, low pollution and the efficiency is increased. A new optimization technique -Manta Ray Foraging is suggested for economical operation of CHP grid and optimization was done.

2. CHP microgrid mathematical model

The mathematical model of CHP microgrid shows the required all the sources (Solar, Wind, Gas) with their limits of operation. The data used for solar and wind taken is forecasted data which is depending upon the weather condition and the time situation and duration. The data of required power (heat and Electrical) is also taken with the reference forecasted data. In case of wind turbine and PV system the installation cost has not been considered.

The complete expression for the objective function of micro grid is:

$$F = \min \sum_{i=1}^{T} (c_{ph} + c_{se}) P_{ex}^{i}/_{2} + \frac{c_{ph} - c_{se}}{2} . |P_{ex}^{i}| + c_{gas} * \left(\frac{P_{fl}^{i}}{\eta_{fl}^{i}} + \frac{P_{gb}^{i}}{\eta_{gb}} \right) + P_{fl}^{i} * c_{fl_{om}} + P_{fl}^{i} * r_{fl}^{i} * \eta_{hr_{bl}} * c_{bl_{om}} + P_{gb}^{i} * c_{gb_{om}} + P_{wt}^{i} * c_{wt_{om}} + P_{pv}^{i} * c_{pv_{om}} \quad (1)$$

were,

$\boldsymbol{T}$: time (h);

$\boldsymbol{P_{ex}^{i}}$: Power Exchanging b/w main grid & CHP system for i interval (kW) (+ve for purchasing, -ve for selling);

$\boldsymbol{P_{fl}^{i}}$: power of fuel cell for *i period*(kW);

$\boldsymbol{P_{gb}^{i}}$: power generated by boiler in i *period* (kW);

$\boldsymbol{P_{wt}^{i}}$: power of wind generator (kW);

$\boldsymbol{P_{pv}^{i}}$: power of photo-voltaic (kW);

$\boldsymbol{c_{ph}}$: purchasing power tariff to be purchased from grid (¥/kWh);

$\boldsymbol{c_{se}}$: tariff to sell power to grid (¥/kWh);

$\boldsymbol{c_{gas}}$: natural gas tariff (¥/kWh);

$\boldsymbol{c_{fl_om}}$: maintenance, operation cost for fuel cell (¥/kWh);

$\boldsymbol{c_{bl_om}}$: gas boiler's maintenance and operation cost (¥/kWh);

$\boldsymbol{c_{wt_om}}$: O and M cost of wind power generation (¥/kWh);

$\boldsymbol{c_{pv_om}}$: O and M cost of photo-voltaic array (PV) (¥/kWh);

$\boldsymbol{\eta_{fl}^{i}}$: efficiency of cell in *i* interval(p.u.);

$\boldsymbol{r_{fl}^{i}}$: heat ratio electrical energy *of cell* (kW);

$\boldsymbol{\eta_{gb}}$: The efficiency of Boiler (p.u.);

$\boldsymbol{\eta_{hr_bl}}$: The efficiency of waste heat boiler (p.u.);

2.1 CHP micro grid constraints

The mathematical model used for the CHP system with

different sources has different constraints associated with individual energy source.

2.1.1 Constraints (Power Balance)

It is important for any system to follow the power balance condition i.e total power produced by different sources & the power required (demand) by different loads are equal. Supply produced by sources is higher than the supply demand it is positive and if the demand is above the supply, it will be negative.

$$P_{ex}^{i} + P_{fl}^{i} + P_{wt}^{i} + P_{pv}^{i} - P_{el}^{i} = 0 \quad (2)$$

Heat balance constraint

The equation of heat balance needs to be satisfied by the heat of gas boiler and wasted heat recovered.

$$P_{fl}^{i} * r_{fl}^{i} * \eta_{hr_bl} + P_{gb}^{i} - P_{th}^{i} = 0 \quad (3)$$

2.1.3. Power Switching Constraints (CHP and Main Grid)

switching power between CHP system and grid should be allowed in permissible limits.

$$P_{ex}^{min} \leq \left|P_{ex}^{i}\right| \leq P_{ex}^{max} \quad (4)$$

2.1.4. Ramp rate limit constraint of cell

In case of fuel cell used in the Chip grid it is very important to maintain the upper ramp rate limit i.e the generation in any time cannot exceed above a certain limit P_{fl_up}, to the power generated at the same previous time interval and at the same time it cannot be less than the generating at previous interval above limit ΔP_{fl_down}

Down-ramp limit of the fuel cell

$$\Delta P_{fl_down}.T \leq P_{fl}^{i} - P_{fl}^{i-1} \leq \Delta P_{fl_up}.T \quad (5)$$

were,

$\boldsymbol{P_{el}^{i}}$: Electrical Power demand at i interval(kW);
$\boldsymbol{P_{th}^{i}}$: Heat power demand for i period (kW);
$\boldsymbol{P_{ex}^{min}}$: Minimum switching power;
$\boldsymbol{P_{ex}^{max}}$: maximum power limit for switching;
$\Delta \boldsymbol{P_{fl_down}}$: lower limit of ramp rate (kW);
$\Delta \boldsymbol{P_{fl_up}}$: upper ramp rate limit (kW);
$\boldsymbol{P_{fl}^{min}}$: minimum power generation limits of cell (kW);
$\boldsymbol{P_{fl}^{max}}$: maximum power generation limits of fuel cell (kW);
$\boldsymbol{P_{bl}^{min}}$: minimum permissible limits of waste heat boiler (kW);
$\boldsymbol{P_{bl}^{max}}$: maximum limits of power to be generated for waste heat boiler (kW);
$\boldsymbol{P_{gb}^{min}}$: Minimum power generation limit of boiler (kW);
$\boldsymbol{P_{gb}^{max}}$: Maximum generating limit of gas boiler (kW);

2.1.5 Capacity constraint (Generation)

All the sources can generate the power within the specified allowed limit of power generation.

Constraints of Fuel cell

$$P_{fl}^{min} \leq P_{fl}^{i} \leq P_{fl}^{max} \quad (5)$$

Waste heat Boiler Constraints

$$P_{bl}^{min} \leq P_{fl}^{i} * r_{fl}^{i} * \eta_{hr_bl} \leq P_{bl}^{max} \quad (6)$$

Gas Boiler:

$$P_{gb}^{min} \leq P_{gb}^{i} \leq P_{gb}^{max} \quad (7)$$

3. Particle swarm optimization (PSO)

In 1995 ken eddy proposed a technique for the optimization problems which was stochastic in nature. the behavior of the algorithm of PSO is motivated by the strategies of the bird/swarm which is searching the best source of food in its surrounding with the ability of its own mind, intelligence and the inertia. PSO algorithm adhere the food searching behavior of swarms for the best solution[27]. With the help of their own previous result and with the experience of other particles it improves the result and try to find the best optimal solution. It is important to understand that the disadvantage of PSO is optimization is that it provides local solution sometimes.

4. Improved particle swarm optimization

Chaotic sequence and crossover frequencies are two most important aspects of IPSO which helps in improving the result of PSO. Chaos means disordered behavior which cannot be determined. It is a Such kind of universal chaos behavior is evident in different type of scientific problems[27]. A very interested concept of mutation factor is utilized in differential evolutions so that the result can be improvised.

A sample chaotic behavior for a logistic map of a dynamic system can be represented as [29].

$$f_r = \mu * f_{r-1}(1 - f_{r-1}) \quad (14)$$

The cross over operation improves the result by increased exploration of solution. With the help of cross over operation premature convergence is also avoided. The solution we get is diversified so in any search space the promising regions can be explored and exploited.

In case of crossover operation, the mixing of previous best $Pbest_i$is done with position of updated particle i, i.e. $X_i = (x_{i1}, \ldots \ldots \ldots \ldots \ldots, x_{in})$so that improved result can be calculated.

5. Manta Ray Foraging Optimization technique (MRFO)

This is a technique that takes inspiration from the way manta rays hunt for food. Manta rays are known for their massive size and graceful appearance, but they also have a fascinating approach to finding sustenance. Plankton is the primary food source for manta rays, and they have evolved unique methods for capturing it.

Manta rays can consume several kilograms of plankton in a single day. To achieve this, they employ various strategies depending on their individual capabilities and

the size of the group. Manta rays have been observed using different foraging techniques, such as Chain, Cyclone and Summersault foraging, each of which is optimized for different scenarios.

Chain foraging involves several manta rays swimming in a single-file line, each following the one in front of them, to create a chain. The first manta ray in the chain creates a trail of plankton, which the others follow and consume. This method is beneficial in areas where plankton is scarce, and the rays need to conserve energy.

Cyclone foraging, involves manta rays swimming in a tight spiral, creating a vortex that concentrates plankton. The rays swim inwards towards the centre of the spiral, where the plankton is most concentrated, and consume as much as they can before swimming out again. This technique is most effective in areas where plankton is abundant.

Summersault foraging is a rare foraging technique where manta rays perform a summersault while feeding. This technique allows them to capture plankton from the water's surface and is useful when the plankton is dispersed and difficult to capture in large quantities.

The Manta Ray Foraging Optimization technique is designed to mimic these foraging strategies to solve optimization problems. For example, the Chain foraging technique can be used to optimize routing algorithms, while the Cyclone foraging technique can be used to optimize swarm intelligence algorithms. By taking inspiration from the natural world, we can develop more efficient and effective algorithms to solve complex problems.

5.1 Steps

In this paper, Manta Ray Foraging Optimization (PSO) technique is used for optimizing the cost of a CHP based microgrid system which consist of a photovoltaic system, wind turbine, gas boiler and fuel cell. The algorithm initializes a set of manta rays with random positions and velocities, and then it iteratively updates the positions and velocities of the rays using a set of rules based on the MRFO algorithm. The code also includes a mechanism to prevent the rays from flying out of the search space by limiting their positions to a certain range.

(1) The code first defines the input data for the energy system, including the power generation of the PV system, wind turbine, electrical load, and thermal load over 24 hours.

(2) It sets the constraints on the operation of system, including limits to the power output of the fuel cell, gas and waste heat boiler, as well as the fuel cell power ramp-up, down rates.

(3) It defines the cost parameters associated with operating the system, including the costs of operating the fuel cell, waste heat boiler, photovoltaic system, and gas boiler, as well as the cost of natural gas.

(4) It initializes the MRFO algorithm by setting the population size, maximum number of iterations, and compute fitness of each individual and obtain best solution.

(5) It then enters a loop for each iteration of the MRFO algorithm, in which it updates population using either chain foraging or cyclone foraging. If random value generated is greater than 0.5 population is updated using chain foraging else cyclone foraging.

(6) After updating the population, it evaluates the fitness of each particle by simulating the operation of the energy system for 24 hours. The fitness of updated population is compared with fitness of previous population based on which the pbest and gbest are updated.

(7) The fitness function takes into account the power output of the system, the cost of operating the system, and the degree to which the system meets the electrical and thermal load requirements and obtain the best solution.

(8) Population is updated again using somersault foraging at the end, the fitness of each population is obtained considering the system meets the desired thermal and electrical demand and as explained in step 6 pbest and gbest are updated.

(9) After the maximum number of iterations is reached, the algorithm outputs the best solution found by the MRFO algorithm, including the power output of the PV system, wind turbine, fuel cell, and gas boiler for each hour of the day.

6. Simulation results and discussion

The simulation of the model of CHP microgrid is run in MATLAB/Simulink. The schedule for optimal result analyzed for one day on hourly basis. prediction of solar power, wind power and load demand of heat and electrical is done for 24 hours and this predicted data is taken. Forecasted curve for wind power, solar power, electricity demand and heat demand were built up for 24 hours and shown in Fig. 4-7. 300 kW, 200kW, 300kW and 150kW are taken as a base value for power respectively.

For meaningful and simple simulation, the assumption is done that schohastic variable will be uniformly distributed with forecasted value so that it can work as an expected value of distribution. Electrical and heat loads are considered as uniform distributed and variance of 0.1 is also considered. PV and wind power data is considered with the deviation of 10 percent. Wind and solar power are dependent on the weather conditions, Wind power continuously changes and its fluctuating for the whole day and at the other side the solar power changes from day time to evening time its maximum at the day time and no production at the night time. Both wind and solar power are complementary to each other as during the day time the solar energy is maximum and at the night time wind energy is maximum. The forecasted value of solar and wind power is used for the electrical and heat power demand.

In this paper the combined heat micro grid is simulated and the scheduling of al the energy generation unit is done

without considering the peak value pricing. In case of less power generation as compared to the supply demand fuel cells are main grid are used to provide the supply. The simulation of CHP grid with PSO, IPSO and MRFO is done and the result for all the optimization compared.

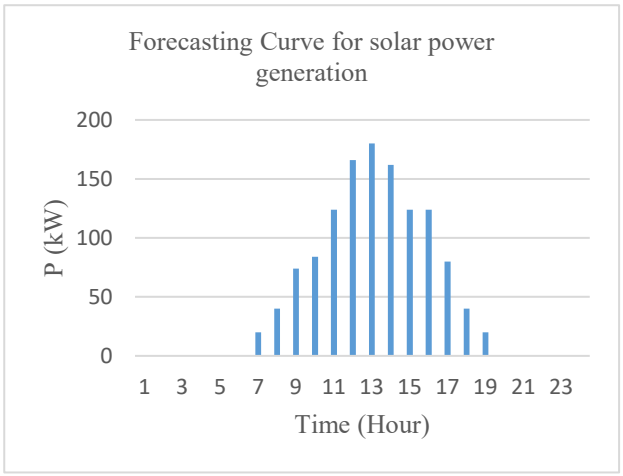

Fig. 2: Forecasting Curve for solar power generation

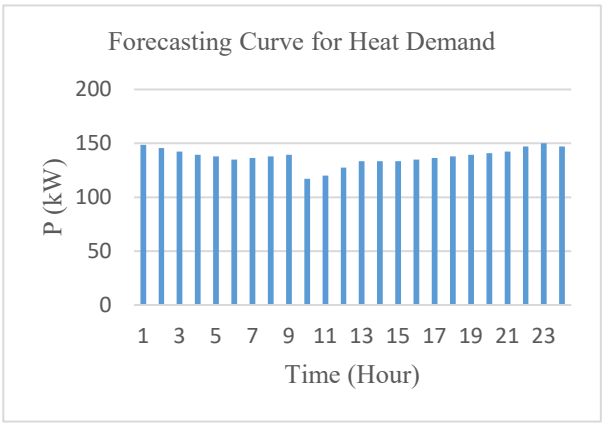

Fig. 3: Forecasting Curve for heat demand

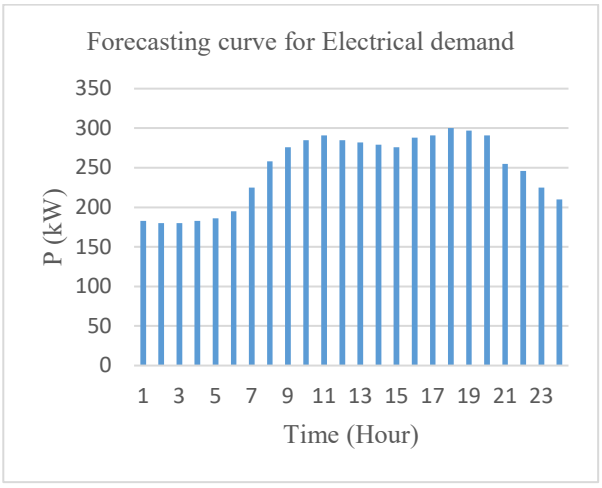

Fig. 4: Forecasting Curve for electrical demand

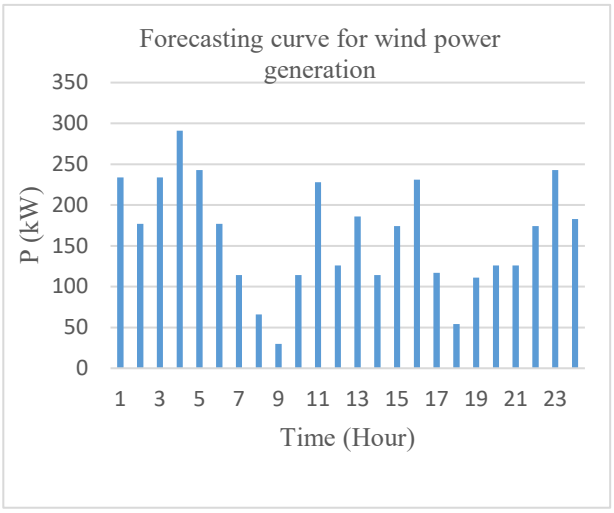

Fig. 5: Forecasting Curve for wind power generation

6.1 Optimal Cost using different optimization technique

Table 1: Summary of cost using different techniques

Optimization Technique	Best Cost
PSO	1.84685e+03
PSO with Chaotic sequence operation	1.84549e+03
PSO with Crossover operation	1.8429e+03
PSO including Chaotic sequence, Crossover operation	1.8472e+03
Proposed MRFO	1.8180e3

6.2. Optimal Power Scheduling for 24 hours obtained using different optimization techniques

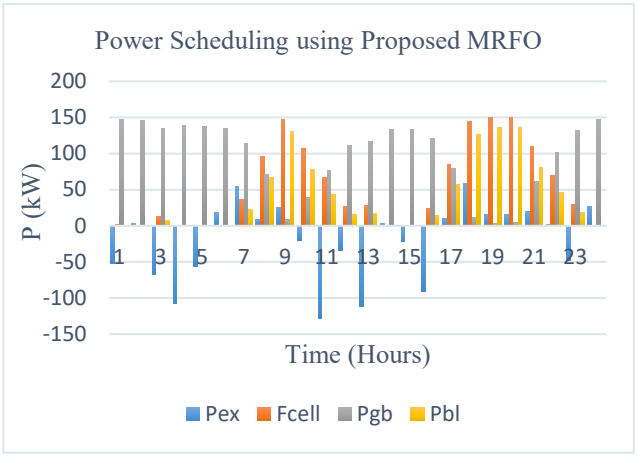

Fig. 6: Power Scheduling using Proposed MRFO

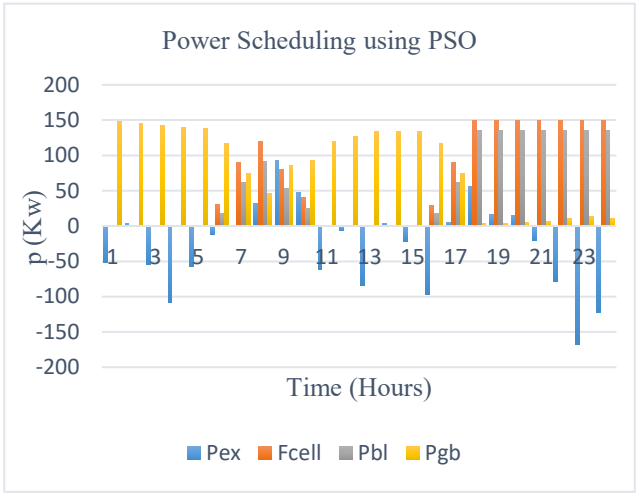

Fig. 7: Power Scheduling using PSO

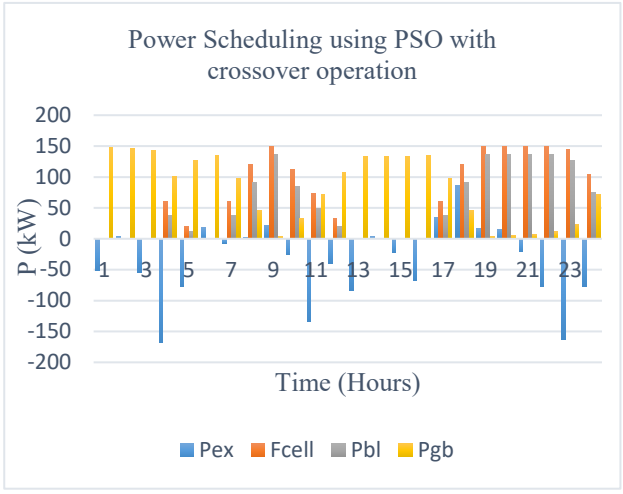

Fig. 8: Power Scheduling using PSO with crossover operation

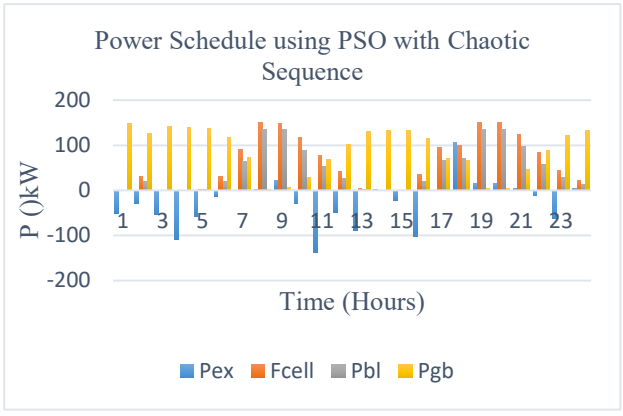

Fig. 9: Power Scheduling using PSO with chaotic sequence

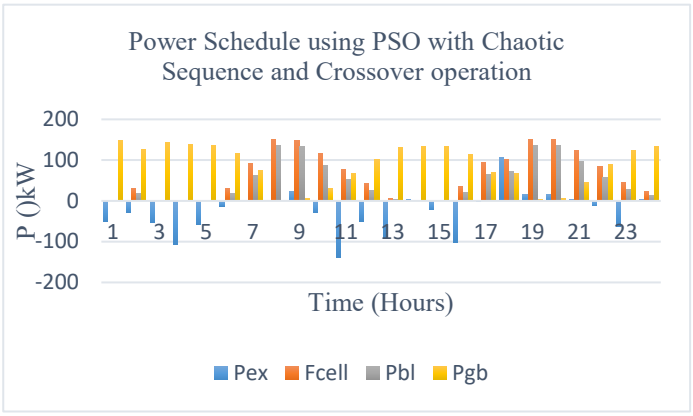

Fig. 10: Power Scheduling using PSO with chaotic sequence and crossover operation

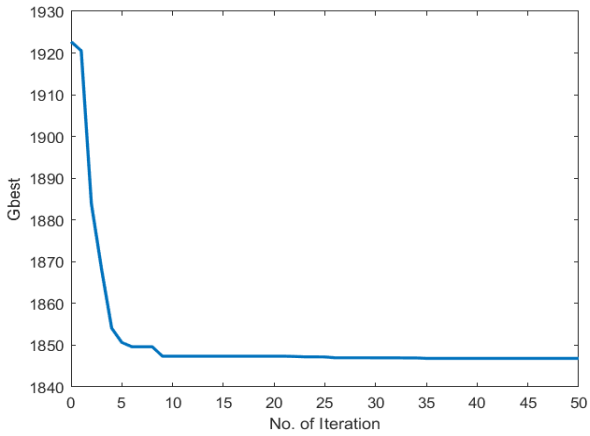

Fig. 11 (a): Convergence graph using PSO

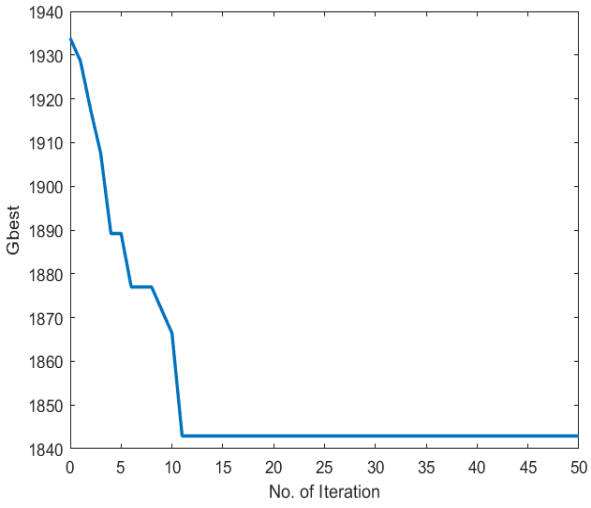

Fig. 11 (b): Convergence graph using PSO with crossover operation

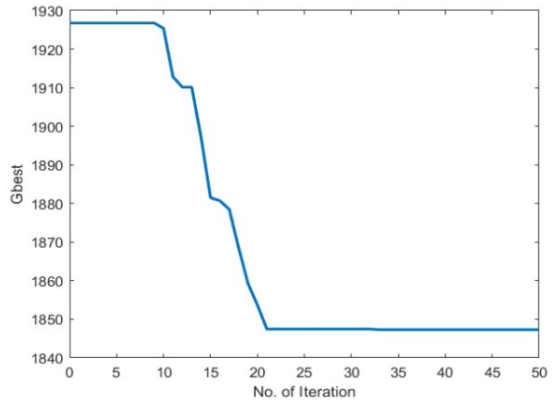

Fig. 11 (c): Convergence graph using PSO using Chaotic Sequence

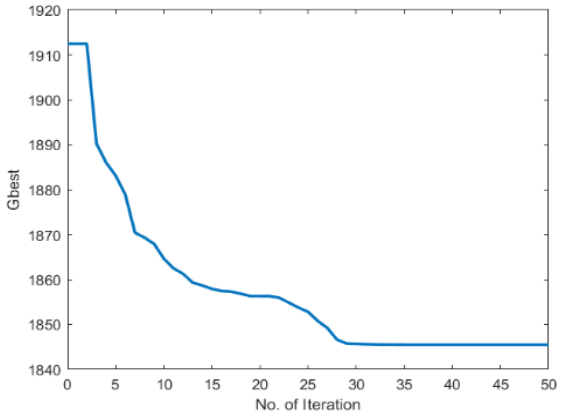

Fig. 11 (d): Convergence graph using PSO using crossover operation and Chaotic Sequence

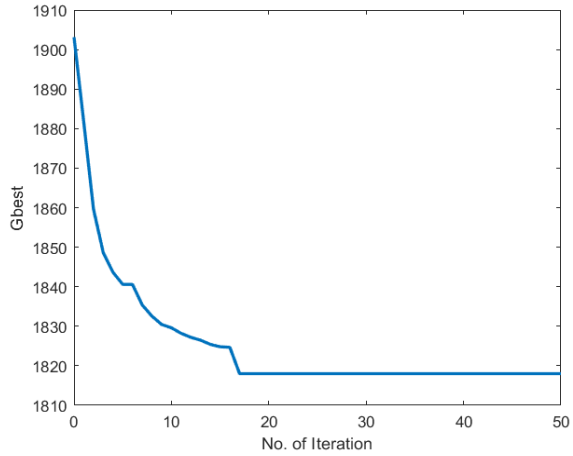

Fig. 11 (e): Convergence graph for proposed MRFO method

7. Conclusion

In this paper a model of CHP micro grid with different RES (wind, fuel, and solar) taken along with the gas boiler, waste heat boiler. Both type of electrical and thermal load also taken for the load demand. MRFO is implemented and it is proposed to provide the optimal solution for the CHP Micro grid problem with some limitations of CHP grid. The forecasting data for 24 hours is taken for different RES and heat and electrical demand. The results of MRFO were compared with different optimization techniques and found better than the different optimization. The convergence curve shown for different optimizations represents that the rate of convergence is very fast. From the convergence graph Fig. 11(a)-11(e), it can be seen that the MRFO technique demonstrates a faster convergence rate towards reaching the minimum cost of the objective function compared to other optimization techniques. As it iteratively progresses through the optimization process, MRFO efficiently approaches the optimal solution, which is the desired minimum cost. This efficiency translates to the technique requiring fewer iterations to achieve the desired outcome. Since MRFO achieves the desired outcome with fewer iterations, it reduces the overall computational workload and resource requirements compared to slower converging optimization methods.

Acknowledgements

Surmadhur Pant, acknowledge and thank the management of Shivalik College of Engineering, Dehradun for permitting and providing the infrastructural support to pursue PhD at ICFAI University, Dehradun.

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