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Optimal power scheduling for economic dispatch using moth flame optimizer

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ABSTRACT

This paper proposes the optimal generator allocation to solve Economic Dispatch (ED) problem in power system using Moth Flame Optimizer (MFO). With this approach, the optimum power for each unit generating in the system will be searched based on the power constraints per unit and the amount of power demand. The objective function of this study is to minimize the total cost of generation. The amount of power loss is measured to determine the effectiveness of the proposed technique. The performance of the MFO technique is also compared to the evolutionary programming (EP) and Particle Swarm Optimization (PSO) methods. Five- and thirty-bus power system networks are selected as test systems and simulated using MATLAB. Based on simulation results, MFO provides better results in regulating the optimum power generation with minimum generation cost and power loss, compared to EP and PSO.

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1. INTRODUCTION

Today, the issue of electricity generation has always been a major topic. The ever-increasing population, coupled with the lack of new oil sources, has led to rising fuel costs. This has forced scientists to develop a system for optimum fuel use without compromising power demand. This system will ensure proper power unit scheduling and power capacity are generated according to demand. This scheduling system can be created based on the economic dispatch (ED) calculation. The purpose of ED is to determine the optimal power generation unit with the lowest cost of power generation. At the same time, it has to produce the total amount of power supply according to the power demand and power constraints of each generator unit. ED can be categorized as one type of optimization problem. ED solutions using optimization techniques can be categorized into two parts, namely mathematical and heuristic techniques. Some of the mathematical techniques that have been introduced to solve ED problems include linear programming [1, 2], quadratic programming [3] and mixed integer programming [4]. These traditional methods used to solve ED problems are time consuming and cannot solve non-linear cost functions. The solutions obtained using this method are also not optimal. Due to the disadvantages of this traditional method, heuristic approaches have been introduced as one of the solutions to ED problems. ED problems can be categorized into Convex and Non-Convex. In the Non-Convex problem, the impact of the valve point is considered in the power generation cost function. Both Convex and Non-Convex problems were successfully solved using heuristic techniques as reported, respectively in [5, 6] and [7, 8].

The artificial intelligence (AI) approach has been widely used in the field of power systems. Among the techniques used are evolutionary programming (EP) [9-12], particle swarm optimization (PSO) [13-17], ant colony optimization (ACO) [18-21], gravitational search algorithm (GSA) [22, 23] and whale opitimization algorithm (WOA) [24, 25]. EP is developed based on biological evolutionary processes. A key feature of the EP process is the mutation, in which each parent produces a new breed with different characteristics. Selection will be based on the most fittess generation. Whereas, the PSO technique attempts to mimic the behavior of a herd of animals or insects. During the search process, two types of exploration: global and local are conducted. Balance between these two explorations is the key to search for optimal solution. Meanwhile, ACO is a heuristic method that inspired by the behavior of colony of ants. This method was mainly used to solve the travelling salesman problem (TSP). Ant colonies will track the same path between the source of their food and colony, based on pheromone trail left by other ants. After finding the pheromone trail, the ants will stop the random travelling and begin to follow the trail. In this study, a new metaheuristic-based method called Moth Flame Optimizer (MFO) was introduced [26-30]. The MFO was developed based on the method of flying moths at night, called transverse orientation. At night, flying moths are guided by moonlight, where they maintain a constant angle to find their way. Among the advantages of MFO over other techniques is the simplicity and speed of the search. Its optimization capabilities have been proven and used in a variety of optimization problems such as economics delivery, engineering design and medical applications.

This study proposes efficient techniques for calculating optimal power generation capacity based on the power demand and constraints of each generator unit using MFO optimization techniques. Two events using a five-bus system with three power generation units and a thirty-bus system with six power generation were simulated using Matlab. The objective function of this optimization process is to minimize the total cost of power generation. To determine the performance of the proposed technique, the MFO approach will also be compared to the EP and PSO methods. The rest of the paper is organized as follows: Section 2 presents the formulation of ED. Section 3 explained the MFO algorithm. Section 4 discussed the optimal power scheduling algorithm. Section 5 provided the simulation results and discussions. Lastly, Section 6 presents the conclusions.

2. FORMULATION OF ELD

Economic load dispatch (ELD) aims to schedule power generation for each generating unit that is in accordance with the conditions and constraints of a given operation. The total production cost C_T of one power system network can be expressed as [5]:

$$C_T = \sum_{i=1}^{n} C_i \,(P_i) \tag{1}$$

where C_T is the total production cost, $C_i(P_i)$ is the production cost of the i^{th} generating unit P_i, and n is number of the generating units in the system. To calculate the production cost per unit of generator, the power generation cost function $C_i\,(P_i)$ is based on the fuel cost coefficient and the corresponding power output for that unit. $C_i\,(P_i)$ is usually expressed in the form of quadratic equations as follows:

$$C_i(P_i) = a_i + b_i \cdot P_i + c_i \cdot P_i^2 \tag{2}$$

Here, a_i, b_i, and c_i are the fuel cost coefficients for the i^{th} generating unit P_i. The objective function J of the optimization process can be written as,

$$J = Minimize\ (C_T) \tag{3}$$

In this study, operating limits for each generator unit and power demand are constraints that need to be considered in order to optimize the objective function. The cost function of one generator unit is unique compared to the cost function of the other generator unit. The operating limit for each generator unit can be written as,

$$P_{i,min} \le P_i \le P_{i,max} \tag{4}$$

where $P_{i,max}$ and $P_{i,min}$ are respectively the maximum and minimum operating limits of the i^{th} generating unit P_i. To ensure that the power supply is enough, the amount of power generated by the generator unit must always adhere to the total power demand. A good generation system also produces a low amount of power loss. In this study, the amount of power generated by all generation units P_G is equal to the sum of the total power demand P_D and total power loss P_L.

$$P_G = \sum_{i=1}^{n} P_i = P_L + P_D \quad (5)$$

3. MFO

Moth-Flame Optimizer (MFO) was proposed by Mirjalili in 2015. MFO is a new optimization technique inspired by moth navigation methods in nature. Known as a transverse orientation, this approach ensures that the moth is at a constant angle to the source of light such as the moon and the candle flame for orientation [26]. In the MFO algorithm, moths are considered as search agents that move around the search space, while light sources are considered the best position now. Therefore, each agent moth will search around the source of the light to obtain a better position and update the best position. In this study, the set of moths (agent) M can be described as follows:

$$M = \begin{bmatrix} m_{1,1} & \cdots & m_{1,d} \\ \vdots & \ddots & \vdots \\ m_{n,1} & \cdots & m_{n,d} \end{bmatrix} \quad (6)$$

Here, d is the number of variable and n is the number of moths. Meanwhile, the set of light source (position) F can be described as follows:

$$F = \begin{bmatrix} F_{1,1} & \cdots & F_{1,d} \\ \vdots & \ddots & \vdots \\ F_{n,1} & \cdots & F_{n,d} \end{bmatrix} \quad (7)$$

Here, both n and d are the set of moth dimension. The position of i^{th} moth M_i can be described as the following:

$$M_i = S(M_i, F_j) \quad (8)$$

Here, S is the spiral function, M_i is the number of i^{th} moth and F_j is the number of j^{th} light source. The equation of spiral function S in (5) can be shown as follows,

$$S(M_i, F_j) = |M_i - F_j| \cdot e^{\beta\tau} \cdot \cos(2\pi\tau) + F_j \quad (9)$$

Here, β is a constant and τ is the random number between -1 to 1. The detailed explanations of the MFO algorithm process can be found in [25].

In this study, MFO techniques will be compared to existing techniques of EP and PSO. Further details on the concepts, equations and pseudocodes of EP and PSO can be found in [12] and [16], respectively.

4. OPTIMAL POWER SCHEDULING ALGORITHM

To find the minimum value of C_T, the optimization process for power generation scheduling for all generating units was done repeatedly, until the stopping criteria were met. Following is the optimization process for power scheduling using MFO:

a) Determine the value of P_i using MFO based on the given constraint limit for each generating unit.
b) Calculate C_T using (1) and (2).
c) Determine P_L using (5).
d) Evaluate the values of the selected parameters and repeat Steps (i), (ii) and (iii) until the difference between the maximum and minimum values of objective function J is 0.001 or the number of iterations reaches 100.

5. RESULTS AND ANALYSIS

In this study, simulations were conducted on a five-bus system with three generators and a thirty-bus reliability test system system with six generators, respectively, as Event A and Event B. There were three cases evaluated for each event. All the events and cases carried out under the specific power demand are illustrated in Table 1. Table 2 presents the fuel cost coefficients (a_i, b_i, and c_i) with minimum and maximum power limits (P_{min} and P_{max}) for each generator unit in Event A and B [5].

Table 1. List of events, cases, and power demands

Event	Test System	Case	Power Demand	Event	Test System	Case	Power Demand
Event A	Five-bus system with three generators	Case A-1	75 MW	Event B	Thirty-bus reliability test system with six generators	Case B-1	570 MW
		Case A-2	135 MW			Case B-2	790 MW
		Case A-3	195 MW			Case B-3	1030 MW

Table 2. Fuel cost coefficients and power limits for generator units in Event A and Event B

Event	Unit	a_i (MW)^2	b_i (MW)	c_i	P_{min} (MW)	P_{max} (MW)
Event A	1	200	7.0	0.008	10	85
	2	180	6.3	0.009	10	80
	3	140	6.8	0.007	10	70
Event B	1	240	7.0	0.0070	100	500
	2	200	10.0	0.0095	50	200
	3	220	8.5	0.0090	80	300
	4	200	11.0	0.0090	50	150
	5	220	10.5	0.0080	50	200
	26	190	12.0	0.0075	50	120

5.1. Event A

In Event A, optimal power scheduling is performed on three cases: Case A-1, A-2 and A-3 with different power demands. For each case, three optimization techniques: EP, PSO and MFO are used in the power scheduling optimization process. The results for the generated power values (P_1, P_2, P_3, P_G), total power loss P_L and total power generation costs C_T using EP, PSO and MFO optimization techniques for all cases in Event A are summarized in Table 3.

Table 3. Power scheduling for generator units in Event A

Case	A-1 (P_D = 75 MW)			A-2 (P_D = 135 MW)			A-3 (P_D = 195 MW)		
Method	EP [5]	PSO [5]	MFO	EP [5]	PSO [5]	MFO	EP [5]	PSO [5]	MFO
P_1 (MW)	15.0071	11.0974	10.2994	36.2415	27.2484	27.7994	58.5381	50.0044	45.5813
P_2 (MW)	21.0649	50.9199	44.5020	52.9243	63.2321	62.0632	76.8676	85.1790	79.6866
P_3 (MW)	38.9297	12.9827	20.1986	46.3397	44.5196	45.1375	59.6950	59.8166	69.7321
P_G (MW)	75.0017	75.0000	75.0000	135.5055	135.0000	135.0000	195.1007	195.0000	195.0000
P_L (MW)	0.0017	0.0000	0.0000	0.5055	0.0000	0.0000	0.1007	0.0000	0.0000
C_T ($/h)	1038.89	1032.26	1031.34	1469.25	1467.63	1467.64	1925.49	1923.76	1923.08

For Case A-1, it is found that the values of generator units P_1, P_2 and P_3 selected based on EP, PSO and MFO techniques are scattered. This indicates that more options for scheduling of generating units due to the small power demand P_D. Based on the A-1 results, the MFO and PSO methods appear to generate the total amount of power P_G that same as P_D, without power losses. This shows that both PSO and MFO perform very well compared to EP technique. In terms of power generation costs, MFO provides the lowest cost, followed by PSO and EP techniques. In Case A-2, the value of the generator unit is found to be in a small range of values, especially those selected based on PSO and MFO techniques. This is because the selected power demand is high and results in less choice for generator unit scheduling. From a P_D standpoint, EP still produces small power loss compared to MFO and PSO techniques which give power equivalent to P_D and zero power loss. This time, the PSO provided lower C_T than MFO, followed by EP. The results for Case A-3 are very similar to the results of Case A-2, except for the value of C_T. The choice of generator unit values by MFO and PSO is very close to each other and there is no loss of power generated by these two techniques. The choice of generator unit value by MFO and PSO is very similar and no loss of power is generated. Like Case A-1, this time MFO managed to schedule power generation at a lower cost than PSO.

5.2. Event B

Same as Event A, optimal power scheduling in Event B is performed on three cases, namely Case B-1, B-2 and B-3 with different power demands using EP, PSO and MFO methods. The results for P_1, P_2, P_3, P_4, P_5, P_{26}, P_G, P_L and C_T using all three optimization techniques in Event B are summarized in Table 4.

Table 4. Power scheduling for generator units in Event B

Case	B-1 (P_D = 570 MW)			B-2 (P_D = 790 MW)			B-3 (P_D = 1030 MW)		
Method	EP [5]	PSO [5]	MFO	EP [5]	PSO [5]	MFO	EP [5]	PSO [5]	MFO
P_1 (MW)	246.7543	219.3933	245.4596	271.9857	326.9195	327.3241	390.9723	392.5252	399.9455
P_2 (MW)	50.1785	50.0034	55.2024	63.6149	95.6884	76.9488	93.9187	145.8794	136.0565
P_3 (MW)	100.7877	139.8063	116.1585	192.9592	162.7036	198.6866	208.2881	223.8009	230.9463
P_4 (MW)	61.2489	50.0005	50.0000	106.7976	93.5241	54.2322	95.0191	97.9224	90.7998
P_5 (MW)	51.0050	58.6951	53.1785	84.4445	60.8599	82.8084	170.7287	119.4907	121.6523
$P2_6$ (MW)	60.1072	52.1014	50.0010	70.2890	50.3045	50.0000	71.1670	50.3815	50.5996
P_G (MW)	570.0816	570.0000	570.0000	790.0909	790.0000	790.0000	1030.0939	1030.0000	1030.0000
P_L (MW)	0.0816	0.0000	0.0000	0.0909	0.0000	0.0000	0.0939	0.0000	0.0000
C_T ($/h)	6909.57	6892.68	6871.99	9443.24	9370.45	9347.24	12305.00	12266.20	12263.95

The results in Event B show a pattern similar to Event A. The values for each generator unit in Case B-1 and B-2 give different values for the three optimization techniques. This is due to the low power demand, so there are many options for coupling the generator unit to get the required power demand. Meanwhile, the results for Case B-3 shows the value of each unit of the generator is in a narrow range for the three optimization techniques. This is because there are very few options for coupling generator units to obtain high power demand. Overall, the six-unit generator scheduling technique using PSO and MFO is capable of delivering the same value with power demand, without power loss. For the same generator system, EP method also produces almost identical power to the demand. However, there is a slight power loss generated by the EP, not exceeding 0.1 MW for Case B-1, Case B-2 and Case B-3. For all three cases, MFO is able to save on generating costs, followed by PSO and EP. From this result, MFO remains at the forefront of producing the lowest power generation cost and the lowest power loss compared to PSO and EP techniques.

6. CONCLUSION

This study proposes a power scheduling strategy using MFO to achieve optimum power output by generator units at minimum power generation costs. Two test systems which each has three different power demand is chosen as a test system and is carried out using MATLAB. The results show that MFO and PSO have successfully generated the same amount of power generation as power demand, with no loss of power. In terms of cost, MFO outperforms PSO in providing lower generation costs for the same power demand. In addition, the EP provides the highest total cost of generation compared to MFO and PSO. In fact, power generation using EP also results in power loss. In conclusion, MFO is the most appropriate technique in power scheduling for economic dispatch (ED) problems in power systems.

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