An Extension of Particle Swarm Optimization (E-PSO) Algorithm for Solving Economic Dispatch Problem

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Abstract—Producing the energy power that meets the load demands at a minimum cost while satisfying the constraints is known as economic dispatch. Economic dispatch becomes one of the most complex problems in the planning and operation of a power system that aims to determine the optimal generation scheduling at minimum cost. For that reason many optimization researches on finding an optimal solution regarding the total cost of generation have been carried out. This paper presents the implementation of the extension of the PSO (E-PSO) system in solving the continuous nonlinear function of the cost curves of the generator. In this paper, a 6-unit generation system has been applied to show the effectiveness of the E-PSO compared to the standard PSO. The results show that E-PSO is capable in solving the economic dispatch problem in term of minimizing the total cost of generation while considering the generator limits and transmission losses.

Keywords—economic dispatch problems, particle swarm optimization, particle displacement

I. INTRODUCTION

Economic dispatch (ED) has the aim of achieving the minimal power generation cost while all operating constraints are satisfied. Known as a nonlinear problem, ED is considered as a complex system to be solved by using the optimization techniques have been carried out to address this problem. Generally, the cost of the operational generator is represented as a smooth quadratic function which can be easily solved by using mathematical programming based [1]. Practically these cost functions of modern power generation units are highly nonlinear, and discrete in nature [2]. Consequently, these heuristic algorithms like lambda-iterative, Lagrange relaxation and gradient technique failed to search the global optimal solutions while Dynamic Programming experienced a drawback of “curse of dimensionality” [1]–[3].

The advances in computation create a better solution of complex problems that led into using stochastic optimization techniques. For the last decades, there many optimization methods that inspired by the behavior of a group of swarm have been demonstrated to solve the ED problems such as firefly algorithm (FA) [4], [5], ant-colony optimization (ACO) [6], artificial bee colony (ABC) optimization [7], [8], differential search algorithm (DSA) [9], particle swarm optimization (PSO) [10] and recently chukoo search algorithm (CSA) [11]. All these methods have their own advantages and disadvantages. Though, the performance of the methods can be improved by some modification or hybridization of the algorithms such that methods are Self-Organizing Hierarchical PSO [2], Modified ABC algorithm [8], Enhanced Bee Swarm Optimization Algorithm [12], Improved PSO [3] and more techniques are discussed in [1], [13].

This paper will present the implementation of the extension of the PSO (E-PSO) system which proposed by Kemmoe Tchomte and Gourgand [14] to determine the optimal solution of the economic dispatch problem in a manner to minimize the generation cost of the operational generators. Standard particle swarm optimization (PSO) considers on the diversification or exploration process of the particles displacement. During exploration process, the particles move to the unexplored space to search for the best position with no specific area located around the good quality solutions. For this reason, instead of diversification process, Kemmoe Tchomté and Gourgand has proposed the concept of intensification process of the particles displacement where the particle will move to the search space when there is necessity near the solutions area. Hence, the idea is to take into account both diversification and intensification processes for the particles during the exploration of search space in order to obtain higher quality solutions [14].

The paper is organized as follows: Section II explains briefly the economic dispatch problem formulation; Section III presents description on PSO while the method for solving the problem is included in Section IV. Lastly, the results and discussions are discussed in Section V followed by conclusion section.

II. ECONOMIC DISPATCH

Producing the energy power that meets the load demands at a minimum cost while satisfying the constraints is known as economic dispatch. Economic dispatch becomes one of the most complex problems in the planning and operation of a power system that aims to determine the optimal
generation scheduling at minimum cost. For that reason many optimization researches on finding an optimal solution regarding the total cost of generation have been carried out. The power generation needs to satisfy the certain equality and inequality constraints as this is not an easy task since especially in the large interconnected power system. Normally, the ED problem is solved by minimizing the selected objective functions while maintaining an acceptable system performance in term of generator capability limits and the output of the compensating devices.

The objective function of the total cost of the power generation;

$$\min C_T = \sum_{i=1}^{\|G\|} C_i P_i = \sum_{i=1}^{\|G\|} a_i + b_i P_i$$ \hspace{1cm} (1)

Where $C_T$ the total fuel is cost; $C_i$, $P_i$ and $P_i$ are the cost function and the real power output of generator $i$, respectively; $k$ is the number of committed generators, $a_i$ and $b_i$ denote the cost coefficients of the $i$-th generator. Whilst it is subjected to the following equality and inequality constraints:

$$\sum_{i=1}^{\|G\|} P_i = \sum_{i=1}^{\|G\|} P_{D,i}$$ \hspace{1cm} (2)

$$P_{D,i} = \sum_{i=1}^{\|G\|} \frac{P_i P_D}{P_i + \sum_{j=1}^{\|G\|} P_j} + \sum_{j=1}^{\|G\|} E_{D,j}$$ \hspace{1cm} (3)

Where $P_{\text{loss}}$ is total active power losses of the network, $P_{D}$ is total average demand forecast for the dispatch period and is output power of generator $i$ for dispatched hour, is minimum power output limit of $i$-th generator and is maximum power output limit of $i$-th generator. From the Kron’s loss formula in equation (4), , and are called the loss coefficients or B-coefficients.

III. PARTICLE SWARM OPTIMIZATION

PSO is familiar and accepted optimization method in determining the optimal solution of economic dispatch problems. PSO method was introduced by Kennedy and Eberhart in 1995 which inspired by social behavior of bird flocking or fish schooling [15] and has been modified by Shi and Eberhart in 1998 [16].

A. Standard PSO

In PSO, the swarm is represented as particles which moving around in the search space looking for the best solution. In this situation, each particle is treated as a point in a $k$-dimensional space which adjusts its movement according to its own movement experience as well as the movement experience of the other particles. Each particle has a position vector of and a velocity vector, . Every particle has a memory of the best position so far in the search space that called $P_{\text{best}}$, and the best location of all particles in the swarm is called $G_{\text{best}}$. Afterward, the velocity of the individual particle will be updated at each step based on the following equation as in (5):

$$V_{i,t+1} = \omega V_{i,t} + c_1 r_1 (P_{i,t} - x_{i,t}) + c_2 r_2 (G_{i,t} - x_{i,t})$$ \hspace{1cm} (5)

where $V_{i,t}$ is velocity of individual $i$ at iteration $t$, is weight parameter, $c_1$ and $c_2$ are weight factors, $r_1$ and $r_2$ are random numbers ($0 \leq r \leq 1$), $x_{i,t}$ is position of individual $i$ until iteration $t$, $P_{\text{best}}$ and $G_{\text{best}}$ are best position of individual and group $i$ until iteration $t$ respectively.

The updating of position is given by:

$$x_{i,t+1} = x_{i,t} + V_{i,t+1}$$ \hspace{1cm} (6)

where $x_{i,t+1}$ is the position of the $i$-th particle at iteration $t$.

In order to obtain less iteration with sufficient optimal solution, the weight inertia is set by using the following equation [10];

$$\omega = \omega_{\text{max}} - \frac{\omega_{\text{max}} - \omega_{\text{min}}}{\text{iter}_{\text{max}}} \times \text{iter}$$ \hspace{1cm} (7)

where $\omega_{\text{min}}$ and $\omega_{\text{max}}$ are the initial and final inertia parameter weights respectively, $\text{iter}_{\text{max}}$ is maximum iteration number and iter is current iteration number.

B. Extension of PSO

As in standard PSO, the exploration process of the particles to search for the best local, $P_{\text{best}}$ and global, $G_{\text{best}}$ positions have shown a good result but with less searching efficiency. The particle will move from the current position, $x_{ij, \text{search}}$ in search space to find the best local, $P_{\text{best}}$ and global, $G_{\text{best}}$ positions but the particles move far away from the best solutions. Therefore, Kemmoë Tchomté and Gourgand has considered and applied the concept of intensification process of the particles displacement which introduced by Glover and Laguna [17]. During the exploration, the particles will search the best local and global positions with good quality solutions near the searching area as shown in Fig. 1 [14].

Hence, Kemmoë Tchomté and Gourgand has proposed the a new particle updating position as follows [14];

$$S_{i,t} = x_{i,t} + c_1 V_{i,t} \text{ and } \quad T_{i,t} = S_{i,t} + c_2 V_{i,t}$$ \hspace{1cm} (8)

$$x_{i,t+1} = T_{i,t} + \alpha$$ \hspace{1cm} (9)

$$V_{i,t+1} = \alpha V_{i,t} + \beta(P_{i,t} - x_{i,t}) + r(G_{i,t})$$ \hspace{1cm} (10)

Where;

$$\alpha = c_4 (1 -$$ \hspace{1cm} (11)

$$c_2$$ \hspace{1cm} (12)

$$c_4$$ \hspace{1cm} (13)
IV. E-PSO FOR SOLVING ED

In order to determine the total cost of generation, $C_T$ using E-PSO method, the implementation of the algorithm function follows the steps below.

Step 1: Initialization of PSO parameters. For initialization, all parameters of PSO such as size of particle, number of dimension, iteration, constant, inertial weight are considered. The particles ($P_i = P_1, P_2, P_3, P_4$ and $P_5$) are randomly generated between the maximum and the minimum operating limits of the generators.

Step 2: Evaluation of fitness function. The fitness function as represented in equation (1) is calculated and will be the initial particles of the swarm which are set as the initial $P_{best}$ values of the particles. The best value among all $P_{best}$ values is identified as $G_{best}$.

Step 3: Evaluation of velocity and position. Using equation (8) – (10), the velocity, $V_{i,t}$ and position, $x_{i,t}$ (with additional evaluation of $S_{i,t}$ and $T_{i,k}$) of each particle is evaluated and will become the initial value of $P_{best}$ and $G_{best}$ at the first iteration.

Step 4: Update $P_{best}$ and $G_{best}$. The particle position vector is updated. The swarm will get the new values of $P_{best}$ and $G_{best}$. If the evaluation value of each individual is better than the previous $P_{best}$, the current value is set to be the new $P_{best}$. Thus, a new $G_{best}$ will be chosen accordingly among the new $P_{best}$.

Step 5: Stopping criterion. If the number of iteration reaches the maximum number of iteration set earlier in PSO, then the latest $G_{best}$ will be the optimal generation power unit with minimum total generation cost at the maximum evaluation function iteration.

Fig. 2. Flow Chart of E-PSO for Solving ED Problem
V. RESULTS AND DISCUSSIONS

The proposed method has been tested on a 26-bus system with six thermal units which are located at bus 1, 2, 3, 4, 5 and 26. The total load demand is 1263 MW and the characteristics of the six thermal units can be obtained in Table I. The PSO parameters in this simulation are set as follows [10]:

- Number of particles, \( n = 20, 40 \) and 60
- Maximum iteration = 1000
- \( c_1 = 0.9, c_2 = c_3 = 2.0 \)

In this case, the particles that are \( P_1, P_2, P_3, P_4, P_5 \) and \( P_{26} \) were randomly generated within the generator capacity limits and subsequently the system was simulated ten times.

Table II shows the individual best solution after ten simulations that satisfy the constraints of generator limit and the transmission losses. The results are compared with different number of particles between standard PSO and E-PSO algorithm system. It can be seen that total generation cost with 40 particles give the best solutions followed by 60 and 20 number of particles respectively by using both methods. Overall, the best solution for the total generation cost with \$15454.096 (n=40) is determined by E-PSO algorithm.

Moreover, Table III shows the comparison between standard PSO and E-PSO algorithm after ten simulations in terms of minimum, maximum and average value of generation cost. From the observation, the average generation cost for particles of 60 presents the best cost with \$15478.15 compared to the two groups of particles. Among the three groups of particles, the highest cost is \$15604.29 which was from the particles of 60 using standard PSO. Lastly, the least cost is achieved from the group of 40 particles with \$15454.10 using the E-PSO algorithm.

Furthermore, the comparison of the best solutions among the ten simulations has been observed that represented in Table IV. Based on Table IV, it can be observed that all the three groups of particles which apply E-PSO algorithm in a manner to minimize the cost of generation were able to be achieved.

VI. CONCLUSION

In this paper, an extension of PSO (E-PSO) has been presented to solve ED problems. The effectiveness of the E-PSO has been demonstrated to carry out the optimal generation cost of the 6-unit system while satisfying the equality and inequality constraints. Based on ten
simulations, E-PSO shows a potential and capability in solving ED problem with better solutions than standard PSO. Furthermore, for the future study, the number of simulation will be increased to observe the performance of the E-PSO algorithm. Afterward, the algorithm could be applied with practical characteristics of generator as the constraints in a way to solve the nonlinearity of the ED problems.

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