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A hybrid optimization technique for solving economic dispatch problem

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Abstract. Economic dispatch (ED) is one the main power system problems solved during operational planning phase. It is solved by power system engineers with the objective to find the best setting of dispatchable generating units output so that the total production cost is cheap and at the same time abiding the system constraints. For the past ten years, researchers and engineers have been focusing on hybrid optimization techniques to solve ED problems. The strength of each hybridized technique is combined to form an improved optimization technique. Most of the hybrid techniques are combination of two or more meta-heuristic techniques. This paper proposed a new hybrid technique termed as immune evolutionary programming (IEP) to solve economic dispatch problem. The technique is a combination of two population based optimization techniques which are artificial immune system (AIS) and evolutionary programming (EP). In order to study the effectiveness of the proposed technique, the results produced have been compared with the results produced using AIS and EP techniques. It is found that IEP succeeded to give the lowest total production cost compared to the other two techniques.

1. Introduction

Economic dispatch will always be the main topic among the power system engineers and researchers to be discussed in power system planning and operation. This happens because most of the main sources of electricity come from fossil-fuelled generating units. The fuel of the generating units can be coal, natural gas or petroleum. Therefore, the fuel price must be taken into account in dispatching the electric power. The input-output curve of each generating unit is different to one another. The difference can be caused by the type of fuel, design and efficiency of the generating units. In the process of solving ED problem, cheap generating units are forced to dispatch their power to the load first followed by expensive generating units. Basically, the generating units are ranked ascendingly based on their fuel price. ED is one of the optimization type of problems. Hence, it must be solved using optimization techniques. Optimization techniques can be divided into two categories: mathematical techniques and heuristic

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techniques. Several mathematical techniques have been introduced by researchers to solve ED problems such as linear programming [1]–[3], quadratic programming [4], mixed integer programming [5], etc. For the past ten years, heuristic techniques become more popular to be used for solving ED problems. This is because their capability to handle the non-smooth cost function of ED problems better than mathematical techniques. Examples of heuristic techniques that have been used for solving ED problems are evolutionary programming [5], particle swarm optimization [6], artificial bee colony algorithm [7], kinetic gas molecule [8], etc.

In recent years, the trend of solving ED problems have changed from single techniques to hybrid techniques. Normally, a hybrid technique is a combination of two or more techniques. It is proven that these hybrid techniques have capability to solve the ED problems better than single techniques. For example, Gherbi et al. [9] proposed to hybrid two meta-heuristic techniques which are firefly algorithm and bat algorithm. The technique outperformed single techniques like genetic algorithm and those two techniques that made up the hybrid technique. Instead of combining the firefly algorithm with bat algorithm, Musau et al. [10] chose to combine with Levy Flights. The hybrid technique was used to solve multi-objective economic and emission dispatch. In [11] evolutionary programming and tabu search algorithm have been hybridized to solve multi-area ED problem. Elaiw et al. [12] solved the ED problem with valve-point loading effect using a hybrid technique called DE-SQP. The technique is a combination between differential evolution and sequential quadratic programming. This is a new approach that combine between mathematical and heuristic type of techniques. Different with Elaiw et al., Sayah & Hamouda [13] combined the DE with PSO instead. The hybrid technique is termed as DEPSO which PSO acts as the main optimizer of the hybrid algorithm. Pandian & Thanushkodi [14] used a hybrid EP-EPSO technique to solve smooth and non-smooth ED problems. The technique is made up of evolutionary programming and particle swarm optimization techniques. Genetic algorithm (GA) and active power optimization (APO) have been hybridized in [15] to solve non-convex ED problem. The global optimizer for this technique is GA while an operator of APO named Newton's second order approach (NSOA) is adopted into the GA. The NSOA of APO helped the GA in searching the best optimal solution of the non-convex ED.

This paper presented a new hybrid technique termed as Immune Evolutionary Programming (IEP) for solving ED problem. The technique is made up of two heuristic techniques which are evolutionary programming (EP) and artificial immune system (AIS). EP and AIS are population type of optimization techniques. These two techniques have been popularly used to solve power system problems such as distributed generation installation [16], FACTS devices installation [17] and ED problems [18]. The proposed IEP technique have been tested on the IEEE 26-bus reliability test system (RTS) and its results have been compared with EP and AIS techniques. IEP managed to give better total production cost compared to the other two techniques.

2. Economic dispatch problem formulation
The main objective of solving economic dispatch problem is to minimize total production cost. The objective function of total production cost can be written as follows:

$$Minimize\ C_{total} = \sum_{i=1}^{n} C_i(P_i), i \in \{1,2, \dots, n\} \tag{1}$$

C_{total} is the total production cost, $C_i(P_i)$ is production cost of ith generating unit and n is number of generating units in the system. The production cost function of a single generating unit is made up of fuel cost coefficients and its real power output. Production cost function of ith generating unit can be represented as a smooth quadratic function as shown in (2).

$$C_i(P_i) = aP_i^2 + bP_i + c \tag{2}$$

In optimizing the objective function, some constraints must be considered. The constraints for this ED problem are:

A. Operating limits of generating units
Each dispatchable generating unit has its own cost function and it can be different from one to another. The cost function depends on the type fuel used and the capacity of the generating units. The operating limits of a generating unit can be written as follows:

$$P_{i(min)} \leq P_i \leq P_{i(max)}, i \in \{1,2,\dots,n\} \tag{3}$$

$P_{i(min)}$ and $P_{i(max)}$ are the minimum operating limit and the operating maximum limit of ith generating unit's, respectively.

B. Power balance constraint
It is a must to ensure the power generated is sufficient for the demand. Therefore, the power generated must be equal to total system loss plus demand. This power balance constraint can be written as follows:

$$P_{generate} = P_{loss} + P_{demand} \tag{4}$$

Total system loss, P_{loss} can be calculated using the equation shown in (5).

$$P_{loss} = \sum_{k=1}^{l} g_k[V_i^2 + V_j^2 - 2V_iV_j cos(\delta_i - \delta_j), k \in \{1,2,\dots,l\} \tag{5}$$

Where,
g_k is conductance of kth line,
V_i and δ_i are voltage magnitude and angle of bus i, respectively
V_j and δ_j are voltage magnitude and angle of bus j, respectively, and
l is number of lines in the system.

3. The proposed hybrid technique
The proposed hybrid technique termed as Immune evolutionary programming (IEP) is developed from two single optimization techniques which are evolutionary programming (EP) and artificial immune system (AIS). EP is the main optimizer for this algorithm and the cloning operator of AIS is adopted into EP. The structures of these two methods are shown in Figure 1 and Figure 2.
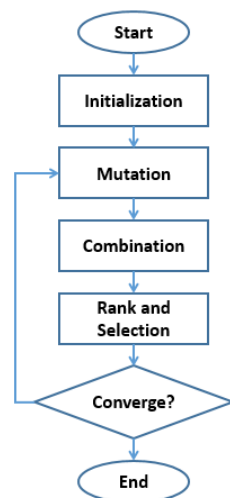
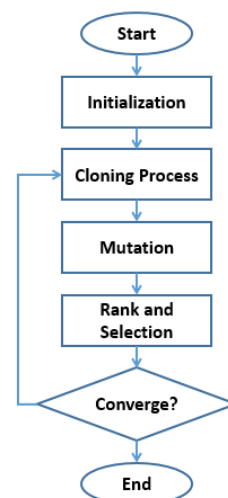**Figure 1.** Standard procedure of EP algorithm.

Figure 2. Standard procedure of AIS algorithm.

The advantages of their operators are gathered in the new hybrid technique in order to get better solution of ED problem. The cloning operator of AIS can be used to multiply the number of initial individuals produced from the initialization process. This will increase the chances to find the best global optima. Besides that, the combination operator of EP also plays important role in finding the fittest individuals that resulting to the best fitness value. The whole structure of IEP algorithm is shown in Figure 3.
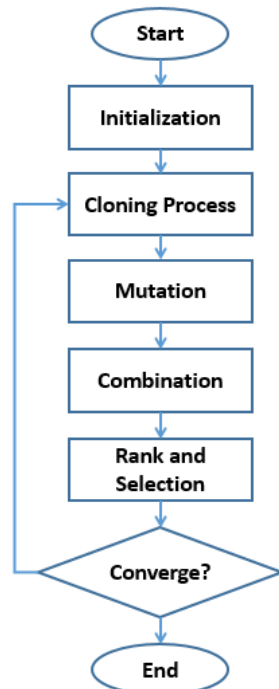

Figure 3. The IEP procedure.

The IEP algorithm starts with the initialization process. During this process, the values of decision variables are generated. For this ED problem, the decision variables are the real power output of generating units. The operating limits of the generating units are taken into account in generating the values. Then, fitness value which is total production cost is calculated based on the generated decision variables values. It is ensured that the fitness value is lower than the base value. The base value came

from the non-optimal solution which is load flow solution. From this initialization process, a population of decision variables and fitness is produced. The size of the population is twenty.

Subsequently, the population produced from the initialization process will undergo the cloning process where the number of individuals are multiplied by ten to be 200 individuals. The population produced from the cloning process is called parents. After that, the parents will be mutated to produce their offsprings. Gaussian mutation technique shown in (6) is used to produce the offsprings. The size of this offspring population is also 200 individuals.

$$x_{i+m,j} = x_{i,j} + N\left(0, \beta\left(x_{jmax} - x_{jmin}\right)\left(\frac{f_i}{f_{max}}\right)\right) \tag{6}$$

Where:
$x_{i+m,j}$ is mutated parent individual (offspring) $\quad$ x_{jmin} is minimum random number for every variable
x_{ij} is parent individual $\quad$ f_i is fitness for *ith* random number
β is mutation scale, $0 < \beta < 1$ $\quad$ f_{max} is maximum fitness
x_{jmax} is maximum random number for every variable

The fourth process is combination. During this process, the parent population and offspring population are combined to be 400 individuals. From this 400 individuals, there are then ranked based on their fitness. The fittest individuals will have high chances to be selected for the next steps. Only twenty fittest individuals are selected to undergo the convergence test. The process will continue with cloning process until the IEP algorithm is converged. The IEP algorithm is said to converge when the difference between the first and the twentieth fitness values is 0.00001. This can be represented mathematically as follows:

$$C_{total(20th)} - C_{total(1st)} \leq 0.00001 \tag{7}$$

4. Results and discussion
The IEEE 26-bus reliability test system (RTS) is used for the demonstration. Prior to the IEP implementation, the ED problem has been solved using the single EP and AIS techniques. This is done for comparison purposes. Three cases have been introduced to study the performance of the IEP technique to solve ED problem. Each case has different load level. The first case has 50 % load increment which makes the load 1894.50 MW. While the second case has 70 % load increment. And, the third case has 100 % load increment.
All the optimization results produced from the proposed IEP, AIS and EP for case 1, case 2 and case 3 are presented in Table 1, Table 2 and Table 3 respectively.

Table 1. ED solution of 26-bus system with 50 % load increment.

Optimization Technique	**IEP**	**AIS**	**EP**
P_{G1} (MW)	101.34	113.83	113.82
P_{G2} (MW)	75.03	58.02	58.01
P_{G3} (MW)	93.96	196.53	196.53
P_{G4} (MW)	98.93	117.11	117.11
P_{G5} (MW)	112.48	51.15	51.15
P_{G26} (MW)[a]	74.33	76.84	76.84
Total Production Cost ($/h)	7.13	7.72	7.72

Table 2. ED solution of 26-bus system with 70 % load increment.

Optimization Technique	IEP	AIS	EP
P_{G1} (MW)	134.13	113.83	113.82
P_{G2} (MW)	57.85	58.02	58.01
P_{G3} (MW)	95.56	196.53	196.53
P_{G4} (MW)	103.31	117.11	117.11
P_{G5} (MW)	94.00	51.15	51.15
P_{G26} (MW)[a]	53.43	76.84	76.83
Total Production Cost ($/h)	6.79	7.72	7.72

Table 3. ED solution of 26-bus system with 100 % load increment.

Optimization Technique	IEP	AIS	EP
P_{G1} (MW)	119.28	130.56	109.71
P_{G2} (MW)	73.85	81.33	92.32
P_{G3} (MW)	107.13	91.26	186.41
P_{G4} (MW)	118.99	122.50	143.48
P_{G5} (MW)	52.36	119.24	195.15
P_{G26} (MW)[a]	106.15	94.49	91.09
Total Production Cost ($/h)	7.38	8.08	10.30

From the optimization results presented in Table 1, Table and Table 3, it can be seen that the proposed IEP technique outperformed the single AIS and EP techniques in giving the lowest production cost for the all three cases. The production costs produced in case 1 and case 2 are almost the same. This is because the load difference between case 1 and case 2 is small, unlike case 3 which has double the load compared to case 1.

5. Conclusion
In this paper, a new hybrid optimization technique termed as immune evolutionary programming has been successfully used to solve ED problem. Cloning operator of AIS has been adopted into the proposed IEP to improve its search pattern for the global optima. Meanwhile, the combination operator of EP increases its chance to find a better ED solution. It can be concluded that the objective of this ED problem to minimize the total production cost is achieved in this paper.

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