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SOLVING ECONOMIC DISPATCH (ED) PROBLEM USING ARTIFICIAL IMMUNE SYSTEM, EVOLUTIONARY PROGRAMMING AND PARTICLE SWARM OPTIMIZATION

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ABSTRACT

Nowadays, the demand of the electrical energy is increased due to increment in loading and it is desired to use the existing transmission network to its thermal stability limits. The electrical power system are designed and operated to meet the continuous variation of power demand. The power demand is shared among the generating units and economic of operation is the main consideration in assigning the power to be generated by each generating unit. This paper presents the application Evolutionary Programming (EP), Artificial Immune System (AIS), and Particle Swarm Optimization (PSO) techniques for solving an economic dispatch (ED) problem. The purpose of ED technique in this study mainly to minimize the total generation cost and transmission losses in the system. The proposed optimization technique was validated on 26-bus IEEE Reliability Test System (RTS).

Keywords: evolutionary programming, particle swarm optimization, artificial immune system, economic dispatch.

INTRODUCTION

Daily generation scheduling is an essential operational problem with an electrical utility and has been a subject of intensive research over the past years. With the existence of electrical power systems, more or less are capable to produce sufficient electrical power to feed a certain range of load demand. As an engineer, it is always concerned with the cost of products and services. With problem arises in the electric networks, the energy crisis in the world and continuous rises in prices upon distribution, it is important for an engineer to reduce the running charges of the electric energy.

Economic Dispatch (ED) can be defined as the process of determining the optimal output of generation levels to generation facilities at the lowest cost and reliable to support the overall load of the system. ED can be considered as minimizing only the fuel cost through determining the allocation of generation among a set of committed units in the same thermal power plant or among a number of committed thermal power plants of different locations subject to the constraint that total generation equal to the demand or total generation equal to demand and transmission losses for ED among power plants. Rahman et.al. [1] state that economic dispatch is a procedure to determine the electrical power to be generated by the committed generating units in a power system so that the total generation cost of the system is minimized, while satisfying the load demand simultaneously.

ED is important tasks in power system planning and operation. Both tasks can be formulated mathematically as optimization problems with the objective of minimizing the fuel cost function [2]. The economic load dispatch (ELD) is one of the most important optimization problems from the viewpoint of power system to derive optimal economy. Classically, it is to identify the optimal combination of the generation level of all generating units which minimizes the total fuel cost while satisfying the load. This classical ELD formulation has been solved by various methods like Lagrange method, Newton's method etc [3].

ECONOMIC DISPATCH

Having high-quality, reliable power supply to the consumer with lower operating cost while meeting the operating limit and constraints imposed on the generating unit is one of the main objectives of electric power utilities. Besides that, an Economic dispatch problem has become a crucial task in the operation and planning of power systems. The primary objective of ED is to schedule the committed generating unit's output at minimum cost satisfying all unit and system operational constraints. Improvement in scheduling the unit outputs can lead to significant cost saving.

Dhillon *et al*. [4] formulated the problem as multiobjective. They considered objectives such as operating costs, minimal emission and minimize transmission losses in thermal power dispatch systems, considering uncertainties and inaccuracies in system data. The validity and effectiveness of the method were demonstrated by analysis a 6-generator case.

The objective of the classical ED problem is to minimize the total system fuel cost over some appropriate period while satisfying various constraints, and thus the problem can be defined as the following constrained optimization problem [5]:

Minimize

$$\min f = \sum_{j=1}^{N_g} F_j\left(P_j\right) \tag{1}$$

Subject to

$$P_j = \sum_{j=1}^{N_g} P_D + P_L \tag{2}$$

$$Pj^{min} < Pj < Pj^{max} \tag{3}$$

where $F_j(P_j)$ *is* the cost function of the j^{th} generating unit (in \$/h), P_j is the real output of generating unit j (in MW), and Ng is the total number of generating units in this power system.

Equality constraint in Equation. (2) means that the total system generation includes the load demand of the system and the transmission losses. While the total generation cost is being minimized, the total generation Equation. (1) should be equal to the total system demand P_D (in MW) plus the transmission network loss P_L (in MW). Inequality constraint in Equation. (3) requires that the generation of each unit should be between its minimum (Pj^{min}) and maximum (Pj^{max}) production limits, which are directly related to the design of the program.

The cost function of each generating unit is related to the actual power injected into the system, and is typically modeled by a smooth quadratic function as:

$$F_j(P_j) = a_j + b_j + c_j P_j^2 \tag{4}$$

where a_j, b_j and c_j are the cost coefficients of the j^{th} generating unit.

This paper presents AIS, EP and PSO based optimization technique to minimize total generation cost and total transmission losses in a power system. All three techniques were validated on the IEEE 26-bus Reliability Test System (RTS).

ARTIFICIAL IMMUNE SYSTEM (AIS)

There have been a number of methods available in recent years for optimization in transmission and distribution system, namely the conventional or artificial intelligence (AI) based technique. Artificial Immune System (AIS) is a new branch of AI used for computational models and problem solving methods [6, 7, 8]. The AIS can be defined as the metaphorical system developed using ideas, theories, and components, extracted from the natural immune system [9]. The algorithms for AIS are shown below:

Step-1: Initialization; during initialization, random number will be generated which represent the control parameters which determine the objective function. Maximum of 100 random numbers will be generated. The program is used to generate 10 random numbers one at a time. Every time a random number is generated, fitness will be calculated. The random number is calculated using equation as follow:

$$r = a + (b - a) * rand(1,1) \tag{5}$$

where: r = random number
a = minimum generator real power limits
b = maximum generator real power limits

Step-2: Cloning or proliferation; population of variable x will be cloned by 10. Thus the number of cloned population is 100. The clone population x' will then be assigned back to the generator and fitness of the objective function is calculated.

Step-3: Mutation or affinity maturation; each individual clone will be mutated. The type of mutation used is a Gaussian Mutation Technique. The equation of mutation can be express as Equation. (6).

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

where: $x_{i+m,\,j}$ = offspring
$x_{i,\,j}$ = parents
β = search step
$x_{j\,max}$ = max parents
$x_{j\,min}$ = min parents
f_i = fitness 'ith'
f_{max} = max fitness

Step-4: Combination process; the population of mature clones and the initialization population are combined and rank in ascending order based on the objective function. The minimum and maximum total transmission loss is determined from the combined population. Ten of the best individuals (with the highest affinity) are selected to become a memory population or the next generation.

Step-5: Tournament selection; the selection technique used is the tournament scheme. This is done to select a new population of the same size as the initial from the initialization and mutated clones. This selection is used to identify the candidates that can be transcribed into the next generation of the combined population of the parents and offspring. An individual is randomly selected from the set of parents and offsprings population. The populations of individuals with better fitness function were sorted in ascending order.

Step-6: Convergence test; optimization is achieved if the differences between the maximum and minimum fitness in the combined population satisfy the convergence criterion, which is stated in Equation. (7).

$$\textit{Max fitness} - \textit{min fitness} \leq 0.0001 \tag{7}$$

If the first iteration is not achieved, the newly selected memory set will replace the initial population and the process is repeated.

EVOLUTIONARY PROGRAMMING

Evolutionary Programming (EP) is a technique that has been applied to power system in order to minimize total transmission losses. EP starts with an initial population of randomly generated solutions, and evolves toward better solutions over a number of generations or iterations [10-12]. Being population based model, this

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ARPN Journal of Engineering and Applied Sciences

method is able to produce a family of good solutions with respect to the objective or fitness function.

A new population called offspring population is formed from an existing parent population through a mutation operator. This operator perturbs each individual in the parent population by a random amount to produce the offspring individual. The degree of feasibility and optimality of each offspring individual in the offspring population is measured by its fitness value, which can be expressed as a function of the objective function [10].

Initialization step is to generate random numbers and build up a population from several of random numbers which satisfy some constraints. Through the random numbers, population was held and it measured by objective function which is its fitness value.

Mutation is a process to generate offsprings or children from parents. In this case, random numbers are parents. Random numbers are chosen to select the row and column of the variables to be mutated. A chosen variable is replaced by a new random variable. There are few types of mutation Gaussian, Cauchy and combined Gaussian-Cauchy mutation. In this project, Gaussian mutation was used to mutate the random numbers. Gaussian mutation is also known as Classical Evolutionary Programming. The equation of mutation can be express as Equation. (6).

Combination process is to combine the parents and offsprings in the series, which means by rows. Thus, the number of rows will be doubled. After the combination, the parent and corresponding offspring will compete with each other by comparing the cost. The vector with has minimum cost whether it is parent or offsprings are selected for the next new generation. The optimal solution was found among all population groups. All steps from initialization and mutation will be repeated until it meets with the constraint on the fitness value.

PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization is one of the stochastic search algorithm which is the most recent development among others optimization. It was first introduced by Kennedy and Eberhart in 1995 [13]. In PSO, by following the current optimum particle, the potential solutions that called particles, fly through the problem space and every particle finds its personal best position and group best position through iteration. Then, these particles modified their progressing direction and speed to reach the optimized position quickly. It has been successfully applied in many areas because of the rapid convergence speed of PSO [14].

Figure-1 shows a flowchart of PSO technique to solve the economic dispatch problem. The basic elements of standard PSO are briefly stated and defined as follows [13]:

- Particle X_i (t), i = 1, . . . , n: It is a potential solution represented by an n-dimensional vector, where n is the number of decision variables.
- Swarm: It is an apparently disorganized population of moving particles that tend to cluster together while each particle seems to be moving in a random direction.
- Individual best position P_i(t), i = 1, . . . ,n: As a particle moves through the search space, it compares the fitness value at the current position to the best fitness value it has ever attained at any time up to the current time.
- Global best position, P_g*(t)*: It is the best position among all individual best positions achieved so far.
- Particle velocity V_i (t), i = 1, . . . , n: It is the velocity of the moving particles, which is represented by an n-dimensional vector. According to the individual best and global best positions, the particle velocity is updated. After obtaining the velocity updating, each particle position is changed to the next generation.

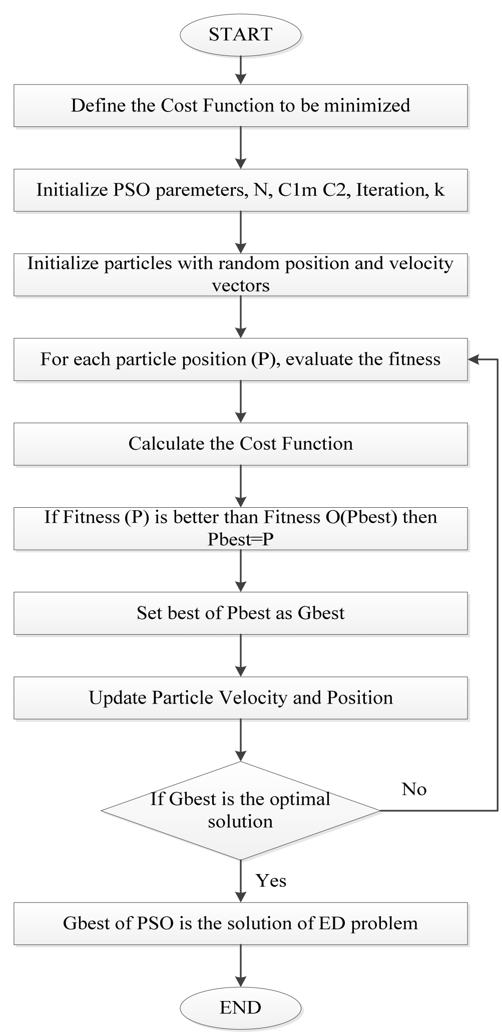

Figure-1. Flow chart of PSO technique.

ARPN Journal of Engineering and Applied Sciences

The procedure for implementing the global version (or star neighborhood topology) of PSO can be summarized by the following steps.

Step-1: Initialize the total cost function from the individual cost function of the various generating stations. For the population size, the particles randomly generated in the range and located between maximum and minimum operating limits of the generators.

Step-2: Initialize PSO parameters such as, number of particles*, C1, C2, W* etc.

Step-3. Initialization: Initialize a swarm (population) of particles with random positions and velocities in the n dimensional problem space using a uniform probability distribution function.

Step-4: Evaluation: Evaluate the fitness value of each particle in the swarm (population).

Table-1. Results for ED using AIS, EP and PSO with bus 25 loaded.

Optimization Condition	Loading (Mvar)	Generation cost ($/h)			Total losses (MW)		
		AIS	EP	PSO	AIS	EP	PSO
Pre	0	16757.66			15.3457		
Post		16219.53	16220.66	16193.31	14.7696	14.7696	15.5018
Pre	50	16785.44			16.9815		
Post		16239.11	16240.44	16212.62	16.7200	16.7868	16.7677
Pre	100	16874.50			22.1700		
Post		16286.89	16287.50	16278.12	21.4205	21.4205	21.4799
Pre	150	17048.26			32.1916		
Post		16396.04	16396.26	16389.15	32.0288	32.0289	33.7684
Pre	200	17463.98			55.8214		
Post		16644.26	16635.98	16635.34	55.5645	54.7209	54.7209

Table-2. Results of comparative studies for ED.

Criteria	Pre_Opt	Post_Opt at Q = 200 MVar		
		AIS	EP	PSO
Total Cost ($/h)	17463.98	16644.26	16635.98	16635.34
Total Loss (MW)	55.8214	55.5645	54.7209	54.7209

Step-5: First comparison: Compare each particle's fitness with the particle's *Pbest*. If the current value is better than *Pbest*, then set the *Pbest* value equal to the current value and the *Pbest* location equal to the current location in n-dimensional space.

Step-6: Second comparison: Compare the fitness with the population's overall previous best. If the current value is better than Gbest, then reset Gbest to the current particle's array index and value.

Step-7: Updating: Change the velocity and position of the particle.

Step-8: Repeat steps 4-9 until the stopping criterion of maximum generations is met.

Step-9: Stopping criterion: Loop to step 2 until a stopping criterion is met, usually a sufficiently good fitness or a maximum number of iterations.

RESULTS AND DISCUSSIONS

Validation process was conducted on IEEE 26-Bus RTS. This system has 6 generator buses and 5 control variables that used for ED considering 1 bus was taken as the swing bus. This study consequently compared between the three techniques such as AIS, EP and PSO. The comparison is made in terms of total cost minimization and total loss reduction. Table-1 shows the performance of three optimization methods namely AIS, EP and PSO for solving the ED problems when bus 25 was subjected to the load variation considering the total cost minimization as the objective function. From the table, it is observed that the total cost at every loading condition with the implementation of AIS (post) is lower than before the implementation of ED (pre). This means that the total cost have been improved when ED was implemented. On the other hand, the total loss in the system has also been improved.

Detailed assessment of results on the loading conditional explains the above phenomenon. The total cost at Q = 200 MVar identified using AIS is reduced significantly from 17463.98 $/h to 16644.26 $/h. It has also reduced the value of total loss from 55.8214 MW to 55.5645 MW. The results for other loading conditions can be observed in the same table. AIS has successfully minimized the total cost in the system indicated by minimization of total cost values.

In addition, the result for ED performed using EP are also tabulated in a same table. From the table, it is observed that, at Q = 200 MVar, the cost has been minimized from 17463.98 $/h to 16635.98 $/h. At the

ARPN Journal of Engineering and Applied Sciences

same time, total lost is reduced from 55.8214 MW to 54.7209 MW, respectively. As for the PSO, it is observed the total cost has been reduced from 17 463.98 $/h to 16 635.34 $/h for 200 MVar loading condition with the total lost is reduced from 55.8214 MW to 54.7209 MW. The results for other loading condition indicated in the same table.

Table-2 tabulates the results of comparative studies using AIS, EP and PSO. From the table, it is observed that PSO managed to minimize the total cost value to 16635.34 $/h while AIS and EP managed to minimize the total cost value to 16644.26 $/h and 16635.98 $/h. The difference in cost minimization is very close using this three techniques. This indicates that PSO is comparable with AIS and EP.

On the other hand, the reductions of total loss are the lowest performed using PSO and EP. It is observed that PSO and EP managed to reduce the total loss value to 54.7209 MW nevertheless AIS managed to reduce the total loss value to 55.5645 MW. Furthermore, the PSO has outperformed EP and AIS in all criteria concerning total cost minimization and total loss reduction. This reveals the superiority of PSO over the others.

CONCLUSIONS

AIS, EP and PSO techniques have been developed in this study to perform ED in a power transmission system. The three techniques have been successfully tested on the IEEE-26 bus RTS. The merit of PSO over EP and AIS can be highlighted in terms of cost minimization. The original philosophy of using PSO in solving the discrete or a graph problem has been enhanced into a continuous problem as highlighted in this study. Minor modification of the developed PSO algorithm or engine could be the next step for solving more complex power system optimization problems.

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