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NOVEL OPTIMIZATION BASED ON THE ANT COLONY FOR ECONOMIC DISPATCH

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Abstract- This paper presents a novel stochastic optimization approach to determining the feasible optimal solution of the economic dispatch (ED) problem considering various generator constraints and also conserves an acceptable system performance in terms of limits on generator real and reactive power outputs bus voltages, shunt capacitors/reactors, transformers tap-setting and power flow of transmission lines. To show its efficiency and effectiveness, simulation results on the IEEE 30-bus electrical network whit the proposed ant colony optimization (ACO) is applied to types of ED problems with non-smooth cost functions. The experimental results show that the proposed ACO approach is comparatively capable of obtaining higher quality solution.

Keywords: Non-Smooth Cost Functions, Ant Colony Optimization, Economic Dispatch, Ant Colony Optimization (ACO).

I. INTRODUCTION

The economic load dispatch reflects the optimal electrical output of generation facilities, to fulfill the system load demand, at the lowest possible cost, while providing power in a robust and reliable way. Economic load dispatch problem is one of the fundamental matters in power system operation. In essence, it is an optimization problem and its main objective is to cut-down the total generation cost, without breaching any constraints [1]. It plays an important role in operation planning and control of modern power systems. It combines a highly nonlinear, nonconvex and computationally difficult environment with a need for optimality. Several classical optimization techniques, such as, linear programming (LP), homogenous linear programming (HLP) [2], nonlinear programming (NLP) [3], quadratic programming (QP) [4] and dynamic programming (DP) [5] were used to solve the economic dispatch. The LP is so fastest; so far it has failed to consider the system constraints effectively.

The DP is one of the approaches to solve the nonlinear and discontinuous ED. problem, but the problem of "curse of dimensionality" or local optimality with the DP method is caused in the solution procedure. NLP needs a convex and continuous solution space ordinarily. Artificial intelligence, unlike strict mathematical methods, has the apparent ability to adapt to nonlinear, nonconvex and discontinuous problems. The genetic algorithms (GA) [6, 7], has been successfully applied to ED problem for valve point discontinuities. The results were verified for a sample problem by using a dynamic programming technique.

With several different techniques, refined CA enhances program efficiency and accuracy. Tabu search (TS) [8], neural networks (NN) [9], chaotic optimization (CO) [10] and integrated algorithm were devoted to solving the highly nonlinear ED problems without restrictions to the shape of fuel cost functions. Recently, a new global optimization technique known as ant colony optimization (ACO) has become a candidate for many optimization applications. Dorigo and Maniezzo developed traditional ant colony optimization in 1990's, which can only be used to solve different combinatorial optimization problem. It was inspired by the behavior of real ant colonies, in particular, by their foraging behavior, and has the characteristics of versatility, robustness and population based approach.

The ant colony optimization has been used to solve several combinatorial optimization problems, such as the traveling salesman problem (TSP) [11], the asymmetric traveling salesman problem (ATSP) [11], quadratic assignment problem (QAP) [11], job-shop scheduling problem (JSP) [11], single machine total tardiness problem (SMTTP) [12], redundancy allocation [13], recognizing Hamiltonian graphs [14], subset problems [15], random binary constraint satisfaction problems (CSPs) [16], optimal design and scheduling of batch plants [17] and short term generation scheduling problem of thermal units [18].

This paper presents an innovative approach based on ant colony algorithm was chosen for solving the load flow problem for 30-bus IEEE system [19] as Figure 1.

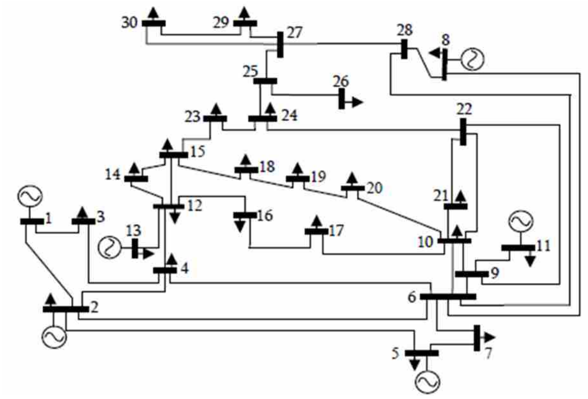

Figure 1. Topology of the IEEE 30-bus

II. ECONOMIC LOAD DISPATCH

The objective of Economic Load Dispatch is to minimize the operating cost of each generating unit in the system. Thus, an optimal generated output can be acquired from the solution. Economic Load Dispatch can be calculated by using the following equation:

$$optimum\ \cos t = \sum_{i}^{N_g} F_i(P_i) \tag{1}$$

where *cost* is the operating cost of power system and the objective function is to minimize the cost, N_g is the number of units, $F_i(P_i)$ is the cost function and P_i is the power output of the unit i. The $F_i(P_i)$ is usually approximated by a quadratic function of its power output P_i as:

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

where a_i, b_i, and c_i are the cost coefficients of unit i. The above equation is subjected to both the equality and inequality constraint as follow:

- Real power balance constraint is given by:

$$\sum_{i}^{N_g} F_i(P_i) = P_D + P_L \tag{3}$$

- Real power generation limit is given by:

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

where P_D is the total load demand in MW, P_L is the total transmission loss of the system in MW, $P_{i,\min}$ and $P_{i,\max}$ are the minimum and maximum generation limit of P_i. Next, the search of the optimal control vector is performed using into account the real power flow equation which present the system transmission losses (P_L). These losses can be approximated in terms of B coefficients as [20]:

$$Pf = \left(1 - \frac{\partial P_L}{\partial P_g}\right)^{-1} \tag{5}$$

These losses are represented as a penalty vector [21, 22] given by:

$$P_L = \sum_{i}^{N} \sum_{j}^{N} P_i B_{ij} P_j \tag{6}$$

The transmission loss of a power System P_L can be calculated by B-Coefficients method [23] and given by:

$$P_L = \sum_{i}^{N} \sum_{j}^{N} P_i B P_j + \sum_{i}^{N} B_{oi} + B_{oo} \tag{7}$$

where B is an $n_g \times n_g$ coefficients matrix, $B0$ is an n_g dimensional coefficient column vector and B_{00} is a coefficient.

III. ANT COLONY OPTIMIZATION

A. Basic Principle of Ant Colony

The ACO algorithm is inspired by the collective behaviour of a real ant colony. Marco Dorigo first introduced the ACO in his Ph.D. thesis in 1992. Further studies have been carried out. The characteristics of an artificial ant colony include positive feedback, distributed computation, and the use of a constructive greedy heuristic. Positive feedback accounts for rapid discovery of good solutions. Distributed computation avoids premature convergence. The greedy heuristic helps to find acceptable solutions in the early stages of the search process. ACO is an evolutionary meta-heuristic algorithm based on a graph representation.

The main idea of ACO is to model the problem as the search for a minimum cost path in a graph. Artificial ants walk through this graph and look for good paths. Better paths are found as the emergent result of the global cooperation among ants in the colony. Naturally, an ant deposits pheromone while walking. It probabilistically prefers to follow a direction which enriches pheromone. This behaviour can be explained how ants can find the shortest path that reconnects a line broken by an obstacle. For example, finding the new shortest path once the old one is no longer feasible due to the new obstacle.

This can be clearly illustrated by Figure 1(a). Ants are on a straight line that connects a food source to their nests. In Figure 1(b), those ants are just in front of the obstacle and they cannot continue to go. Therefore, they have to choose between turning right or left. Half the ants choose to turn right and another half choose to turn left. A similar situation arises on another side of the obstacle in Figure 1(c). Ants choosing the shorter path more rapidly reconstitute the interrupted pheromone trail compared with those choosing the longer path.

Thus, the shorter path receives a greater amount of pheromone per time unit and, in turn, a larger number of ants choose the shorter path. Due to this positive feedback, all ants rapidly choose the shorter path in Figure 1(d). All ants move at approximately the same speed and deposit a pheromone trail at approximately the same rate. The time consumed on the longer side of an obstacle is greater than the shorter one. This makes the accumulation of pheromone trail more quickly on the shorter side.

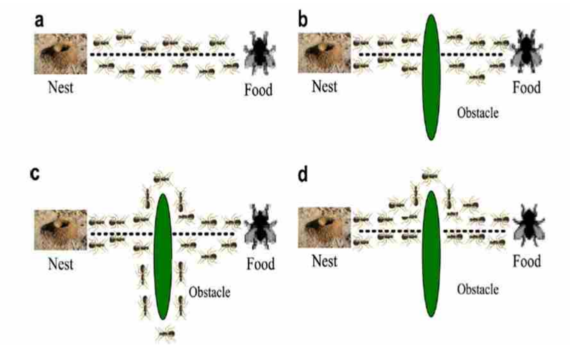

Figure 1. Behavior of ants

B. ACO Algorithm

B.1. State Transition Rule

The state transition rule used by the ant colony is given in below. This represents the probability that the ant k selects the jth power output of the ith generator:

$$P_{ij}^{k}(t)=\frac{[\tau_{ij}]^{\alpha}[\eta_{ij}]^{\beta}}{\sum_{m=1}^{M_i}[\tau_{ij}]^{\alpha}[\eta_{ij}]^{\beta}} \quad (8)$$

where τ_{ij} and η_{ij} are the pheromone intensity and the heuristic information between the jth power output of the ith generator, respectively, α is the relative importance of the trail and β is the relative importance of the heuristic information η_{ij}. The heuristic information can be formulated by:

$$\eta_{ij}=1/C_{ij} \quad (9)$$

where C_{ij} represents the associated cost. That is, the node with smaller cost has greater probability to be chosen.

B.2. Global Updating Rule

During the construction process, it cannot guarantee that an ant can construct a feasible solution which obeys the equality and inequality constraints. The unfeasibility of solutions is treated in the pheromone update. The amount of pheromone deposited by an ant is set to a high value if the generated solution is feasible and to a low value if the generated solution is infeasible. These values are dependent of the solution quality. Infeasibilities can then be handled by assigning penalties which are proportional to the amount of cost violations. In the case of feasible solutions, an additional penalty proportional to the obtained solution is introduced to improve the solution's quality. Following the above remarks, the trail intensity is updated as follows:

$$\tau_{ij}(new)=\rho\tau_{ij}(old)+\Delta\tau_{ij} \quad (10)$$

ρ is a coefficient such that (1-ρ) represents the evaporation of trail and $\Delta\tau_{ij}$ is:

$$\Delta\tau_{ij}=\sum_{k=1}^{m}\Delta\tau_{ij}^{k} \quad (11)$$

where m is the number of ants and:

$$\Delta\tau_{ij}^{k}=\begin{cases} Q/L_k & \text{if}\,(i,j)\in \text{tour of ant}\,k \\ 0 & \text{otherwise}\end{cases} \quad (12)$$

where Q_0 is a constant related to the amount of pheromone laid by ants and L_k is tour length of kth ant.

IV. ACO ALGORITHM FOR SOLVING ED PROBLEM

In this study, an innovative approach based on Ant Colony Algorithm was chosen for solving the load flow problem, i.e. This method pretend the two groups of ants in a parallel mood, in a way that one group moves in the increasing direction and the other one moves in the increasing direction. After giving the primary values, the two groups converge to the minimum found amount and on their way to this point. In this way, we should enter the probability of the answer to the existing answer, according to the value of the β, α and the probability function.

The initialization method that we have utilized in the following algorithm is an innovative method which is proposed by our group. The increasing primary amount is chosen in a way that at first, all the units should take their minimum amount and after that, we act according to the conditions "3" and "4" and the following algorithm:

In this method chose an ant. According to the probability function of one of the units, then chose one of them. Then for adding the "δ" (delta) value, we act in accordance to the primary value that was defined for it previously. Originally, the amount of change or the amounting is pretend to be increasing and testing this condition that by adding the amount of delta, the condition "4" will not be violated, will fix the desired amount and go to the next level, otherwise this level should be repeated and in the condition that "3" is violated, have to go to the level "C".

1. If the condition "3" is correct, go to the level "C", otherwise have to go back to the level "A" and do the initialization again.
2. The primary amounting is done.
3. Choose another ant (The number of ants is determined at first).

In this study we should do the same guess algorithm in a decreasing way, in which we give the maximum amount of units to them and we step in the decreasing route. In order to get to the optimum result in accordance to the guess algorithm, In the part that we are getting the best results, in which the more number of these results the more the accuracy and the less the speed of running the code(CPU time) and the existing results include the prices of each unit.

Actually we have obtained a lot of data at the end of the process. In this study we have to get to the most optimum level within the data, by combining the repetition of the ant algorithm with "summation, subtraction, division and multiplication" functions, regardless of the fact that we will probably need to use the guess algorithm. Of course, the formula "8" will help us to decide whether to use the ant algorithm or to use guess algorithm.

At the end we can pretend another group of ants, that increase the accuracy, that will move among the most optimized answers that were found up to now, and then they will chose the best one and decreasing the amount of "delta" will result in increasing accuracy and decreasing much more speed.

It should be mentioned that this last part is helpful mostly in huge systems (e.g. 40 generator systems), and will not be needed to use it in small systems. The method used the IEEE 30-bus system with six generating (assuming the losses not to be zero). It should be mentioned that in this case, limitations such as speed and the forbidden work zones of each generator is considered.

V. SIMULATION RESULTS

To assess the feasibility of the ACO approach, compare studies of ED with all optimization methods (GA, TS, PSO, and ACO) and conventional method same as Newton-Raphson were implemented in Matlab (version 7.6.0.6324). These programs were run on a Pentium Dual core, 2.5 GHz personal microcomputers with 3 GB RAM under Windows XP. In each case study, 100 independent runs are carried out for each optimization method. In addition, 100 different initial trial solutions are used for each method.

The ACO is applied to ED problems for IEEE 30 Bus system with six generating. The input data for 6 generating units system are given in [19], (Table 3) with 283.4 MW load demand. The global solutions for these systems are not discovered yet after performing 100 trials. The best results for P_is for IEEE 30-bus system with six generating, in order for the best answer to be found, are shown in the Table 1.

In the Table 2, there is a brief comparison between our suggested method and some other innovating methods proposed by other researchers and some standard methods based on the smart algorithms (that described above) and conventional method which are the results of other researchers. The transmission loss coefficient denoted as B_{ij} is given according to the following that calculated with *N-R* conventional method [19].

$$B_{ij} = \begin{bmatrix} 0.218 & 0.103 & 0.009 & -.010 & 0.002 & 0.027 \\ 0.103 & 0.181 & 0.004 & -.015 & 0.002 & 0.030 \\ 0.009 & 0.004 & 0.417 & -.131 & -.153 & -.107 \\ -.140 & -.015 & -.131 & 0.221 & 0.094 & 0.050 \\ 0.002 & 0.002 & -.153 & 0.094 & 0.243 & 0.000 \\ 0.027 & 0.030 & -.050 & 0.50 & 0.000 & 0.358 \end{bmatrix} \times 10^{-3}$$

VI. CONCLUSIONS

Research in the area of metaheuristics has made possible the development of optimization methods that have the goal of providing high-quality solutions to complex systems. The simulation results and the comparison between other researches results, and the significant difference between them, The IEEE 30-bus test systems were used to investigate the effectiveness of the proposed technique. The Proposed ACO is compared with other, such as DE-OBL, ABC, DE, ACO-OPF and GA. It is obvious that, the proposed technique can be a proper method for medium-scale system an ant colony optimization method can give a best result.

Table 1. Fuel cost coefficients for IEEE 30-bus system with six generating

Generator	P_{min} (MW)	P_{max} (MW)	P(MW)
P_{G1}	50	200	141.161
P_{G2}	20	80	51.3999
P_{G3}	15	50	27.1548
P_{G4}	10	35	20.129
P_{G5}	10	30	18.1032
P_{G6}	12	40	19.0903
		P_{loss}	6.2173
		PD	283.2555
		Total generation cost	764.1544

Table 2. Convergence results for IEEE 30-bus system with six generating

Method	Best Cost
Load demand	283.4 MW
Proposed ACO	764.1544
DE-OBL [19]	794.9129
ABC	801.881
DE	802.23
ACO-OPF [24]	803.123
GA	803.699

APPENDIX

Table 3. Fuel cost coefficients for the 13 thermal units [19]

Generator	P_{min} (MW)	P_{max} (MW)	a_i (\$/(MW)^2)	b_i (\$/MW)	c_i (\$)
P_{G1}	50	200	0.00375	2	0
P_{G2}	20	80	0.01750	1.75	0
P_{G3}	15	50	0.06250	1	0
P_{G4}	10	35	0.00834	3.25	0
P_{G5}	10	30	0.02500	3	0
P_{G6}	12	40	0.02500	3	0

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BIOGRAPHIES

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