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Congestion Management Based Combined Economic Emission Dispatch Using A New Optimization Technique

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Abstract: This paper deals with the congestion management approach under Combined Economic Emission Dispatch (CEED) in a deregulated electricity market using Artificial Bee Colony (ABC) algorithm. Transmission congestion is a condition that occurs when excess power flows over a line exceeding the power flow limit of the line in a deregulated electricity market. As the real power dispatch has a major role in relieving the transmission congestion at low cost, this paper deals with rescheduling of real power generation to manage congestion. Contributions made in this paper are of two stages. Transmission Congestion Distribution Factors for the congested lines is evaluated in the first stage for optimum selection of participating generators. An algorithm based on ABC is used in the second stage for obtaining minimum values of generator power outputs after rescheduling under CEED. The price penalty factor method is used to convert multi-objective CEED problem into single objective function. Test results on IEEE 30-bus six generatorsystems indicate the effectiveness of ABC approach in optimizing rescheduling cost and CEED.

Keywords: Congestion management, Deregulated Electricity market, Transmission Congestion Distribution Factor, Artificial Bee Colony, Combined Economic Emission Dispatch.

I. Introduction

In a competitive electricity environment, the issue of transmission congestion is more pronounced. Deregulated Electricity markets will not be able to operate at its competitive equilibrium point with congestion prevailing in the system. Operating limits are to be observed including thermal, voltage and stability limits. In order to alleviate congestion, re-dispatch of generators is carried out.

Different congestion management approaches are presented in [1]. Transmission congestion distribution factors (TCDFs) are discussed in [2-4] .Real and reactive power flow sensitivity factors to determine real and reactive rescheduling for congestion management is discussed in [5]. In [6] congestion management problem is formulated as a bi-objective optimization problem considering alleviation of overloads and also minimization of congestion cost as two conflicting objective function. Optimal power flow (OPF)-based approach for minimization of congestion cost and service costs are expressed is discussed in [7]. Sensitivities of real power injection for rescheduling of real power generation for congestion management is used in [8].In [9] the minimization of rescheduling cost based on particle swarm optimization (PSO) is proposed. Relative Electrical Distance (RED) concept is introduced in [10] to mitigate the transmission overload by real power generation rescheduling. The method minimizes the system losses and operates within the voltage profile. However, the rescheduling cost is not considered by this method. The ABC algorithm was introduced by Dr.Korbaga. ABC is applied for solving various optimization problems in electrical engineering [11].

The present work proposes a new technique for congestion management under Combined Economic Emission Dispatch (CEED) environment. By considering both economy and emission simultaneously CEED problem has been formulated as a bi-objective problem. This bi-objective CEED problem is converted into a single objective function using price penalty factor function [12]. The proposed method utilizes sensitivity index termed as Real Power Transmission Congestion Distribution Factors (PTCDFs) [9] for congestion management in competitive power markets. ABC is used to minimize the System Re-Dispatch Cost. The IEEE-30 bus system is used as test system for showing the effectiveness of the proposed method. The simulation results indicate that the proposed method is efficient for optimization of the congestion cost in a deregulated electricity market.

II. Introduction

Congestion Management under CEED Environment

Congestion is a condition when the system constraints are violated, it can be related to exceeding the power flow limit of lines. Therefore, congestion management must be an action of removing this overload. This knowledge can be gained by TCDFs. The transmission congestion distribution factor (TCDF) indicates the change of active power flow due to change in active power generation. The TCDF values of generator g on the line connected between buses i and j can be written as following [8].

$$TCDF_g^{ij} = \frac{\Delta P_{ij}}{\Delta P_{Gg}} = \frac{\partial P_{ij}}{\partial \theta_i} \cdot \frac{\partial \theta_i}{\partial P_{Gg}} + \frac{\partial P_{ji}}{\partial \theta_j} \cdot \frac{\partial \theta_j}{\partial P_{Gg}} \quad (1)$$

Power flow equation between the congested lines is calculated by

$$P_{ij} = -V_i^2 \cdot G_{ij} + V_i \cdot V_j \cdot G_{ij} \cdot \cos(\theta_i - \theta_j) + V_i \cdot V_j \cdot B_{ij} \cdot \sin(\theta_i - \theta_j) \qquad (2)$$

Differentiating (2) with respecting to θ_i and θ_j gives us the relation given in (3) and (4)

$$\frac{\partial P_{ij}}{\partial \theta_i} = P_{ij} = -V_i \cdot V_j \cdot G_{ij} \cdot \sin(\theta_i - \theta_j) + V_i \cdot V_j \cdot B_{ij} \cdot \cos(\theta_i - \theta_j)$$
$$\frac{\partial P_{ji}}{\partial \theta_j} = P_{ij} = +V_i \cdot V_j \cdot G_{ij} \cdot \sin(\theta_i - \theta_j) - V_i \cdot V_j \cdot B_{ij} \cdot \cos(\theta_i - \theta_j) = -\frac{\partial P_{ij}}{\partial \theta_i} \qquad (3)(4)$$

The active power injected at a bus-s is calculated as

$$P_s = |V_s| \cdot \sum_{t=1}^{n} \{ (G_{st} \cdot \cos(\theta_s - \theta_t) + B_{st} \cdot \sin(\theta_s - \theta_t)) \cdot |V_t| \}$$
$$= |V_s|^2 \cdot G_{ss} + |V_s| \cdot \sum_{\substack{t=1 \\ t \neq s}}^{n} \{ (G_{st} \cdot \cos(\theta_s - \theta_t) + B_{st} \cdot \sin(\theta_s - \theta_t)) \cdot |V_t| \} \qquad (5)$$

Differentiation of (5) gives us the following relation

$$\frac{dP_s}{d\theta_t} = |V_s| \cdot |V_t| \{ (G_{st} \cdot \sin(\theta_s - \theta_t) + B_{st} \cdot \cos(\theta_s - \theta_t)) \}$$
$$\frac{dP_s}{d\theta_s} = |V_s| \cdot \sum_{\substack{t=1 \\ t \neq s}}^{n} \{ (-G_{st} \cdot \sin(\theta_s - \theta_t) + B_{st} \cdot \cos(\theta_s - \theta_t)) \cdot |V_t| \} \qquad (6)$$

The relation between the change in active power at each bus and voltage phase angles can be written as

$$[\Delta P]_{n\,x\,1} = [H]_{n\,x\,n} \cdot [\Delta \theta]_{n\,x\,1} \qquad (7)$$

$$[H]_{n\,x\,n} = \begin{bmatrix} \frac{\partial P_1}{\partial \theta_1} & \frac{\partial P_1}{\partial \theta_2} & \cdots & \frac{\partial P_1}{\partial \theta_n} \\ \frac{\partial P_2}{\partial \theta_1} & \frac{\partial P_2}{\partial \theta_2} & \cdots & \frac{\partial P_2}{\partial \theta_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_n}{\partial \theta_1} & \frac{\partial P_n}{\partial \theta_2} & \cdots & \frac{\partial P_n}{\partial \theta_n} \end{bmatrix}_{n\,x\,n} \qquad (8)$$

Given, $[M]=[H]^{-1}$ (9)

Thus, $[\Delta\theta]=[M]\cdot[\Delta P]$ (10)

Since bus 1 is a reference bus, the first row and first column of [M] is eliminated. Therefore, the modified [M] can be written as,

$$[\Delta\theta]_{n\,x\,1}=\begin{bmatrix}0 & 0\\ 0 & [M_{-1}]\end{bmatrix}_{n\,x\,n}\cdot[\Delta P]_{n\,x\,1} \tag{11}$$

In (11), the modified [M] represents the values of $\partial\theta_i/\partial P_{Gg}$ *and* $\partial\theta_j/\partial P_{Gg}$ in (1) to calculate TCDF values. Generators with large TCDF values will be selected for re-dispatch since they are more influential on the congested line.

III. Re-dispatch:

The objective function can be expressed as[8]:

$$Min\sum_{g}^{Ng} IC_g(\Delta P_g)\cdot\Delta P_g \tag{12}$$

Subject to Power balance constraints

$$\sum_{g=1}^{Ng}\Delta P_g=0 \tag{13}$$

Operating limit constraints

$$\Delta P_g^{\min}\le\Delta P_g\le\Delta P_g^{\max};\ g=1,2,\ldots,N_g$$
$$\Delta P_g^{\min}=P_g-P_g^{\min}\ and\ \Delta P_g^{\max}=P_g^{\max}-P_g \tag{14}$$

Line flow constraints

$$\sum_{g=1}^{N_g}(TCDF_g^{ij}\cdot\Delta P_g)+F_l^0\le F_l^{max};l=1,2,\ldots,n_l \tag{15}$$

IV. Generation cost:

The generation cost can be expressed in terms of

$$C_{pi}(P_i)=\sum_{i=1}^{N_g}(F(P_i)+h\,x\,E(P_i)) \tag{16}$$

Where

$$F(P_i)=a_i\cdot P_i^2+b_i\cdot P_i+c_i$$

$$E(P_i)=\sum_{i=1}^{N_g}(10^{-2}(\alpha_i\cdot P_i^2+\beta_i\cdot P_i+\gamma_i))$$

$$h_i=\frac{F(P_i)}{E(P_i)},i=1,2,\ldots,N_g$$

(17)(18)(19)

V. Artificial Bee Colony Optimization:

Artificial Bee Colony algorithm is formulated on the basis of natural foraging behavior of honey bees. ABC is simple and widely used due to good convergence properties.ABC starts searching with random set of solutions i.e., (Colony size), rather than single solution like Genetic Algorithm. Each population member is to be evaluated for the given objective function. The best fits are now carried for next generation while the others are terminated. It is then compensated by a set of new random solutions every generation. The process repeats until maximum no of cycles get completed which is the stopping criterion. At the end of each cycle the solutions with best fitness value is taken as the desired solution. [13].

ABC is applied for obtaining solution of CEED.An encoding scheme based on generating unit is used. When applied to large size systems, iterations have to be increased proportionally. The growth of solution time is approximately linearly with problem size. Boundary limits are assigned for the variables to fulfill the constraints and to obtain an optimized objective function. The congestion cost and Generation cost obtained are optimized here.

Random Solution Generation:

When the employed bees move to a new location they select the food sources which are in their proximity. Each employed bee associated with a food source is responsible for the nectar extraction from it.

$$P_i = P_{i\min} + rand(0,1) \times (P_{i\max} - P_{i\min}) \quad \forall i, j \in [1,2,3,\ldots,N_g] \tag{20}$$

Where P_{imin} and P_{imax} are lower and upper bounds of variable P_i. In (20) 'rand (0, 1)' represents a random number between 0 and 1.

$$\sum P_{Gi} = P_D + \sum\sum P_i B_{ij} P_j \ \forall i \in (1,2,3,\ldots,N_g)$$

The solution in matrix form is represented as

$$X = [P_1\ P_2\ P_3\ P_4 \ldots P_{ng}] \tag{21}$$

A random variable is chosen of all N_g variables and a neighbour is chosen of all n-1 neighbours randomly and a mutant solution is produced as shown below.

$$X_{1mutant} = X_1(i) + (X_j(i) - X_1(i)) \times (2 \times (rand - 1)) \tag{22}$$

Where i, j are the randomly chosen parameter and neighbour values respectively. Discarding of least fit solution is done between the mutant and original solutions done using a greedy selection. This process of selection is to be repeated for each solution. The mutant solution with less fit increases its trial and this may lead to dissertation of the food source if the trial exceeds a threshold limit.

In order to satisfy the equality constraint, slack bus power (P_{G1}) is solved from the above quadratic equation and replaces it with the randomly selected P_{G1}.The solution can be represented in matrix form as follows

$$X_i = [P_1\ P_2\ P_3\ P_4 \ldots P_{ng}] \tag{23}$$

Similarly, the Food sources $[X_1\ X_2\ X_3\ X_4 \ldots X_n]$ are the set of all randomly chosen solutions, satisfying the constraints.

VI. Evaluation of Fitness of solutions:

Quality and quantity of the nectar determines the rank of food sources. Fitness is assigned to each solution, which denotes the goodness of each solution.

$$Fitness(\mathrm{i}) = 1/(1+\sum F_i)\ \forall i \in (1,2,3,...,N_g) \qquad (24)$$

$\sum F_i$ Denote the total operating cost of generation.

VII. Employed Bee phase:

Every solution is to be handled by an employed bee and it searches for the better food source in their neighbourhood. If it finds,then it leaves the previous food source and starts handling the new food source until it explores a food source which is better than the previous one. A mutant solution is generated for each solution using its neighbour based on random selection and the parameter to be changed. $[X_1\, X_2\, X_3\, X_4 ... X_n]$ is the set of solution where X, a random number representing the expectancy of the onlooker bee is chosen and compared with the solution probability .If it meets the expectancy of the onlooker bee then it starts exploiting the food source and it becomes an employed bee and the corresponding employed bee of food source retires . This new employed bee starts exploring the neighbourhood food source and repeats the employed bee behaviour.

VIII. Onlooker Bee phase:

The onlooker bees find a food source by receiving the information given to them by the employed bees. A food source will be selected whose probability is proportional to its food quality which is given by

$$\mathrm{Probability(i)} = \mathrm{a} \times \mathrm{Fitness(i)}/\max(\mathrm{Fitness}) + \mathrm{b}$$
$$\mathrm{Where}(\mathrm{a}+\mathrm{b}=1) \qquad (25)$$

If the expectation level is not fulfilled, then the onlooker bee searches for other food source (solution) which matches its expectancy until it gets employed. This process gets repeated until all the food source gets employed by the onlooker bees. The food source which has the highest probability is selected and the one with lowest value is eliminated lot of times.

IX. Scout Bee phase:

The scout bee explores the search area and it is represented by a randomly generated solution. If thetrials of mutation an employed bee exceed a threshold limit then the scout bee replaces it. The scout bee will then search the unexplored area of the given space. The best solution and value of fitness are processed for every iterations. This is repeated for iterations of maximum number and the output at the end of total iteration will ensure optimized solution.

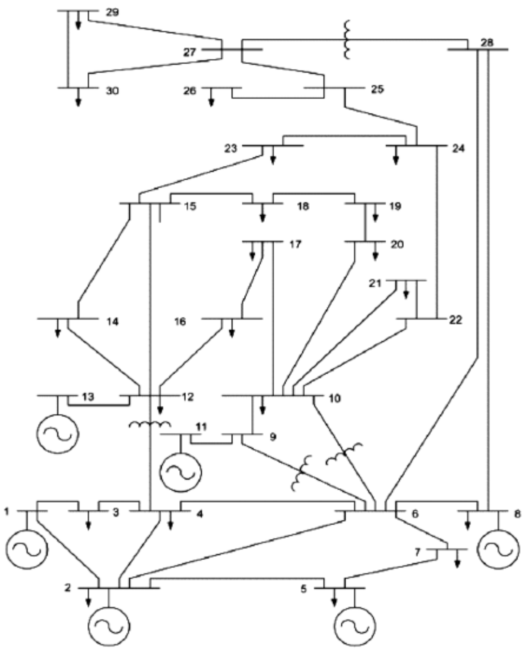

Fig. 1. The IEEE 30 bus configuration

X. Results and discussion

Here, the IEEE 30-bus system with 41 lines and 6 generators is used. The system data can be found in [14]and the system configuration is shown in Fig. 1. . Bus 1 is assigned as the reference bus. There exists a congested line between buses 1 and 2 as shown in Table 1.

Table1:LineFlows on the congested line

CONGESTED LINE	1-2
POWER FLOW	173.1839 MW
LINE LIMIT	130 MW
EXCESS FLOW	43.1839 MW

The TCDF values of 6 generation units in the IEEE 30-bus system are shown in Table 3. Here, the TCDF values of all 6 generators are high. Considering TCDF values, all generators should be used to relieve the congested line. For a larger system, selected group of generators having the larger TCDF values can be used to save the computational effort.

Table 2: TCDF values of all 6 generators

GENERATOR NO	TCDF VALUE
1	0
2	-0.8830
3	-0.8583
4	-0.7331
5	-0.7164
6	-0.6772

The optimal Power generation of the 6 generators are shown in the table 3.The cost involved in Combined Economic Emission Dispatch is given in the end of the same table. The graph between CEED cost and iteration is shown in fig 2.

Table 3:Power generation, power loss and CEED cost of the generators

Pg1(MW)	118.2274
Pg2(MW)	50.4314
Pg3(MW)	34.9423
Pg4(MW)	32.8734
Pg5(MW)	32.5592
Pg6(MW)	34.8159
P loss(MW)	3.8496
CEED Cost($/hr)	16978

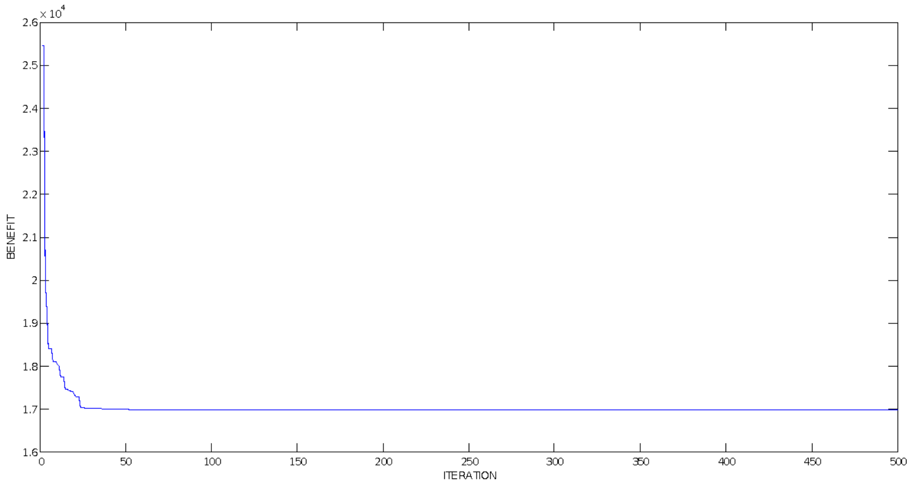

Fig 2: CEEDcost vs iteration

Taking in account of TCDF values, all generators are selected for re-dispatch and the values are obtained as shown in table 4.Fig 3 shows the convergence graph between re-dispatch power and iterations.

Table 4:Power re-dispatch

Δ Pg1(MW)	-47.9000
Δ Pg2(MW)	18.6124
Δ Pg3(MW)	16.6412
Δ Pg4(MW)	11.3266
Δ Pg5(MW)	2.8339
Δ Pg6(MW)	2.9285
Congestion Cost($/hr)	403.2764

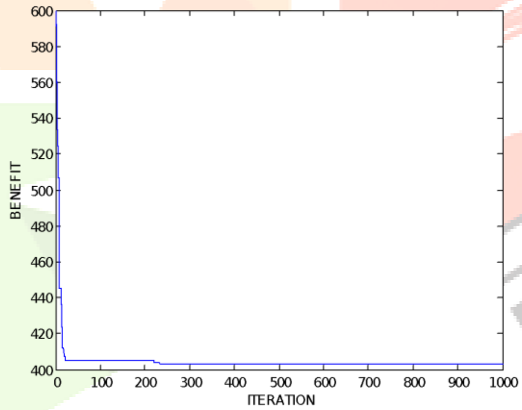

Fig 3: Congestion cost vs Iteration

Conclusion

In this paper, optimal congestion management by corrective re-dispatch in the context of power system restructuring using Artificial Bee Colony (ABC) under Combined Economic Emission Dispatch (CEED) environment was proposed and tested on IEEE 30 Bus system. The result of case studies have shown that, under CEED environment ABC would be an effective tool in handling transmission congestion in deregulated environment and efficiently minimizes re-dispatch cost and also resulting in secure operating condition. This paper work can be further developed by including reactive power support which will minimizes the total operating cost.

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