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Congestion Management Based On Active Power Rescheduling Of Generator units using Cuckoo Search Algorithm

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Abstract—In this paper, an efficient method has been proposed for transmission line over load alleviation in deregulated power system. Here the generators are selected based on their sensitivity to the congested line and the active power of the participating generators is rescheduled using Cuckoo Search (CS) algorithm for relieving congestion. The algorithm is tested in IEEE 30-bus system and compared with the particle swarm optimization for its effectiveness and robustness in congestion management. It is observed that CS algorithm minimizes the cost effectively when compared to the particle swarm optimization (PSO).

Keywords—Congestion management, Deregulated market, Cuckoo Search Algorithm, PSO, Generator Sensitivity.

I. INTRODUCTION

In competitive markets, electricity price is regulated based on proposals offered by all market participant, these markets provide the possibility of exchanging energy between various participants. Electricity is a commodity with special features which should be considered when making laws. For example, it is difficult to save, in any case it has losses when transmitting and controlling the electricity flow requires using expensive equipment. Congestion is defined as the overloading of one or more transmission lines and/or transformers in the power system. In the deregulated electricity market, congestion occurs when the transmission system is unable to accommodate all of their desired transactions due to violation of MVA limit of transmission lines. In such market, most of the time, the transmission lines operate near to their stability limits as all market players try to maximize their profits from various transactions by fully utilizing transmission systems. R.D. Christie et al. [1] explained in detail the congestion management and felt that controlling the transmission system so that transfer limits are observed is perhaps the fundamental transmission management problem. In order to relieve congestion, one can either use FACTS devices [2], operate taps of a transformer, redispatch of generation [3] and curtailment of pool loads and/or bilateral contracts. In a deregulated environment, all the GENCOs and DISCOs plan their transactions ahead of time. But by the time of implementation of transactions there may be congestion in some of the transmission lines. Hence, ISO has to relieve the congestion so that the system remains in secure state. ISO use mainly two types of techniques to relieve congestion and they are as follows:

i) Cost free means:

a. Out-aging of congested lines. b. Operation of transformer taps/phase shifters.

c. Operation of FACTS [2] devices particularly series devices.

ii) Non-cost free means:

a. Re-dispatch of generation [3] in a manner different from the natural settling point of the market. Some generators back down while others increase their output. The effect of this is that generators no longer operate at equal incremental costs.

b. Curtailment of loads and the exercise of (non-cost-free) load interruption options.

R.S. Fang et al. [4] considered an open transmission dispatch environment in which pool and bilateral/multilateral dispatches coexist and proceeded to develop a congestion management strategy for this scenario. K.L. Lo et al. [5] presented congestion management techniques applied to various kinds of electricity markets. Ashwani Kumar et al. [6] reviewed extensively the literature for reporting several techniques of congestion management and informed that the congestion management is one of the major tasks performed by Independent System Operators (ISOs) to ensure the operation of transmission system within operating limits. In the emerging electric power markets, the congestion management becomes extremely important and it can impose a barrier to the electricity trading. Ashwani Kumar et al. [7] proposed an efficient zonal congestion management approach using real and reactive power rescheduling based on AC Transmission Congestion Distribution factors considering optimal allocation of reactive power resources. The impact of optimal rescheduling of generators and capacitors has been demonstrated in congestion management. H.Y.Yamina and Shahidehpour [8] described a coordinating mechanism between generating companies and system operator for congestion management using Benders cuts. F. Capitanescu and Van Cutsem [9]proposed two approaches for a unified management of congestions due to voltage instability and thermal overload in a deregulated environment. J. Fu and Lamont [10] discussed a combined framework for service identification and congestion management while a new approach were applied to identify the services of reactive support and real power loss for managing congestion using the upper bound cost minimization.

J. Kennedy and Eberhart [11] described the Particle Swarm Optimization(PSO) concept in terms of its precursors, briefly reviewing the stages of its development from social simulation to optimize and discussed application of the Algorithm to the training of artificial neural network weights. Y. Shi [12] surveyed the research and development of PSO in five categories viz. algorithms, topology, parameters, hybrid PSO

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algorithms and applications. Y. Del Valle et al. [13] presented a detailed review of the PSO technique, the basic concepts and different structures and variants ,as well as its applications to power system optimization problems. Z.X. Chen et al. [14] introduced PSO for solving Optimal Power Flow (OPF) with which congestion management in pool market is practically implemented on IEEE 30 Bus system and proved that congestion relief using PSO is effective in comparison with Interior Point Method and Genetic Algorithm approach. J. Hazra and Sinha[15] proposed cost efficient generation rescheduling and/or load shedding approach for congestion management in transmission grids using Multi Objective Particle Swarm Optimization (MOPSO)method. K.M. Passino [16] explained in detail the biology and physics underlying the chemotactic (foraging) behaviour of Escherichia colibacteria that formulated Simple Bacterial Foraging (SBF) Optimization Algorithm for optimization process represented by the activity of social bacterial foraging. Janardan Nanda et al. [17] made a maiden attempt to examine and highlight the effective application of Bacterial Foraging algorithm to optimize several important parameters in Multi area Automatic Generation Control (AGC) of a thermal system and compared its performance to establish its superiority over Genetic Algorithm (GA) & classical methods. H. Vahedi et al. [18] proposed a novel Mixed Integer SBF algorithm for solving constrained OPF problem for practical applications.

It is observed that researchers have not attempted so far to dynamically adjust the run length vector of the CS algorithmfor optimal rescheduling of the active powers of the participating generators by relieve congestion in the congested line. Further, no attempt has been made so far to employ CS algorithm for optimal rescheduling of active power of the select participating generators to relieve congestion in the congested line. To incorporate the innovativeness into congestion management, a new method of CS algorithm is attempted for the first time to relieve congestion in the congested line by optimal rescheduling of active powers of the select participating generators instead of selecting all the generators to relieve congestion, in this paper it is proposed to select only those generators which are very sensitive for relieving congestion in transmission lines. Thisis done by the selection of participating generators using generator sensitivities to the power flow on congested lines. Further, itis proposed to solve congestion management problem by optimal rescheduling of active power of participating generators employing the CS algorithm. Subsequently, CS algorithmis compared with PSO algorithms to determine the best optimal solution for rescheduling the active power of participating generators to relieve the congestion.

In this paper static congestion management by optimal rescheduling of active power of the generators selected based on their sensitivities to the congested line is attempted by CS algorithm for the first time and compared with the PSO. The main advantage of this approach of relieving congestion in the congested line is quite efficient as it is a non-cost free means technique. This paper illustrates the effectiveness of the proposed method on the congestion management problem considering IEEE30-bus system

II. Congestion Management Method

Congestion is defined as the overloading of one or more transmission lines and/or transformers in the power system. In the deregulated electricity market, congestion occurs when the transmission system is unable to accommodate all of their desired transactions due to violation of MVA limits of transmission lines.

Congestion may lead to rise in cost of electricity, tripping of overloaded lines and consequential tripping of other healthy lines. It may also create voltage stability related problems. It should be relieved to maintain power system stability and security, failing which results into system blackout with heavy loss of revenue. Various factors and phenomena cause congestion on transmission lines that inherent limitations of transmission network can be pointed as one of them which are divided into two major categories:

1. Physical limitations
2. System limitations

Thermal limitation of a transmission line or a transformer is among physical limitations of transmission network. Voltage limitation in a node, transient stability, dynamic stability, reliability and similar cases are also examples of system limitations of transmission network. Given the above limitations, many factors can be effective in the occurrence of congestion on transmission lines, such as energy consumption increase in point in the network, concurrent use of electrical appliances during peak hours and non-coordinated exchanges. Also the departure of a number of transmission lines or power generation units in a point in the network due to error or repairs makes more loading of network healthy lines and congestion on these lines. Hence, ISO has to relieve the congestion so that the system remains in a secure state. ISO mainly uses two types of techniques to relieve congestion. These are listed below.

i**) Cost free means**

a. Out-aging of congested lines
b. Operation of transformer taps/phase shifters
c. Operation of FACTS [2] devices, particularly series devices

ii) Non-Cost free means

a. Re-dispatching power generation [3] in a manner different from the natural settling point of the market. Some generators back down, while others increase their output. Consequently, generators no longer operate at equal incremental costs.
b. Curtailment of loads and the exercise of (non-cost free) load interruption options.

III. GENERATOR SENSITIVITY IV.

A change in real power flow in a transmission line k connected between bus i and bus j due to change in power generation by generator ‘g’ can be termed as generator sensitivity to congested line (GS).

$$\mathbf{GS_g}=\frac{\Delta P_{ij}}{\Delta P_g} \quad (1)$$

Where,
ΔP_{ij} = change in the real power flow of the congested line.

ΔP_g = change in the real power generated by the generator.

IV. OBJECTIVE FUNCTION

The objective function of rescheduling real power generation using cost

Minimization is given by

$C = \text{minimize} \sum_{g=1}^{Ng} C_g(\Delta P_g)\Delta P_g$ (2)

Where,

$C_g(\Delta P_g)$ = incremental and decremental bids submitted by generators

ΔP_g= Unit change in real power adjustment at generator

N_g= Number of generators

Subject to

$\sum_{g=1}^{Ng}((GS_g)\Delta P_g) + PF_k^0 \leq PF_k^{max}$ (3)

Where k=1, 2, 3…N_l(4)

$\Delta P_g^{min} \leq \Delta Pg \leq \Delta P_g^{max}$(5)

$\Delta P_g^{min} = P_g - P_g^{min}$ (6)

$\Delta P_g^{max} = P_g^{max} - P_g$(7)

$\sum_{g=1}^{Ng} \Delta Pg = 0$ (8)

Where g= 1, 2… Ng (9)

PF_k^0= power flow caused by all contracts requesting the transmission services.

PF_k^{max} =line flow limit of the line connecting bus-i and bus j

N_l= number of transmission lines in the system.

V. CUCKOO SEARCH ALGORITHM

To work out the problem belongs to optimization, Cuckoo search is one of the metaheuristic algorithms that is used. In mixture with the Levy flight behavior of some birds and fruit flies in nature [28], this algorithm is motivated by the needed brood presentation of cuckoo species. To explain the cuckoo search in plainly, we have three idealized rules which are considered as: 1) Each cuckoo lays one egg at a time, and dump its egg in randomly chosen nest; 2) The best nests with high quality of eggs will carry over to the next generations; 3) The number of obtainable host nests is permanent, and the egg laid by a cuckoo is found out by the host bird with a possibility [29] [30]. The value or fitness of a solution can merely be comparative to the minus value of the objective function [31] in the case of minimization problems. Probing of solution depends on the lower and upper limits of the solution series in CS algorithm. According to the crowded power by synthetic neural network (ANN), superlative reschedule importance are made as a dataset from the generator limits. ANN is a synthetic intelligence (AI) method which applied for optimizing precise generation limits as blocking happened. The neural network contains two stages: training stage and testing stage and it contains three layers: input layer, hidden layer and output layer. In the manuscript, feed forward neural network (FFNN) with back propagation teaching algorithm is applied. The flow chart for suggested approach is explained in Fig.1.

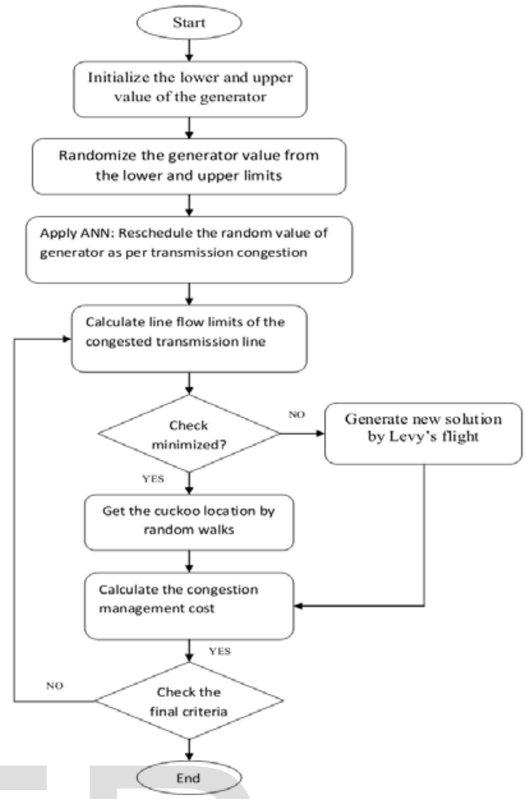

Figure 1: Flow chart of CS for proposed approach.

Steps of cuckoo search:

(i) Initialization

In the first step, the generator values are initialized from the allowable range i.e. the upper and lower limits. From the initialized limits, each generator values are randomized and the values are expressed as follow,

$$G_i = [g_0^{(i)} \ g_1^{(i)} .... g_{N_L-1}^{(i)}] \quad (10)$$

Where, N_L is the length of the randomized values, and G_i is the random value of i^{th} generator which includes by their limits. The equation (10) contains the reschedule value of all the generators. When congestion is to be occurred, the optimal generator values are selected from the randomized values.

(ii) Apply ANN

In training phase of ANN, generator limits are trained by the congested line power. A pre-examined dataset is obtained from and it is used as the training dataset X for neural network. The dataset X is consisted of input as transmission line congested power and the system output (target) is the reschedule power of the generators. The dataset X can be represented as,

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$$X = \begin{bmatrix} c_0^{(i)} \\ c_1^{(i)} \\ \vdots \\ c_{N_L-1}^{(i)} \end{bmatrix} \begin{bmatrix} g_0^{(i)} \\ g_1^{(i)} \\ \vdots \\ g_{N_L-1}^{(i)} \end{bmatrix} \quad (11)$$

where, $c_0^{(i)}$, $c_1^{(i)}$,….., $c_{N_L-1}^{(i)}$ transmission line over loaded values and $g_0^{(i)}$, $g_1^{(i)}$,….., $g_{N_L-1}^{(i)}$ are the reschedule value of all the generator units. The feed forward network structure is described in Fig.2 which illustrated as follow,

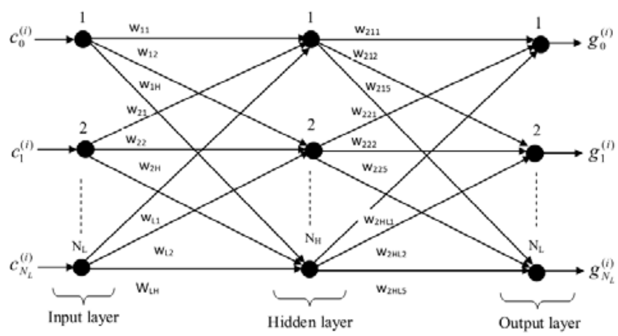

Figure 2: Structure of neural network with proposed approach data.

Back propagation training algorithm:

Step 1:

Assign arbitrary weights generated in the interval $[w_{\min}, w_{\max}]$ to the hidden layer neurons and the output layer neurons. Assign unity value weights to each neuron of the input layer.

Step 2:

Determine the BP error by giving the training dataset X as input to the classifier as follows,

$$BP_e = g_T - g_{out} \quad (12)$$

In Eq. (2), g_T are the target output and the network output g_{out} can be calculated as $g_{out} = [g_0 \;\; g_1 \;\; g_2 \cdots g_{N_T-1}]$. The elements of g_{out} can be determined from every output neuron of the network as follows,

$$g_{out} = \sum_{i=1}^{N_H} w_{ij} y_i \quad (13)$$

where,

$$y_i = \frac{w_{1i}}{1+\exp(-c_1^{(i)})} + \frac{w_{2i}}{1+\exp(-c_2^{(i)})} + \ldots\ldots.. + \frac{w_{ni}}{1+\exp(-c_{N_L}^{(i)})}\,;\; 1 \le i \le N_L \quad (14)$$

In Eq. (13) N_H is the number of hidden neurons, g_{out} is the output from j^{th} output neuron and w_{ij} is the weight of the $i-j$ link of the network. In Eq. (14), y_i is the output of i^{th} hidden neuron.

Step 3:

Determine the change in weights based on the obtained BP error as follows

$$\Delta w = \gamma . g_{out} . BP_e \quad (15)$$

In Eq. (15), γ is the learning rate, usually it ranges from 0.2 to 0.5.

Step 4

Determine the new weights as follows

$$w_{new} = w_{old} + \Delta w \quad (16)$$

Step 5

Until BP error gets reduced to a least value, repeat the process from step 2. Essentially, the condition to be satisfied is $BP_e < 0.1$.

The network gets well-trained when the process is completed. In testing phase, the congested real power applied to network and the exact reschedule generator powers are provided by the trained network. The network output is applied to the evaluation stage.

(iii) Evaluation

During evaluation, the current best nest is calculated from the initialized values. The initialized values are relevant to the objective function, then go to step (v). Otherwise construct the loop by cuckoo random walk which describe in step (iv).

(iv) Loop construction

In the step, generator values are rescheduled for removing the congestion of transmission line. Generator units reschedule power values depends on the cost function of the congestion management. Then, check the system condition balanced or not. If the condition is satisfied, cuckoo turns the location by randomly and evaluates the fitness function. Otherwise, generate a new egg in CS, a Levy flight is performed using the coordinates of an egg selected randomly which can represented as follow,

$$x_i^{t+1} = x_i^t + \alpha \,\Theta\, Lev'\, y(\lambda) \quad (17)$$

Where, Θ denotes the entry wise multiplication, α is the step size and $Lev'\, y(\lambda)$ is the levy distribution.

(v) Fitness evaluation

The fitness function of the solution is evaluated and which represented as follow,

$$fitnessfunction = \min(CMC) \quad (18)$$

Where, CMC is the congestion management cost.

(vi) Solution construction

At the end of maximum iteration, check the final solution and whether the solution is minimized the objective function; then, stop the process otherwise extends the solution until to the satisfied condition.

VI. RESULT AND DISCUSSION

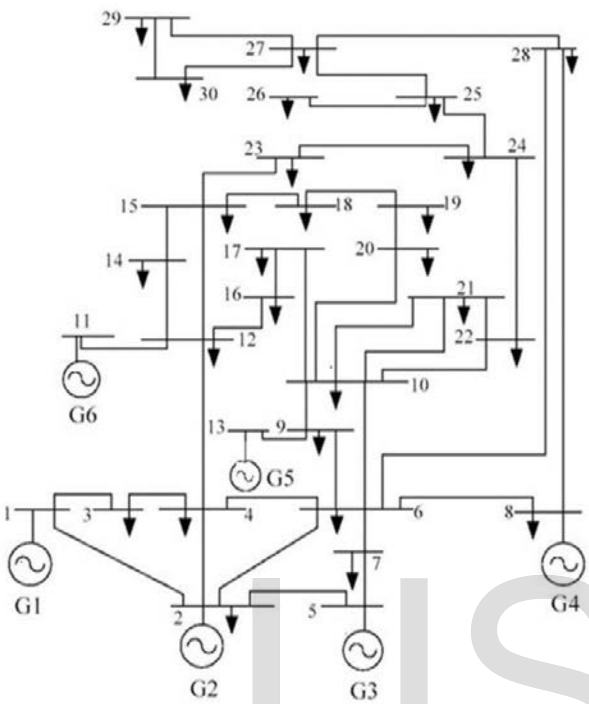

Fig.3. Single Line Diagram of IEEE 30 Bus System

The IEEE 30-bus system (Fig.3) consists of six generator buses and 24 load buses. Accordingly, the Generator Sensitivities are computed for the congested Line-26 for the system. Generators which are to participate in congestion management are to be selected depending on their sensitivities to the congested line. In this test system, it is observed that all the generators show strong influence on the congested line. This is perhaps the system is very small and generally very tightly connected electrically. All the generators are participating in congestion management and the evolutionary algorithms are employed to optimally reschedule the active power of the generators for relieving congestion in Line-26.Mostly, congestion is due to exceeding power flow limit of one or more lines and outage of some important elements.

For evaluating the performance of the proposed technique, the congestion occurred line is considered in between bus-10 and bus-17. This congestion is created by increasing the demand of load bus. In congested line, real power flow after congestion is 5.928 MW. After applying the congestion management technique, the congestion of the line is reduced as 5.48 MW gives in Table I. For the reason of optimal rescheduling of the real power generation of the generators, the congestion has to be relieved. Then, the sensitivity of the generator is calculated after rescheduling real power by using the sensitivity equation. According to the sensitivity of generator, the generators which are to participate in congestion management can be analyzed. In this test system, it is observed that all the generators show strong influence on the congested line. This is perhaps the system is very small and generally very tightly connected electrically. The generator sensitivity chart of the proposed system after solving the transmission line congestion between bus 10 and 17 is illustrated in Fig.4.

TABLE I:REAL POWER FLOW OF CONGESTED LINE BEFORE AND AFTER CONGESTION MANAGEMENT.

Real power flow		Real power (MW) before congestion management	Real power (MW) after congestion management	
From bus	To bus		CS	PSO [32]
10	17	5.928	5.828	5.9

TABLE II: Comparisons of cost of congestion management for IEEE 30-bus system

CM cost (Rs./MWh)	CS	PSO [32]
Best	150.905	160.23
Worst	151.375	161.61
Mean	151.14	161.49

TABLE III :Active power generation before and after congestion management for IEEE 30-bus system

Generator number	Active power (MW) before congestion management (BCM)		Active power (MW) after congestion management (BCM)	
	CS	PSO	CS	PSO [32]
G_1	185	185.046387	115.293	184.240386
G_2	61	46.795654	22.73134	46.632538
G_5	40	19.102783	21.96836	20.564745
G_8	30	10	23.6881	10
G_{11}	27	10	11.33756	10
G_{13}	36	12	20.57916	12

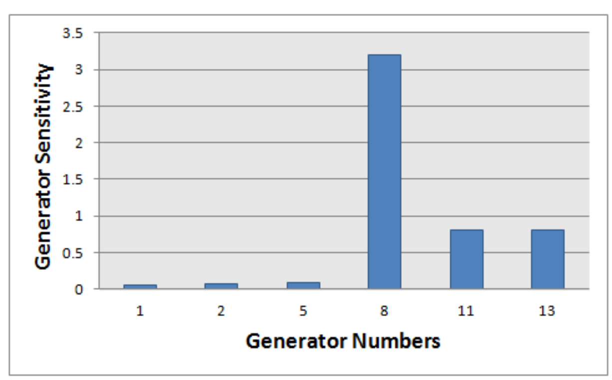

Figure 4: Generator sensitivity after solving congestion of line between bus 10 and 17.

The real power follow of the line (bus 10 and bus 17) of the proposed method is analyzed before managing congestion and

After managing congestion. The analyzed values are compared with CS algorithm and PSO algorithm [32] which gives in Table I. Then, the real power flow of the generator before and after managing congestion is analyzed. The real

power generation by the 6 contributing generators before the congestion management and after the congestion management utilized is give in Table III. From the comparison of the cost of congestion we can conclude that the CS Algorithm is lowest than the particle swarm optimization (Table II).

VII. CONCLUSION

In this work, Congestion management problem has been solved using optimal rescheduling of active powers of generators selected based on the generator sensitivity to the congested line, utilizing CS Algorithm. Here rescheduling is done taking into consideration the minimization of cost and satisfying line flow limits. The results obtained by the CS Algorithm are compared with PSO algorithms. This method is tested on IEEE 30-bus. The results show that CS Algorithm is giving the best optimal solution in comparison with PSO algorithms with respect to cost and runtime for relieving congestion in the congested line.

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