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Congestion Management by integrating Distributed Generation using Cuckoo Search Algorithm

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Abstract - **Power system congestion occurs when transmission line is incapable to transfer contracted power due to the violation of network constraints. In deregulated power system, independent system operator (ISO) is responsible for maintaining fair and secure operation of system. Therefore, congestion management is one of tasks of ISO in deregulated power market. This paper focuses mainly on congestion management by generator rescheduling method. This work also proposes the integration of large scale distributed generation (DG) in the system so that burden on the generators can be reduced. In this work, two sensitivity factors are calculated namely, generator sensitivity factor (GSF) and real power congestion distribution factor (RPCDF). The optimal location of DG units is identified based on RPCDF value and number of generators is selected based on GSF values to reschedule their output. Cuckoo search algorithm (CSA) is a newly developed metaheuristic algorithm which is explored in this present work. The optimization problem is solved using CSA in this work. The result of proposed work shows better stability in terms of voltage improvement and reduction in real power loss. The present work is tested on IEEE 39 Bus New England Test System.**

***Keywords* —Congestion management, generator rescheduling, generator sensitivity factor, real power congestion distribution factor, distributed generation, cuckoo search algorithm**

I. INTRODUCTION

Power system restructuring segregates the ownerships of generation, transmission and distribution system which creates competition among the owners. Thus restructuring brings complex power system where independent system operator (ISO) plays an important role in order to maintain secure and fair operation of system. In this complex system if any transmission line is incapable to transfer the desired power due to the outage of line, then the system is said to be congested. Generally, congestion management is done by generator rescheduling method, integrating FACTS devices, by curtailment of system load etc. This work considers generator rescheduling method for congestion management by integrating large scale DG units in the system. The advantage of connecting DG unit is that it reduces the burden from conventional generators to reschedule their output in a large scale. Thus generator rescheduling along with DG units shows effective results in terms of rescheduled output, rescheduling amount and congestion management [1]-[2].

Load curtailment can be avoided by pay based priority list for different power markets for transmission congestion management, shown in [3]. Relative electrical distance (RED) concept is considered for generator rescheduling for congestion management is shown in [4]. Here all the participated generators are rescheduled based on RED concept which also shows improvement in both real power loss and voltage profile. In [5], power system zones are identified based on real power transmission congestion distribution factor (PTCDF) and reactive power transmission congestion distribution factor (QTCDF). Here real power generator rescheduling is done based on PTCDF values. In [6]-[7], power system congestion management in deregulated pool based market is done by generator rescheduling methods using particle swarm optimization. The number of participated generators is identified by calculating generator sensitivity factor (GSF) values. Based on the GSF values the generators are selected for congestion management. Congestion management using FACTS devices are presented in [8]-[10]. It is shown that various types of FACTS devices can be used for congestion management in a large power system. In [11], congestion management is done by rescheduling both hydro generators and thermal generators. The combined operation of these two types of generators is shown to manage transmission congestion. In [12]-[14], the distributed generations (DG) and its impact in deregulated electricity market is shown. It is noted that DG units plays an important role in deregulated power market for transmission congestion management. Based on sensitivity analysis, the optimal selection of DG is done, presented in [12]-[13]. In [14], the optimal location of DG units is selected based on locational marginal pricing (LMP) method.

The contribution of present work is to manage transmission congestion by well renowned generator rescheduling method. The integration of DG units and its impact on congestion management is also presented in this work. Integration of large scale DG units reduces the burden from generator companies to reschedule their output in a large scale. A newly developed metaheuristic algorithm i.e. cuckoo search algorithm s explored in this work to minimize the congestion cost by finding the optimal size of DG units and also by rescheduling the conventional generators output.

II. CUCKOO SEARCH ALGORITHM

Cuckoo Search Algorithm (CSA) is a newly developed meta heuristic algorithm by Xin-She Yang and Suash Deb [15]. Cuckoos are fascinating birds because they produce beautiful sounds as well as they have aggressive reproduction strategy. Some species of cuckoo such as the ani and guira cuckoos lay their eggs in communal nests and remove others' eggs to raise the hatching probability of their own eggs. Some species lay their eggs in the nests of other host birds. Some host birds can engage in conflict with the intruding cuckoos. If a host bird discovers alien eggs, it will either throw these alien eggs or simply abandon its nest and build a new nest elsewhere. Some cuckoo species such as the new world brood-parasitic *Tapera* have evolved in such a way that female parasitic cuckoos are specialized in the mimicry in terms of pattern and color of the eggs of a few chosen host species which reduces the probability of their eggs being destroyed and hence increases their reproductively [15], [17].

Cuckoo search is based on three idealized rules [16]-[17]:

a. Each cuckoo lays one egg (a design solution) at a time, and following that they keep their egg in a randomly chosen nest among the fixed number of available host nests;

b. The high quality of egg (better solution) corresponding to best nests will be carried over to the next generation;

c. The number of available hosts nests is fixed, and the egg laid by a cuckoo is identified by the host bird The probability of identification is $p_a \in [0,1]$. In this case, it can simply both abandon the nest by throwing the egg and find a new location to build a completely new nest.

A general steps for the cuckoo search algorithm (CSA) is summarized considering these three rules mentioned above. The pseudo code of CSA is shown in fig 1.

```
begin
    Objective function f(x), $x = (x_1, ..., x_d)^T$
    Initialize a population of n number of host nests
    $x_i$ (i = 1, 2, ..., n)
    while (t <Max Generation) or (stop criterion)
        Get a randomly cuckoo by L´evy flights method
        evaluate its fitness $F_i$
        Choose a nest randomly among n pop(say, j)
        if ($F_i > F_j$),
            replace j by the new solution;
        end
        A fraction ($p_a$) of worse nests
        are abandoned and new nests are built;
        Update and keep the best solutions
        Find the current best based on ranking
    end while
    Post process results and visualization
end
```

Fig 1. Pseudo code of cuckoo search algorithm

III. GENERATOR SENSITIVITY FACTOR AND REAL POWER CONGESTION DISTRIBUTION FACTOR

The expression of real power P_{ij} flow through a transmission line-*m* connected between bus-*i* and bus-*j* can be written as:

$$P_{ij} = |V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) - V_i^2 Y_{ij}\cos\theta_{ij} \tag{1}$$

where V_i, V_j and δ_i, δ_j are the voltage magnitudes and voltage angles at bus-*i* and bus-*j* respectively. Y_{ij} and Θ_{ij} are the magnitude and angle ij^{th} part of Y_{Bus} matrix .

Generator sensitivity factor (GSF) describes an amount of change in transmission line (m) real power connected between bus *i* and bus *j* to the amount of change in generator (g) real power output [7].

Mathematically,

$$GSF_g = (\Delta P_{ij} / \Delta P_{Gg}) \tag{2}$$

Here, ΔP_{ij} is the change in real power flow from base value through a congested transmission line whereas ΔP_{Gg} is change in real power output of a generator g from its base value.

$$GSF_g = \frac{\partial P_{ij}}{\partial \delta_i} \cdot \frac{\partial \delta_i}{\partial P_{G_g}} + \frac{\partial P_{ij}}{\partial \delta_j} \cdot \frac{\partial \delta_j}{\partial P_{G_g}} \tag{3}$$

The detail derivations for GSF are shown in [7].

The real power congestion distribution factor (RPCDF) for a line m describes an amount of change in transmission line (m) real power joined between bus *i* and bus *j* to the amount of change in n^{th} bus real power [5]. Mathematically,

$$RPCDF_n^k = \frac{\Delta P_{ij}}{\Delta P_n} \tag{4}$$

Here, ΔP_{ij} is the change in real power flow from base value through a congested transmission line whereas ΔP_n is change in real power of a bus n from its base value.

$$RPCDF_n^k = a_{ij} m_{in} + b_{ij} m_{jn} \qquad (5)$$

Where

$$a_{ij} = V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) \qquad (6)$$

$$b_{ij} = -V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) \qquad (7)$$

Here a_{ij}, b_{ij} are the partial derivatives of change in real power ΔP_{ij} with respect to δ_i and δ_j respectively. Also, m_{in} and m_{jn} are the coefficients of jacobian matrix.

The detail derivations for RPCDF are shown in [5].

In this work, the generators are having strongest and non-uniform values of sensitivity indices are considered to reschedule their output for congestion alleviation in transmission line. Consequently, the location of distributed generation is found by considering a bus which is having most negative RPCDF values.

IV. PROBLEM FORMULATION

The congestion cost

$$Minimize\left(\sum_{g=1}^{N_g} C_g\left(\Delta P_g\right)\Delta P_g\right) + C_{dg} P_{dg} \qquad (8)$$

Here, congestion cost refers to the cost of generator rescheduling and the cost of distributed generation.

Subject to:

$$\sum_{g=1}^{N_g}((GSF_g)\Delta P_g) + L_m^0 \le L_m^{\max} \qquad m = 1,2,.....n_1 \qquad (9)$$

$$P_g - P_g^{\min} = \Delta P_g^{\min} \le \Delta P_g \le \Delta P_g^{\max} = P_g^{\max} - P_g \qquad (10)$$
$$g = 1,2,........N_g$$

$$P_g^{\min} \le P_g + \Delta P_g \le \Delta P_g^{\max} \qquad g = 1,2,........N_g \qquad (11)$$

$$P_{dg}^{\min} \le P_{dg} \le P_{dg}^{\max} \qquad (12)$$

$$V_i^{\min} \le V_i \le V_i^{\max} \qquad (13)$$

$$\sum_{g=1}^{N_g} \Delta P_g = 0 \qquad (14)$$

Where,

C_g: incremental/decremented price bids of generator-*g* which are participating in congestion management.

C_{dg}: incremental/decremented price bids of DG units.

ΔP_g: up-down variation of real power of g^{th} generator.

P_g^{min} & P_g^{max}: Minimum and maximum real power limit of g^{th} generator.

ΔP_g^{min}, ΔP_g^{max} : Minimum and maximum adjustable real power limits of g^{th} generator .

L_m^0: Actual power flow in a transmission line m for base case.

L_m^{max}: Maximum power flow limit of m^{th} transmission line joined between bus-*i* and bus-*j*.

V. RESULTS AND DISCUSSIONS

The present work is tested on IEEE 39 bus New England Test System. This test system consists of 10 generator buses and 29 load buses. The network topology is shown in figure 2 and test system data file for IEEE 39 bus system can be found in [18].

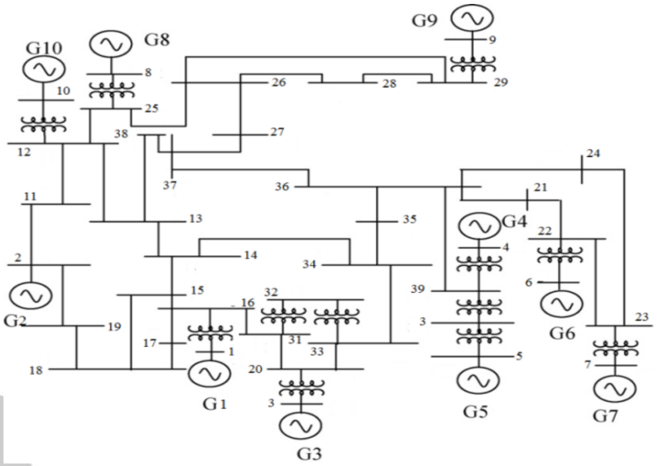

Fig 2. IEEE-39 bus New England Test System

In this work, cuckoo search algorithm (CSA) has been applied to reduce the congestion cost. Rescheduling of generators is done by CSA by considering DG in the system. In this work, line 14-34 is created as forced outage which results in thermal limit violation on line 15-16, thus line 15-16 is known to be congested. The RPCDF values are calculated by considering the outage line 14-34. The most negative RPCDF value is chosen to install the DG units for congestion management.

In table 1, RPCDF values for selected buses with high sensitivity values are presented. It is noted that among all the buses, bus no 14 shows most negative value of RPCDF. Hence bus no 14 is selected for the installation of DG units. Because of outage of line 14-34, line 15-16 is congested. Hence, GSF values for all the system generators are shown in figure 3 by considering congested line 15-16.

TABLE I RPCDF VALUES FOR SELECTED BUSES

Bus No	RPCDF for selected buses
1	0
8	-0.0198
9	0.0289
10	-0.0401
12	-0.0404
14	**-0.2551**
16	-0.0049
19	-0.0328
25	-0.0216
27	0.0487
34	**0.4188**
38	0.0206

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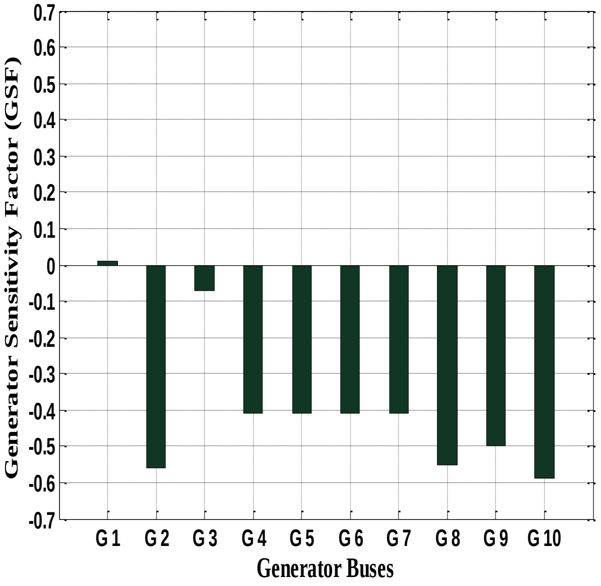

Fig. 3. Generator sensitivity factor for 39 Bus New England Test System

It is observed from the base case load flow study that the power flow through congested line (L 15-16) is 627 MVA (power flow limit 500 MVA) when forced outage of line 14-34 is created. Figure 3 shows that generators No. 4, 5, 6, 7 have uniform flow of sensitivity indices whereas generators no. 2, 3, 8, 9 and 10 have non-uniform flow of sensitivity values. So these non-uniform sensitive generators are rescheduled to minimize congestion cost by integrating DGs in the system.

Table 2 illustrates the usefulness of proposed work by generator rescheduling and installation of DG units. It is observed from table 2 that amount of generator rescheduling is less as compared with other reported results. Here five generators along with slack bus generator are rescheduled. Slack bus generator is rescheduled to minimize the overall system losses. The total rescheduled amount by proposed method is 351.51 MW.

Rescheduling of real power output is done in order to manage transmission line congestion. The GSF values are used here to find the optimal generators which will participate in congestion management. Non-uniform flow of sensitivity indices are considered to select the generators from GSF tables. It is advantageous that the presence of DG units of larger scale reduces the burden from selected generators to reschedule their output in a larger scale. The DG units location is determined from the most negative RPCDF values after outage of line 14-34 is considered. This proposed work as compared with other reported results in table 2 indicates the effectiveness of proposed work.

TABLE II GENERATOR RESCHEDULING USING CSA

Gen Number	**Amount of Rescheduling (MW)**		
	Result Reported in [4]	***Result Reported in [7]***	***Considering DG units using CSA (Proposed Work)***
1	-99.59	-149.1	-114.31
2	98.75	65.6	21.5
3	-159.64	-129	-1.0
4	12.34	Not Participated	Not Participated
5	24.69	Not Participated	Not Participated
6	24.69	Not Participated	Not Participated
7	12.34	Not Participated	Not Participated
8	24.69	75.4	-118.4
9	12.34	52.1	10.7
10	49.38	83.0	85.6
Net Amount (MW)	518.45	554.2	351.51

Table 3 shows the improvement in some system parameters after rescheduling by proposed method. Prior to rescheduling, the total active power loss and system minimum voltage is 59.9 MW and 0.934 p.u.

These system parameters are improved considerably after rescheduling process. The proposed work result is compared with other reported result. It is observed that proposed work shows improvement in real power loss (52.54 MW) and system minimum voltage (0.940 p.u.).

TABLE III
SOME PARMETERS BEFORE AND AFTER RESCHEDULING

System Parameters	**Before Rescheduling**	**After Rescheduling**		
		Result Reported in [4]	***Result Reported in [7]***	***Proposed Work***
Ploss (MW)	59.9	58.0	57.31	52.54
Vmin (p.u.)	0.934	0.932	0.945	0.940

TABLE IV
RESCHEDULING COST AND OPTIMAL SIZE OF DG UNITS

	Result reported in [6]	**Proposed method with DG units**
Rescheduling Cost ($/MW-Day)	92.817	46.2809
Optimal DG Size (p.u.)	2.0949 p.u.	

The optimal size of DG achieves after solving the optimization process using CSA, shown in table 4. The optimal size of DG

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found in proposed work is 2.0949 p.u. Moreover, the rescheduling cost of proposed work is compared with result reported in [6]. The rescheduling cost of proposed work is less as compared with result reported in [6].

TABLE V CONDITION OF CRITICAL LINES PRE AND POST RESCHEDULING

Lines / Transfor-- mers connected between buses	Line No.	Actual Flow (MVA)			Line flow limit (MVA)
		Before Rescheduli-ng	Result reported in [6]	After Reschedulin-g considering DG using CSA	
L_{39-5}	36	519.10	518.6	506.08	1200
L_{22-6}	43	683.63	682.50	650.0	1200
L_{23-7}	42	575.51	575.21	558.39	1100
L_{25-8}	41	539.46	611.54	420.59	1100
L_{29-9}	40	825.85	873.73	835.31	1100
L_{12-13}	32	431.99	538.53	369.80	600
L_{13-14}	30	250.68	323.11	137.57	600
L_{15-16}	**26**	**628.60**	**495.23**	**476.31**	**500**
L_{21-22}	17	614.72	614.21	594.43	1200

Table 5 shows the congested line (L15-16) power flow and some other critical lines power flow during pre and post rescheduling process. It is observed that presence of DG units with generator rescheduling improves power flow through all the critical lines and congested lines. The power flow of congested line by proposed method even also less than the result reported in [6]. Congested line power flow in base case is 628.60 MVA which reduces considerably i.e. 476.31 MVA using proposed method.

The system critical lines are decided based on the power flow through all the lines during base case solution. The power flow through critical lines are very high or near to their thermal limits. The proposed work considering DG units with CSA based solution provides improvement in power flow through all the critical lines which is presented in table 5.

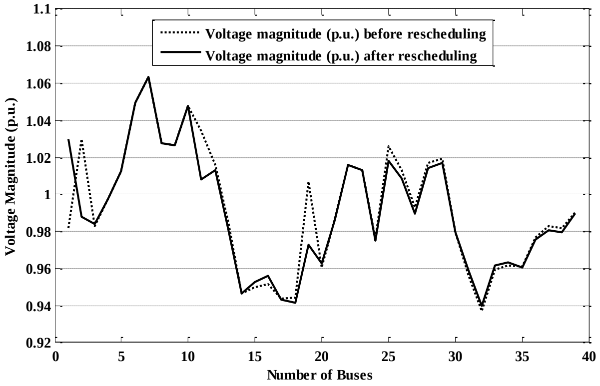

Fig. 4. Voltage variations of all the buses

Figure 4 illustrates the variation in system voltage magnitudes of all buses pre and post rescheduling. From figure 4, it is observed that voltage magnitude of minimum voltage improves using the proposed method. The presence of DG units in the post rescheduling shows better voltage profile than the congested system.

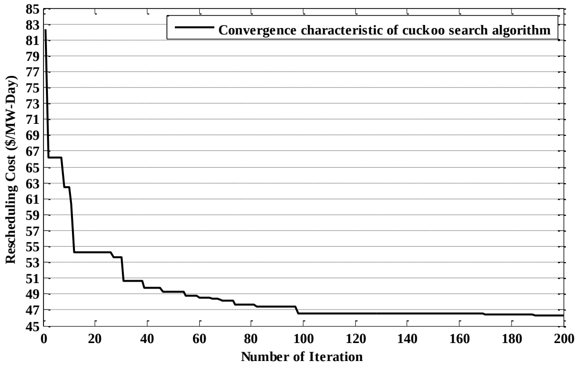

Fig. 5. Convergence characteristic of Cuckoo Search Algorithm

Figure 5 represent the convergence characteristics of objective function using cuckoo search algorithm. The cost of objective function reduces corresponding to increase in number of iteration. The optimal congestion cost is found 46.2809 $/MW-Day for this system.

VI. CONCLUSION

The proposed work considers generator rescheduling and integration of large size DG units in the system to avoid the eliminate transmission line congestion and minimize the congestion cost. CSA is one of the newly developed metaheuristic algorithms which is used to solve the objective function. The DG location is found out from the most negative RPCDF value whereas, generators are selected based on non-uniform GSF values. The DG unit optimal size is found during optimization process, solved by exploring CSA. It is observed that proposed work shows less congestion cost as compared with other reported result. The optimal generator output is also reduced corresponding to other reported results. This proposed method shows reduction in all other critical lines power flow much below their thermal line limits which signifies the value of proposed work. This paper also shows the drastic decrement of real power loss and significant enhancement in minimum voltage. The much improvement in other system parameters like voltage magnitudes and line real power losses indicates the better stability of system.

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