# Power System Congestion Management by Generator Active Power Rescheduling using Cuckoo Search Algorithm.

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*Abstract*— Power system restructuring has resulted in an increase in complexity of the power flow problem. There has been an increase in the number and volume of transactions from the various market participants as they try to make full utilization of the existing resources for profit maximization. In addition, there is a slow rate in construction of new transmission lines due to environmental, right-of-way and economic hurdles. As a result, transmission systems are at most times operated close to their thermal limits leading to frequent occurrence of network congestion. Congestion imposes a barrier to trade in electrical power and poses a threat to the secure, reliable and economic operation of a power system. Hence, congestion management is a fundamental transmission network management problem that the Independent System Operator (ISO) has to frequently address in an open electricity market.

Generator active power rescheduling is the most popular transmission network overload alleviation technique since it offers ease of control at no additional capital cost. In solving the congestion management problem by generator rescheduling, the aim is to alleviate line overload with minimum rescheduling cost while satisfying the power system equality and inequality constraints. The proposed congestion management problem is formulated as a non-linear, non-convex and highly constrained optimization problem. Thus, solution using Swarm Intelligence (SI) algorithms is suitable. This work studies the effectiveness of Cuckoo Search Algorithm (CSA) in solving the congestion management problem in a pool-based electrical market. Only generator active power output is rescheduled. The algorithm is tested on the modified IEEE 30-bus system.

***Keywords***— *congestion management, Cuckoo Search Algorithm, Independent System Operator, network congestion, power flow, rescheduling, transmission systems.*

## I. INTRODUCTION

Energy is the basic necessity for economic development of a country. It exists in different forms in nature, the most refined form being electrical energy. A power system consists of generation stations, power substations, transmission lines, distribution system and load/consumption [1].

Recent global trend has been on restructuring of the Electricity Supply Industry (ESI). There has been a rapid shift from Vertically Integrated Utilities to a liberalized power market with unbundling of the generation, transmission and distribution functions [2].

In the liberalized power systems, the transmission network is a key component in enabling operation of a competitive market. It is a regulated natural monopoly which should allow open access to facilitate a competitive environment in power generation and retail services. The planning and operation of the transmission network still remains a challenge in the development of the liberalized power system. Transmission systems are at most times operated at or near their rated capacity. This is due to an increase in the number of transactions from the various market participants (buyers and sellers) as they try to make full utilization of the existing resources. In addition, there is a slow rate in construction of new transmission lines due to economic and environmental factors. As a result, congestion management is a top transmission network management problem that the ISO has to address frequently to avoid a power system crisis [3] [4].

Congestion is the restriction of transfers between different system nodes or regions in an electrical network which occurs when the transmission system is unable to accommodate all of their desired transactions due to violation of thermal limits of transmission lines. It may result from a change in energy demand or due to contingencies such as generator failure or transmission line outage [3]. Moreover, since the investment in and location of new generation plants is dictated by market forces and may not be well coordinated with transmission expansion planning, network congestion may result [6]. It is a serious economic and reliability concern in the open electricity market [5]. Thus, congestion management is a fundamental transmission system management problem in the restructured power market if secure, efficient and non-discriminatory access to the transmission system is to be maintained. Some of the remedial actions to handle congestion include outaging of congested lines, use of

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Flexoble AC Transmission System (FACTS) devices, generator rescheduling and load shedding [7].

## II. LITERATURE REVIEW

Bompard et al [6] provide a comparative analysis of congestion management schemes used in England and Wales, Norway, Sweden, PJM and California markets in the United States of America. From this work, the researchers developed a unified framework for comparing the performance of the various methods used in these power markets.

Yamina and Shahidehpour [8] developed a coordination process between Generating Companies (GENCOs) and ISO for congestion management before real-time operation using a two-stage Security-constrained Price-based Unit Commitment (SPUC). First, GENCOs apply Price-Based Unit Commitment without transmission security constraints and submit profit maximization bids to the ISO. The ISO checks for violation of transmission line limits under normal operating conditions and during contingency. If there are transmission line limit violations, a rescheduling signal is sent to the GENCOs.

Kumar et al proposed a zonal congestion management approach in [9] while in [10], they proposed a cluster-based congestion management approach. In [9], congestion zones have been determined using active and reactive power flow sensitivity indices. Generators having strongest and non-uniform sensitivity indices are grouped into most sensitive zones and their generation is rescheduled. In [10], clusters of different types are formed based on congestion distribution factors whereby type 1 clusters constitute users with the strongest and non-uniform Transmission Congestion Distribution Factors (TCDFs). In both, network analysis is performed using AC load flow method. A comparison is done between DC load flow method and AC load flow method. The findings show that the computational time while using AC load flow method is close to that of DC load flow method. Also, the AC load flow method is more accurate and it provides lower congestion costs compared to DC load flow method.

Sarwar and Siddiqui [11] achieve zonal congestion management by utilizing Locational Marginal Pricing. A power network is split into zones based on the difference in Locational Marginal Price of the buses across a transmission line. The most congestive zone, designated as “Zone 1", is identified as the one which groups buses with high and non-uniform Locational Marginal Price (LMP). A second zone, denoted as “Zone 2", is less prone to congestion and constitutes of buses with low and uniform LMP differences. A comparative study of Distributed Generator (DG) placement in Zone 1 and Zone 2 indicate that DG placement in the more sensitive Zone 1 is more effective in congestion alleviation.

Yesuratnam and Tukkaram [12] introduced a concept for mitigating transmission overload by real power rescheduling based on Relative Electrical Distance (RED). The RED is the relative location of load buses. The proposed approach alienates congestion by re-scheduling of generators by involving minimal cost in the rescheduling process. However, generators with the same Relative Electrical Distance have an equal power contribution to the congested line. The cost would not be optimized if the generators with equal RED have different incremental or decremental costs.

Sudipta and Singh [13] proposed a methodology for congestion management in a pool market by optimal rescheduling using Particle Swarm Optimization (PSO). Optimal generator rescheduling was done based on generator sensitivity to congested line's power flow.

Balaraman and Kamaraj [14] present a method for congestion management by real power rescheduling using PSO in a pool-based electrical market. Line overload due to unexpected line outage and sudden load variations are considered. Numerical results obtained using PSO are presented and compared with Simulated Annealing (SA) and Random Search Method (RSM). The experimental results show that PSO is capable of obtaining higher quality results than SA and RSM.

Ravindrakumar and Chandramohan [15] propose use of Non-dominated Sorting Genetic Algorithm II (NSGA-II) for line overload alleviation by generator rescheduling in a pool-based electricity market. The aim of the research was to reduce the rescheduling cost. NSGA II is a modified version of Non-dominated Sorting Genetic Algorithm (NSGA). NSGA is a popular non-domination based genetic algorithm for multi-objective optimization. It is a very effective algorithm but has been criticized for its computational complexity, lack of elitism and a need for prior selection of a sharing parameter value. NSGA II has a better sorting algorithm, incorporates elitism and no sharing parameter needs to be chosen a priori. Contingency cases considered in this work were line overload due to unexpected line outage and sudden load variations.

There has also been research focusing on the application of FACTS devices such as Thyristor-Controlled Series Compensator (TCSC), Thyristor Controlled Phase Angle Regulator (TCPAR) and Static Var Compensator (SVC) to solve congestion problems. Mwanza [16], reports that inclusion of FACTS devices greatly reduces amount of redispatched power in a pool-based market. This has the advantage of maintaining the optimal operating point close to that obtained from market settlement. Also, there is a reduction in the congestion cost incurred by the ISO. Rajalakshmi et al [17] present a method for optimal location of TCSC based on real power performance index and reduction of total system VAR power loss. Bhattacharyya et al [18] implemented a fuzzy-DE approach for optimal placement of TCSC and SVC with the objective of minimizing transmission loss while maintaining lowest operating cost. TCSC's were placed in lines with very high reactive power flow while the placement of SVC's was determined by the fuzzy membership of loss sensitivity in the weaker nodes. The results obtained showed a better performance of Fuzzy-DE compared to SDE (Simple Differential Evolution). However, FACTS devices involve high capital cost and a long payback period. Their use is only plausible if they are economically justifiable alternatives to power system reinforcements [7].

Cuckoo Search Algorithm is a nature-inspired metaheuristic approach developed in 2009 by Xin-She Yang and Suash Deb. It has been applied to solve problems in engineering, pattern recognition, job scheduling, Object-Oriented software testing and in wireless sensor networks [19].

## III. MODELLING OF THE ENERGY MANAGEMENT PROBLEM

Congestion management aims at minimizing network congestion while satisfying network constraints. The problem is formulated as [14];

$$minimize\ C_c = \sum_{j=1}^{N_g}(C_k \Delta P_{Gi}^{+} + D_k \Delta P_{Gi}^{-})\ \$/h \quad (2.1)$$

The optimization problem is subject to equality and inequality constraints as stated in the next two subsections.

### A. Equality constraints

$$P_i = |V_i| \sum_{j=1}^{n} |V_j||Y_{ij}| \cos(\theta_{ij} + \delta_j - \delta_i) \qquad (2.2)$$

$$Q_i = -|V_i| \sum_{j=1}^{n} |V_j||Y_{ij}| \sin(\theta_{ij} + \delta_j - \delta_i) \qquad (2.3)$$

$$P_{Gi} - P_{Di} - P_i = 0 \qquad (2.4)$$

$$Q_{Gi} - Q_{Di} - Q_i = 0 \qquad (2.5)$$

### B. Inequality constraints

These represent the operating and physical limits of all the generators, transformers and transmission lines, as stated in equations *2.6-2.9*;

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \qquad (2.6)$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max} \qquad (2.7)$$

$$V^{min} \le V \le V^{max} \qquad (2.8)$$

$$P_{ij} \le P_{ij}^{max} \qquad (2.9)$$

Where;

$P_{Gi}$ and $P_{Di}$ are the active power generation and demand at bus *i* respectively,

$Q_{Gi}$ and $Q_{Di}$ are the reactive power generation and demand at bus *i* respectively,

$N_g$ is the number of generators in the power system.

$P_{Gi}^{min}$ and $P_{Gi}^{max}$ are the minimum and maximum active power generation limits,

$Q_{Gi}^{min}$ and $Q_{Gi}^{max}$ are the minimum and maximum reactive power generation limits,

$V^{min}$ and $V^{max}$ are the bus minimum and maximum voltage limits,

$P_{ij}^{max}$is the maximum line flow limit (MW) of line $l$,

Equations *2.2* and *2.3* represent the power flow equations for a given bus *i* while equations *2.4* and *2.5* represent the power balance constraints.

## IV. CUCKOO SEARCH ALGORITHM

Cuckoo Search Algorithm (CSA) is a nature-inspired metaheuristic algorithm based on the obligate brood parasitism of some cuckoo species such as *Tapera* in combination with the Levy flight behaviour of some birds and fruit flies. In brood parasitism, the birds lay eggs in nests of other host birds, often of other species. Some of the host birds can engage in direct conflict with the intruders. In other instances, if the host bird discovers the alien eggs, it may throw them away or abandon the nest. To reduce the probability of the eggs being abandoned by the host bird, some cuckoo species such as *Tapera* have evolved and are specialized in the mimicry in color and pattern of the eggs of some of the host species. The parasitic cuckoo often chooses a nest where the host bird has just laid its eggs. The cuckoo eggs have slightly shorter incubation period than the host's eggs. Upon hatching, the first instinctive action of the cuckoo chick is to blindly propel the other eggs out of the nest. This increases its share of food provided by the host. The chicks have rapid nestling growth and can also mimic the call of host chick, increasing its feeding opportunity [20].

In this algorithm, the eggs in a nest represent a pool of candidate solutions of an optimization problem, while the cuckoo egg represents a new coming solution. The aim is to use these new, and potentially better solutions associated with the cuckoo eggs to replace the current solution associated with the eggs in the nest. It is based on three rules [21].

1. Each cuckoo lays one egg at a time and dumps it in a randomly chosen nest.
2. The best nests with high quality of eggs (solutions) will be carried over to the next generations.
3. The number of available host nests is fixed, and a host can discover an alien egg with a probability $p_a$ [0; 1]. The host bird can either throw the egg away or abandon the nest so as to build a completely new nest in a new location. This rule can be approximated by a fraction $p_a$ of the $n$ nests being replaced by new nests with new random solutions at new locations.

The algorithm uses a balanced combination of local random walk and global exploration. It can be summarized in a pseudo-code as;

***begin***
*Objective function f(x), x = ($x_1$; $x_2$ ...........$x_d$);*
*Initialize a population of n host nests $x_i$ (i=1, 2........... n);*
***while*** *(t< maximum generation) or (stop criterion);*
*Get a cuckoo i randomly;*
*Generate a new solution by Levy flight;*
*Evaluate its fitness, $F_i$;*
*Randomly choose a nest j among the n nests;*
***if*** *($F_i$ > $F_j$),*
*Replace j with the new solution;*
***endif***
*Abandon a fraction pa of worse nests;*
*Build new nests at new locations by Levy flights;*
*Keep the best solutions;*
*Rank the solutions and find the current best;*
***end while***
*Output the results*
***end***

## V. METHODOLOGY

This work explores the capability of Cuckoo Search Algorithm in solving the congestion management problem. In performing the analysis, modified IEEE 30-bus system was used as the test-bed. Outage of line 1-2 was the considered contingency case. Only generator active power rescheduling was performed. The set of control variables include changes in generator active power output, excluding the slack bus.

### A. Modified IEEE 30-bus system

This system has a total active power demand of 283.4 MW and reactive power demand of 126.2 MVAr. It consists of 6 generator buses, 24 load buses and 41 transmission lines [14].

### *B. Computational procedure of CSA for CM*

1. Bus data, line data, price bids and generator parameters were input and a load flow was run for the base case scenario.
2. A contingency was created by introducing an outage on line 1-2.
3. Load flow was run while satisfying the equality constraints. Hence, excess power flow was determined.
4. Initial Cuckoo population was generated using equation (2.6), which is the amount of rescheduling required by the generators to manage congestion (randomly within the limits).
5. For each generated Cuckoo population, load flow was performed and, hence, the fitness function was evaluated and the best solution was identified.
6. New solutions were generated using Levy flight.
7. The fitness of each new solution obtained was evaluated. Any two nests were randomly chosen and their fitness values were compared. The cuckoo with better fitness value was accepted while the other was rejected.
8. Steps 6-7 were repeated until the congestion is eliminated.

## VI. RESULTS AND DISCUSSION

CSA for congestion management was implemented using MATLAB (version R2014a) software. Simulations were carried out on modified IEEE 30-bus system. Congestion was created by outage of line-1 connected between bus-1 and bus-2. Generator rescheduling cost for the simulated case was calculated and compared with results reported in [14].

Due to outage of line-1, congestion occurs on line-2 and line-4, connected between buses 1-7 and 7-8, respectively. From load flow results, due to the outage, the power flow in these lines become 147.263 MW and 135.960 MW respectively, against the line flow limit of 130 MW for both lines. Net power violation was found to be 23.223 MW. Results obtained after performing generator rescheduling are as tabulated in *Table 1*. *Table 1* also includes results obtained from RSM, SA and PSO techniques reported in [32]. From Table 1, it is evident that CSA gives the lowest rescheduling cost compared to RSM, SA and PSO. CSA gives a rescheduling cost of 487.5818 $/h. The total system loss after congestion management decreases from 15.823 MW to 12.922 MW. A comparative pictorial representation of active power rescheduling and congestion cost offered by CSA, PSO, RSM and SA are shown in *Figure 1* and *Figure 2*, respectively. *Figure 3* shows the bus voltage profile obtained after CM using CSA. It is observed that the voltage magnitude at each bus is within limit.

*Table 1: Comparison of results obtained.*

| Parameters | Method | | | |
|---|---|---|---|---|
| | **CSA** | **PSO** | **RSM** | **SA** |
| Total congestion cost ($/h) | 487.5818 | 538.95 | 716.25 | 719.861 |
| Power flow after CM(MW) | | | | |
| Line 1-7 | 129.2950 | 129.9700 | 129.7800 | 129.5100 |
| Line 7-8 | 120.2600 | 120.7800 | 120.6000 | 120.3500 |
| $\Delta P_{G1}$ (MW) | -9.5090 | -8.6123 | -8.8086 | -9.0763 |
| $\Delta P_{G2}$ (MW) | 15.0668 | 10.4059 | 2.6473 | 3.1332 |
| $\Delta P_{G3}$ (MW) | 0.0000 | 3.0344 | 2.9537 | 3.2345 |
| $\Delta P_{G4}$ (MW) | 0.0001 | 0.0170 | 3.0632 | 2.9681 |
| $\Delta P_{G5}$ (MW) | 0.0002 | 0.8547 | 2.9136 | 2.9540 |
| $\Delta P_{G6}$ (MW) | 0.0001 | -0.0122 | 2.9522 | 2.4437 |
| Total generation rescheduled (MW) | 24.5762 | 22.9360 | 23.3390 | 23.8090 |

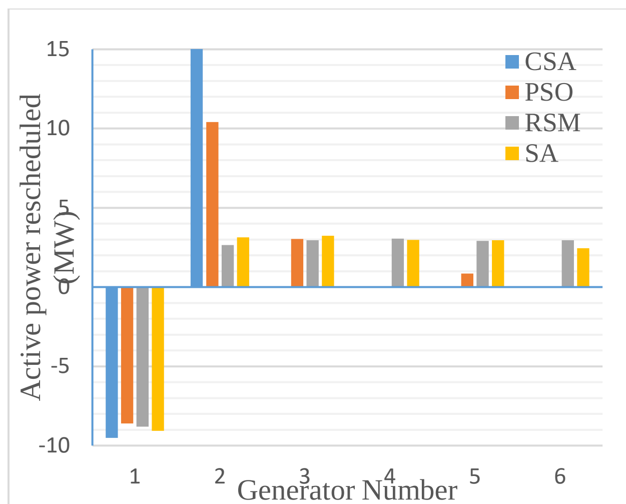


*Figure 1: Comparative active power rescheduling of generators.*

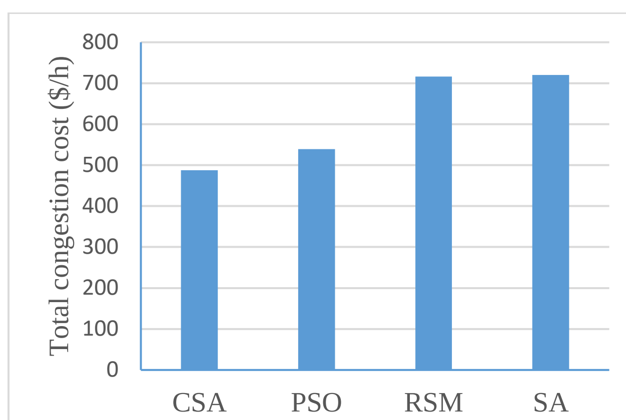


*Figure 2: Congestion cost obtained from different algorithms.*

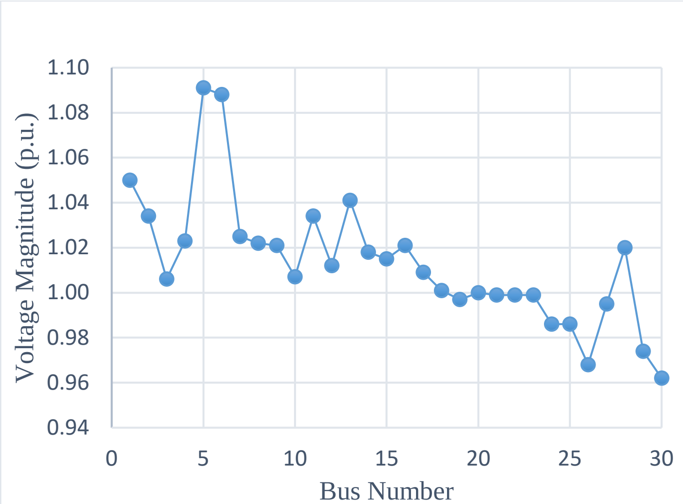


*Figure 3: Voltage profile after Congestion Management*

## VII. Conclusion

This paper presents a generator rescheduling-based approach for power system Congestion Management. A line outage is the only contingency case considered. Congestion in the overloaded lines is managed by generator rescheduling while minimizing the rescheduling cost. The comparative analysis of the obtained results indicates that the proposed CSA-based algorithm gives lower rescheduling cost compared to Particle Swarm Optimization, Simulated Annealing and Random Search Method. In addition, the total system loss has also been reduced after performing Congestion Management.

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