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A Soft Computing-Based Analysis of Congestion Management in Transmission Systems

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Abstract: Congestion in the transmitting system is unitarily responsible for technological problems that appear, especially in a deregulated environment. The post-deregulation operation history of the electrical power system has placed greater pressure on the Independent System Operator (ISO) to assure a secure, congestion-less transmission network. Blackout and brownout voltage dip issues occur due to the heavy loading condition. Hence, this paper presents a novel approach for the relief of congestion by using a nature-inspired algorithm, namely Particle Swarm Optimization and Firefly Algorithm by considering various factors for re-dispatching active power of generators during overloading conditions. The algorithms are tested on IEEE 30 and IEEE 39 Bus standard test systems and the obtained results show the effectiveness of the proposed algorithm in the MATLAB environment. The congestion management (CoM) method is formulated as a constrained optimization problem with the objective function of relieving the overloading through minimization of factors such as Generator Shift Factor (*GSF*), Bus Sensitivity Factor (*BSF*), Line utilization Factor (*LUF*), and Congestion Index (*CI*). These factors are helpful to mitigate the transmission congestion, which in turn helps to reduce the real power losses.

Keywords: congestion index; deregulation; independent system operator; particle swarm optimization and firefly algorithm; line utilization factor

1 INTRODUCTION

In a restructured power system environment, the congestion in the transmission line is a condition where more power will be scheduled to flow across transmission lines and transformers than the specified physical limits [1-3]. The different constraints for the system are thermal limit of lines, bus voltage limits, etc. The reason behind this is the poor coordination between generation and transmission utilities or due to unexpected contingencies like generation outages, sudden increase of load demand or failure of equipment. The rescheduling of real power output of generators is the usual practice to alleviate congestion, but certain critical cases require some improved transmission methods. The emergence of computational intelligence techniques, inspired by biological and human intelligence, is one of the most promising and encouraging fields to solve engineering problems. Various algorithms [2, 3], such as Genetic, Evolutionary and Nature-inspired algorithms have evolved and been deployed over the years to solve the numerous and frequently occurring problems of power supply systems. The optimizations techniques of Particle Swarm Optimization (PSO) and Firefly Algorithm (FA) [2, 3] have been successfully used to solve the congestion problems by ensuring optimal power flow capacities and their results are compared with the genetic algorithm and conventional methods to highlight their potential possibilities and better results.

Various researchers have provided guidelines for congestion management [1-22] in different ways which give an idea to mitigate congestion in various test systems; they are covered in this investigative paper. V. Gomathi [4] et al. proposed an algorithm for congestion management in a deregulated environment by using a wind energy generator. The Locational Marginal Pricing (LMP) and Social benefit of the system were calculated and the results were compared both with and without Renewable Energy Sources (RES) under pool and bilateral market operations. V. Subramaniyan [5] et al. proposed a method to minimize the congestion on the transmission line by integrating Solar Photovoltaics into the system. Uma Velayutham [6] et al. proposed an algorithm to mitigate congestion and to minimize the cost of the system by using IPFC (Interline Power Flow Controller) by a factor called RPPI (Real Power Performance Index). Sadhan Gope [7] et al. proposed a congestion management model for the New England test system (IEEE 39 Bus system) using factors such as Bus Sensitivity Factor (*BSF*) and Generator Shift Factor (*GSF*) to optimally locate the pumped hydro storage tank.

Aditi Gupta [8] et al. proposed a rescheduling based combined bidding approach for a wind integrated hybrid power system to manage congestion; the proposed strategy was analyzed in IEEE 24 Bus system. Nan Lou [9] et al. proposed a technique to minimize congestion and the congestion cost of a system. The recommended model comprised a two-stage approach involving a virtual power plant with cascaded hydro-photovoltaic-pumped storage hybrid generators. An improved hybrid non-dominated sorting genetic algorithm-II (HNSGA-II) was proposed to solve the two-stage problem. Vijaykumar K. Prajapati et al. [3] suggested a method to relieve congestion and reduce the generation cost, total power generation, total loss by increasing the number of Plug-in Electric Vehicles. The proposed approach was modelled in a GAMS environment and implemented in a modified IEEE 39-Bus system. Miloš Pantoš [10] proposed a two-stage optimization technique for market-based congestion management (MBCM) in electric power systems utilizing aggregators of dispersed small-scale electricity consumers, producers and prosumers of the distribution network. Aishvarya Narain [11] et al. analyzed various approaches used for congestion management in a deregulated power system. The authors highlighted several key issues and challenges.

Using generator sensitivities to the power flow on congested lines, Dutta Sudipta [15] et al. proposed a technique for optimum selection of participating generators. The proposed methodology was put to the test on IEEE 30-bus and 118-bus systems, as well as the 39-bus New England system. Kumar Ashwani [16] et al. established an optimal generator rescheduling technique for real-time congestion management, as well as the impact of Sen Transformers on congestion control. Sen Transformers were compared to a universal power flow controller (UPFC) for congestion management. Solving a mixed integer non-linear programming model of congestion management yielded the ideal position of the Sen Transformer and UPFC. On an IEEE 24-bus RTS test system, the proposed model was used to obtain results.

Kumar Ashwani [17, 18] et al. proposed a congestion management strategy in deregulated electricity markets using FACTS devices and a generic load model to ensure load ability limits. Masoud Esmaili [21, 22] et al. discovered a series of FACTS devices for a multi-objective congestion management problem in order to increase power system voltage and transient stability.

Based on the extensive literature survey, it is noted that in all the above-mentioned research studies, the techniques or methodologies for relieving the congestion in a power system have been studied with the help of different equalizing factors. The different methods and optimization techniques to alleviate congestion are also discussed in detail. Considering various factors for re-dispatching active power generation during overloading conditions using a nature-inspired algorithm, a novel approach, namely Particle Swarm Optimization and Firefly algorithm has been proposed and tested on IEEE 30 and IEEE 39 Bus systems in MATLAB environment. The congestion management method is formulated as a constrained optimization problem with the objective function of relieving overloading through minimization of factors such as Generator Shift Factor (*GSF*), Bus Sensitivity Factor (*BSF*), Line utilization Factor (*LUF*), and Congestion Index (*CI*). These factors are helpful in mitigating congestion, which in turn helps to reduce the transmission congestion and real power losses. A comparative analysis of the factors considered for congestion management is carried out under overloading conditions with the use of the Particle Swarm Optimization algorithm in the current research work.

This research paper is structured as follows. The factors considered and problem formulation for the congestion management in IEEE 30 and 39 Bus systems are discussed in Section 2. The implementation of soft computing or nature-inspired algorithm such as the Particle Swarm Optimization and Firefly algorithm is presented in Section 3. The proposed technique is validated in a test system and the results are shown in Section 4. The conclusions and future scope of extending this research study further are discussed in Section 5, followed by the citation of references.

2 PROBLEM FORMULATION

The Newton-Raphson based power flow is conducted for the considered test systems with the base case loading condition to receive the data pertaining to the real power, reactive power and apparent power in all the lines. The voltages at each bus are also noted from the power flow result and it is ensured that they are within the limits. The transmission line can be overloaded by increasing the load in all the buses such that one or more lines are overloaded and the same is ensured by conducting Newton-Raphson based power flow. The transmission lines whose actual MVA capacity exceeds the maximum MVA capacity are identified as congested lines. The real power (MW) output from the generator is rescheduled to relieve the congestion in the system. The power flow is again conducted with rescheduled power (MW) to ensure that the line limits are restored after rescheduling of power from the generators. The objective function is mainly designed to optimize factors such as the Line Utilization factor (*LUF*), Congestion Index (*CI*), Bus Sensitivity Factor (*BSF*), and Generator Sensitivity Factor (*GSF*) using PSO and FF algorithms. The Line utilization factor measures the utilization of transmission lines in the system and it can be represented as:

$$LUF = \frac{Actual\,Transfer\,Capacity}{Maximum\,Transfer\,Capacity} = \frac{T_C}{T_C^{\max}} \tag{1}$$

The *LUF* gives an idea about the power flow in the transmission line. If the value of utilization is less, then the value of power transferred has been low and vice versa. The degree of congestion [1] on a particular line is measured using *CI* and represented as:

$$CI = \left(\frac{Actual\,Transfer\,Capacity}{Maximum\,Transfer\,Capacity}\right)^{2c} = \left(\frac{T_C}{T_C^{\max}}\right)^{2} \tag{2}$$

The choice of exponential in Congestion Index is based on the following assumptions [1]:

- It should be the best smallest integer in order to avoid computation complexity and it will be able to nullify the masking effects.
- If the exponential value is higher, then the congestion index will be low and it is difficult to identify the overloaded lines. So, generally, c is chosen as 1.

However, in this proposed method, the value of exponential component has been taken as 2. Thus, it is evident that *CI* is a reliable index congestion management. The Bus Sensitivity Factor [7, 12] is given by,

$$\begin{aligned} BSF &= \frac{\Delta P_{ij}}{\Delta P_n} = \\ &= \frac{Real\,Power\,flow\,in\,a\,line\,connected\,between\,bus\,i\,and\,j}{Change\,in\,active\,power\,injection\,at\,bus\,n} \end{aligned} \tag{3}$$

The *BSF* can be defined as the ratio of real power flow in a line with the change in active power injection at the corresponding bus. The Generator Sensitivity Factor [7, 12] is represented by,

$$\begin{aligned} GSF &= \frac{\Delta P_{ij}}{\Delta P_g} = \\ &= \frac{Real\,Power\,flow\,in\,a\,line\,connected\,between\,bus\,i\,and\,j}{Change\,in\,active\,power\,generation} \end{aligned} \tag{4}$$

The *GSF* can be defined as the ratio of real power flow in a line with the change in active power generation. The above factor plays a major role in congestion management. The overloaded transmission lines will be displayed with their L*UF* or *CI* or *BSF* or *GSF* and the generators are rescheduled to relieve the congestion based on the minimization of any one of the factors using optimization algorithm. The Generator Rescheduling is performed by considering various constraints given below:

Power Generation Constraint: The minimum and maximum boundaries for the active (P_g) and reactive (Q_g) power generation for the generator.

Power Balance Constraint: The balancing of the real and reactive power among the generation and demand is represented by power balance constraint.

Voltage Constraint: The upper and lower boundaries of the voltage magnitude of the generator.

Transmission Line Loading: The MVA rating of the transmission line decides the line capacity.

The power generation constraint, voltage constraint and transmission line loading are called as inequality constraints [1, 13]. The power balance constraint is called as equality constraint [1, 13].

The Particle Swarm Optimization and Firefly Algorithm are introduced to manage the binding constraints by a method that is different from the traditional method. The various objective functions (*f*(*x*)) considered for Transmission Congestion (*TC*) management using PSO algorithm are given below:

$$f\left(x_1\right)=\sum_{n=1}^{nl}\begin{gathered}\text{Minimization of Transmission Congestion}\\ \text{in lines}\end{gathered} \tag{5}$$

$$f\left(x_2\right)=\sum_{n=1}^{ng}\begin{gathered}\text{Minimization of Transmission Congestion}\\ \text{in linesusing } GSF\end{gathered} \tag{6}$$

where, x_1 and x_2 are the variables used to represent the objective function. The first objective task is to reduce congestion for all lines in the network using *LUF* and *CI* in the transmission lines. The second objective function is to reduce transmission line congestion using *GSF* and using all the generators in the network. Generators having large and non-uniform values of sensitivities are selected for the participation in the Congestion Management by rescheduling their generation. *LUF* and *CI* are optimized to get a value nearer to one.

$$TC_{\text{overload}}=$$
$$=\begin{cases}0; if\ P_{ij}\le P_{ij}^{\max}\\ \text{minimize } LUF \text{ and } CI \text{ nearer to 1 by control variable } P_g\\ \text{using } PSO\ ;\\ \text{if } P_{ij}\ge P_{ij}^{\max}\ \text{ Sub:} P_{g,i}^{\min}\le P_{g,i}\le P_{g,i}^{\max}\end{cases} \tag{7}$$

$$TC_{\text{Base Case}}=$$
$$=\begin{cases}0; \text{if } P_{ij}\le P_{ij}^{\max}\\ \text{reschedule generators which have } Non-Uniform\\ GSF \text{ using } PSO\ ;\\ \text{if } P_{ij}\ge P_{ij}^{\max}\ \text{ Sub: } P_{g,i}^{\min}\le P_{g,i}\le P_{g,i}^{\max}\end{cases} \tag{8}$$

The various objective functions considered for congestion management using *FF* algorithm are given below:

$$f\left(x_3\right)\sum_{n=1}^{nl}\begin{gathered}\text{Minimization of } TC \text{ based on line}\\ \text{outage condition to trace limits on}\\ \text{generator within limits as the}\\ \text{movement and brightness is set to } GSF\end{gathered} \tag{9}$$

$$TC_{\text{Outage}}=$$
$$=\begin{cases}0; \text{if } P_{ij}\le P_{ij}^{\max}\\ \text{reschedule generators with } Non-Uniform\, GSF \text{ for}\\ \text{congested line mitigation ;}\\ \text{if } P_{ij}\ge P_{ij}^{\max}\ \text{ Sub: } P_{g,i}^{\min}\le P_{g,i}\le P_{g,i}^{\max}\end{cases} \tag{10}$$

$$f\left(x_4\right)=$$
$$=\sum_{n=1}^{ng}\begin{gathered}\text{Minimization of reactive power violation with}\\ \text{transformer tap setting using } FF\end{gathered} \tag{11}$$

$$LVC_{\text{base case}}=$$
$$=\begin{cases}0; \text{ if } Q_{gi}^{\min}\le Q_{qi}\le Q_{gi}^{\max}\\ Q \text{ limit violated if } Q_{qi}\le Q_{gi}^{\max};\ \text{change transformer tap setting}\\ \text{value with 0,1 step variation based on firefly movement}\\ \text{subjected to } Q_{gi}^{\min}\le Q_{qi}\le Q_{gi}^{\max}\ \text{ and } V_i^{\min}\le V_i\le V_i^{\max}\end{cases} \tag{12}$$

3 IMPLEMENTATION OF NATURE-INSPIRED ALGORITHMS

Global optimization problems are very difficult to solve as they have many applications and face more problems when dealing with non-linear programs. To overcome these hurdles, optimization tools are used but these tools can solve the problems only based on trial and error techniques. New algorithms have been developed in the present study to see if they can cope with the challenges present in optimization problems. Among these new algorithms, many algorithms coming under Swarm Intelligence such as Particle swarm optimization, Cuckoo search and Firefly algorithm have gained popularity due to their high efficiency. Swarm Intelligence based algorithms are the most popular and widely used among all algorithms. There are many reasons for their popularity; the major reason is that Swarm Intelligence based algorithms usually share information among multiple agents, so that self-organization, co-evolution and learning during iterations help to provide high efficiency. The swarming behaviour of fish and birds seen in nature is used in the Particle Swarm Optimization algorithm while the flashing behaviour of swarming fireflies is the main concept of the Firefly algorithm.

Particle swarm optimization (PSO) is a stochastic optimization strategy based on the population. The objective is to maximize or minimize a fitness function. It also gives better solutions to multiple optima, high dimensionality through adaptation and provides high quality solutions with stable convergence. PSO is employed as an optimization algorithm to minimize *LUF*, *CI* and *GSF* for congestion management by considering the IEEE test system. The generalized PSO algorithm was explained in an earlier research study [6, 14].

The computational procedure for PSO algorithm is explained below based on Fig. 1.

Step 1: For the test system considered (IEEE 30 Bus System) run the newton raphson based optimal power flow.

Step 2: Create a contingency or congestion by increasing the base load of the test system.

Step 3: Again, run the newton raphson based optimal power flow and determine the congested line in the system. Then obtain the Line utilization Factor for the congested lines alone.

Step 4: Now frame the objective function with all the required constraints.

Step 5: Apply PSO algorithm for the congested test system.

Step 5a: For each particle run NR power flow. Compute amount of power, violation in the over loaded lines and voltage violation and thereby compute evaluation value of the factors *LUF*, *BSF* and *GSF*.

Step 5b: Compute new velocities and new search points and increase the iteration count.

Step 5c: The latest g_{best} and P_{best} value is stored as final solution.

Step 6: After rescheduling of the generators run optimal power flow and check for the congested lines.

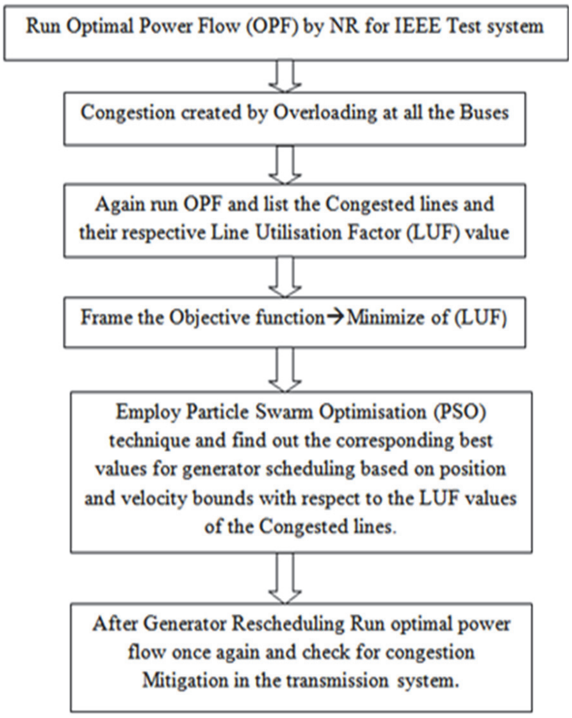

Figure 1 Implementation of PSO

A Firefly algorithmic rule [7] (FA) is a meta-heuristic algorithmic rule galvanized by the flashing behavior of fireflies. Firefly algorithm is a powerful local search in which the brightness is associated with the objective function. This algorithm has four parameters, namely a0, b0, c and population size n. The parameters of FA are tuned for optimal performance and these are $a = 0{,}40$, $b_0 = 0{,}25$, $c = 1$ and *number of fireflies* = 20. Congestion management problem is formulated in optimal power flow environment considering some constraints. Due to the random nature of the firefly algorithm, many trials are performed to get the best results. The minimization objective of congestion is associated with the attractiveness of the firefly that is determined by its brightness or light intensity. The flowchart for the proposed congestion management problem [7] is shown below in Fig. 2.

The process for using the proposed Firefly algorithm to solve the congestion management problem is provided below and is based on Fig. 2.

Step 1: Read the generator information, bus data, and line data.

Step 2: Create a contingency or congestion by increase the base load of the test system.

Step 3: Run the Newton Raphson based load flow in this Step while adhering to equality requirements. Therefore, identify any bus voltage violations and excess power flow.

Step 4: The initial population of fireflies (randomly within the limits) creates the amount of rescheduling necessary for the generators to handle congestion.

Step 5: Load flow is carried out for each population of fireflies that is generated; as a result, the fitness function is assessed and the optimal solution is determined.

Step 6: The positions of all the fireflies are adjusted in relation to their attractiveness.

Step 7: Modified fireflies are used to test the fitness function. A random selection of any two fireflies is made, and their fitness scores are compared. The firefly with the higher fitness score is accepted, while the other is disqualified.

Step 8: The Programme stops if the maximum number of iterations have been made; otherwise, it returns to Step 6.

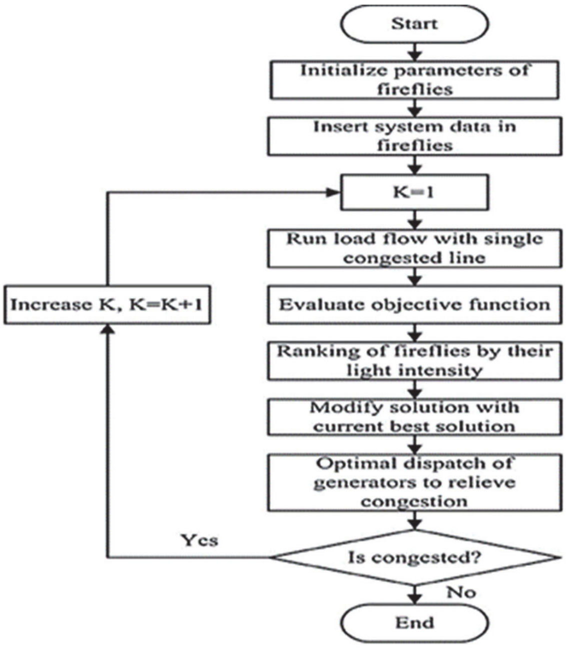

Figure 2 Implementation of firefly algorithm

4 RESULTS AND DISCUSSION

The proposed concept for congestion management has been illustrated in IEEE 30 and IEEE 39 (New England Test) Bus Systems. To understand congestion management in a transmission system, the process begins the progress started with calculation of factors and implementing a strategy to analyze congestion by considering the test systems. The power flow study is conducted under normal loading, during congestion and after generator rescheduling for all test systems. The congestion in the test system is created by significant increase of load in the buses by 20% from the base load. For the IEEE 30 bus system, the line data, bus data, and generator data are taken from [23].

4.1 Implementation of PSO in CM

The following test cases are analysed accordingly for IEEE 30 Bus system:

- Base Case: Single Line Congestion without any loading.
- Overload or Outage Case: Multi-Line Congestion with overloading.

The Particle Swarm Optimization technique is employed as an optimization algorithm in IEEE 30 Bus test system for congestion management. The congested lines in the system are identified by calculation of *LUF* and *CI* factor. After the identification of congested lines, the overloading is relieved by minimizing those factors by using PSO algorithm through appropriate rescheduling of generators.

4.1.1 Case A (Base Case) - Congestion Management Using *GSF*

The IEEE 30 Bus System is considered and Newton-Raphson based power flow is run on the system. It shows that the line between Bus 1 and Bus 2 is congested, as shown in Tab. 1.

Table 1 IEEE 30 bus system congested line (before CoM) - base case

From Bus	To Bus	Actual MVA	Rated MVA
1	2	179,152213	130

The generator in the system has different sensitivity values during base case condition. The rescheduling of generators (Optimizing the real power output) is done by selecting the generator which has the most sensitivity factor. The below Tab. 2 depicts the selection of the generator based on the sensitivities for rescheduling of active power output to relieve congestion in the line between buses 1 and 2.

Table 2 Values for *GSF* and real power rescheduling after implementing PSO - base case

Generator	*GSF* Values	Generator output after Rescheduling / MW
G1	0	138,48
G2	–0,8908	40
G5	–0,8527	13
G8	–0,7394	25
G11	–0,7528	20
G13	–0,6869	28

Table 3 IEEE 30 bus system congested line (after CoM) - base case

From Bus	To Bus	Actual MVA	Rated MVA
1	2	114,5125	130

Tab. 3 above depicts the power flow in the line between buses 1 and 2 after the rescheduling of the generator by minimizing the *GSF* using PSO algorithm. Thus, the PSO algorithmic technique has done effective rescheduling of generator power output based on the *GSF* factor.

4.1.2 Case B (Overload Case) - Congestion Management Using *LUF* and *CI*

The objective function of this case is to find an optimal profile of active power generation so as to minimize the value of *LUF* and *CI* to relieve the congestion under 60 percent overloading condition by satisfying network constraints. The IEEE 30 Bus system is considered and Newton-Raphson based power flow is run on the system; it is seen that the line between many buses (nearly 10 lines) are congested, as shown in Tab. 4.

Table 4 IEEE 30 bus system congested line (before CoM) - overload case

From Bus	To Bus	Actual MVA	Rated MVA
1	2	324,72460	130
1	3	146,92420	130
2	4	73,725613	65
2	5	137,145650	130
2	6	100,730288	65
3	4	131,400542	130
4	6	117,218443	90
4	12	73,614712	65
6	8	53,418006	32
12	15	32,957769	32

The *LUF* and *CI* factor values for the congested ten lines are shown in Tab. 5. Tab. 5 below shows the importance of congestion management since the overloading of the lines leads to major adverse effects (blackout and brownout) and requires immediate management techniques in the system. Now, PSO algorithm is implied in the system to relieve the congestion in the transmission line by minimizing the *LUF* and *CI*.

Table 5 Values for LUF and CI before implementing PSO - overload case

From Bus	To Bus	*LUF*	*CI*
1	2	2,497943	6,239721
1	3	1,130324	1,277632
2	4	1,134240	1,286501
2	5	1,054967	1,112954
2	6	1,549697	2,401560
3	4	1,010773	1,021663
4	6	1,302427	1,696316
4	12	1,132254	1,282633
6	8	1,669313	2,786605
12	15	1,029930	1,060756

Table 6 Values for real power rescheduling after implementing PSO using *LUF* and *CI* - base case

Generator	Generator Reschedule Value / MW	
	Using *LUF*	Using *CI*
G1	150	192
G2	60	68
G5	35	50
G8	25	23
G11	20	20
G13	28	35

Tab. 6 above shows the list of rescheduled active power output of the generators in IEEE 30 Bus test system while considering *LUF* and *CI* as the minimization objective using PSO algorithm. It is found that the generators are rescheduled in different values with respect to *CI* when compared to *LUF*.

Table 7 IEEE 30 bus system congested line (after CoM) - overload case

From Bus	To Bus	Actual MVA	Rated MVA	*LUF*
1	2	214,2281	130	1,647860
1	3	73,503668	65	1,130826
12	15	34,244727	32	1,070148

Tab. 7 shows that the congested lines are minimized from 10 lines to 3 lines but still congestion persists in the system because loading is increased at every iteration to find out the best factor amongst *LUF* and *CI*.

Table 8 IEEE 30 bus system congested line (after CoM) - overload case

From Bus	To Bus	Actual MVA	Rated MVA	*CI*
1	2	148,58717	130	1,174034
12	15	33,975491	32	1,127279

The above Tab. 8 shows that the line flow limit violations are also minimized with *CI* when compared to *LUF*. It is noted that there is significance in the characteristics of these factors, which is advantageous for congestion management in the transmission system. The comparative study of Case A and Case B is done and it is shown that the optimal selection of *LUF* and *CI* factors plays a vital role in congestion management with increased loading condition. The values of percentage reduction in a number of congested lines of IEEE 30 Bus system are found to be significant. It is evident that the congestion is effectively alleviated to a remarkable level in the above considered case for the test system. However, some of the transmission lines are still congested/still have congestion, but with reduced levels of percentage violation when considering SI as a factor to minimize and to mitigate congestion in a transmission system.

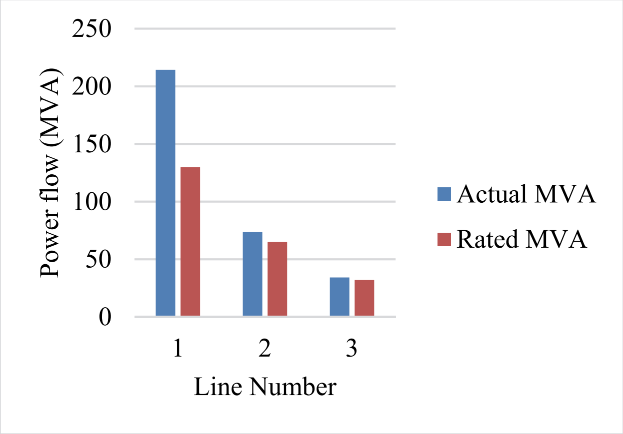

Figure 3 Line flows using *LUF* after CoM

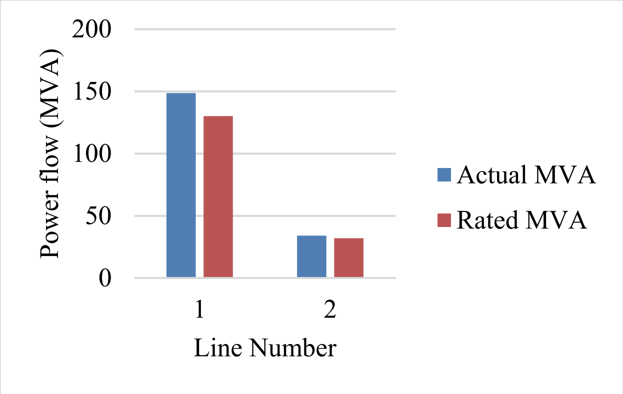

Figure 4 Line flows using *CI* after CoM

The best factor for congestion management is chosen by comparing the results obtained using the PSO algorithmic technique. It is represented in the above graphs for better understanding, to show that the Congestion Index is a better factor since the number of congested lines and line limit violations are reduced largely when compared with Line Utilization Factor. Here, congestion is not alleviated completely, but reduced by a considerable percentage for an incremental rise in load.

4.2 Implementation of FF in CM

The Firefly (FF) algorithm is employed as an optimization algorithm in IEEE 39 Bus test system for congestion management under base case loading condition. The congested lines in the system are identified by calculation of *GSF* factor. After the identification of congested lines, the overloading is relieved by minimizing those factors by using a FF algorithm through appropriate rescheduling of generators.

The congestion management is implemented in such a way that it mitigates the violation of reactive power limit and mitigates/lessens/reduces the congestion occurring in the system. The line between buses 14 and 34 is considered to be in outage state under base caseload condition. The firefly algorithm is implemented using transformer tap setting values and generator rescheduling to minimize the overall system active power loss. The $Q_{\min}$ is violated at bus number 37; $Q_g = -1,37$ (violated), $Q_{\min} = 0$ (actual) is mitigated by optimized tap setting and is shown in the Tab. 9.

Table 9 IEEE 39 bus system minimized transformer tap setting value

Line		Transformer Tap Setting Value	
From Bus	To Bus	After implementing FF Algorithm	Before implementing FF Algorithm
2	30	1,025	1,025
6	31	1,07	1,07
10	32	0,97	1,07
12	11	1,006	1,006
12	13	0,906	1,006
19	20	1,06	1,06
19	33	1,07	1,07
20	34	1,001	1,009
22	35	1,020	1,025
23	36	0,9	1,000
25	37	1,01	1,025
29	38	1,009	1,025

Table 10 IEEE 39 bus system minimized transformer tap setting value

Generator	*GSF*	Actual Generation	Generator Limits / MW	
			Minimum	Maximum
G30	0,002	250	0	1040
G31	–0,595	677,571	0	646
G32	–0,009	650	0	725
G33	–0,42	632	0	652
G34	–0,42	508	0	508
G35	–0,42	650	0	687
G36	–0,42	560	0	580
G37	–0,58	540	0	564
G38	–0,5	830	0	865
G39	–0,6	1000	0	1100

It is found that the reactive power limit violation is eliminated by choosing control variable as voltage in the test system. The objective function is framed according to the transformer tap setting value and the movement of the firefly is studied to trace the voltage limit and to mitigate the reactive power limit violation. The following Tab. 10 shows the *GSF* values for rescheduling of generators.

It is observed that the generators at bus 33, 34, 35, 36 have uniform flow of congestion indices whereas generators at bus 30, 31, 32, 37, 38, 39 have non-uniform flow of congestion values. So, the generators having non-uniform congestion values are rescheduled in order to relieve the congestion.

Table 11 IEEE 39 bus system rescheduled generation (after CoM)

Generator	Rescheduled Generation (base case load flow)	Generator Limits / MW	
		Minimum	Maximum
G30	250	0	1040
G31	632	0	646
G32	675	0	725
G33	632	0	652
G34	508	0	508
G35	650	0	687
G36	560	0	580
G37	556	0	564
G38	856	0	865
G39	1056	0	1100

The above Tab. 11 shows the rescheduled active power generation using Firefly algorithm by considering *GSF* as the factor to be minimized to uniform value.

Table 12 IEEE 39 bus system after CoM line mitigation and real power loss minimization

Congested line flow (15-16) due to line outage (14-34) at base case	628,60
MVA Limit	500
Line flow after rescheduling using FF algorithm based on *GSF*	449,14
Real power loss before Rescheduling	59,0587
Real power loss after Rescheduling	46,666

The above Tab. 12 depicts the usage of Firefly algorithm to mitigate congestion in base case condition. It is inferred that the rescheduling of generators relieves the congested line faster when compared to other algorithmic methodologies. The line outage is chosen based on the Line Sensitivity Factor calculated for the IEEE 39 Bus system. The present research work shows the drastic reduction of real power loss which results in a better and more stable system along with elimination of line flow limit violation occurring in the system. The congestion management problem is formulated as a non-linear optimization problem with more number of constraints. So, it cannot be directly solved by mathematical methods. Hence, a heuristic approach is essential and in this paper, heuristics such as PSO and FF are developed. The feasibility and robustness of the proposed method are examined by two test systems. The speedy determination of line overload is necessary in order to take necessary corrective actions. In this paper, the line limit violation is considered as a major breach and rescheduling is done accordingly. It is anticipated that the proposed methodologies will be able to classify the overload cases correctly and can provide an efficient and effective management scheme to relieve congestion in a transmission system.

5 CONCLUSION

In this paper, two different algorithms are implemented to mitigate transmission congestion by considering various factors with an objective function to minimize congestion by satisfying the constraints. The methods proposed in this paper prove their competency in alleviating transmission congestion, which occurs due to various line outages and sudden load variations. It is finally observed that, with the proposed mechanism, real power losses are considerably reduced based on the amount of rescheduling of generation. This is validated with proper explanations under various sections. The Fast determination of line overload is necessary in order to take necessary corrective actions that are predicted quickly using this method. From the results obtained, the factor to be chosen for handling the congestion in the transmission system is also evaluated. Finally, it is summarized that the proposed method results in significant improvement in alleviation of congestion in the transmission system. Nowadays, there is a boom in the use of renewable energy sources and distributed generation. At present, the transmission network is changing into the smart grid. The analysis adopted in this thesis can be well applied and extended with such modern advancements. Based on the available distributed generations, various factors may be additionally included in the analysis. The future scope of this work can focus on emphasizing the effect or interfacing of alternate (Renewable) energy sources in deregulated power systems.

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