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Research paper

Congestion Management by Optimal Generation Rescheduling Using Sine Cosine Algorithm

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Abstract

Under deregulated market environment, technically efficient and cost-effective operation of the power system becomes imperative. Congestion in transmission lines is one among key facet dealt by network operator as it greatly affects the operation of power system. This paper intends to manage power network congestion by means of rescheduling real power generation. Sensitivity analysis has been carried out to select the generators for rescheduling real power generation. In order to improve the economic efficiency of the electrical power market, an attempt is made to minimize the congestion cost. Sine Cosine Algorithm (SCA) has been employed to solve the considered problem. The viability of the considered method has been investigated by implementing it on the modified IEEE 57-bus test system. To confirm the efficacy of employed algorithm obtained results are compared with those available in the literature. The results illustrate that considered approach offers improved results and effectively minimizes congestion cost.

Keywords:*Congestion Management; Generation Rescheduling; Optimal Power Flow; Sine Cosine Algorithm.*

1. Introduction

In order to realize enhance economic benefits and to make the most of the transmission corridor, often transmission lines are operated near to their operational limits. Under such situation, any uncertainties like the sudden increase in loads, outage of transmission lines causes the violation of operational limits which results in network congestion. The adverse impacts of transmission network congestion are that it may initiate further outages and raises the electricity prices in some part of the network [1]. Consequently, transmission network congestion is highly detrimental and should be alleviated for the secure and reliable operation of the system. Therefore, as a countermeasure, an appropriate scheme is required to deal with the issues of transmission congestion.

A number of techniques have been reported in the literature to deal with the issues of transmission congestion. An exhaustive study of different approaches utilized for managing network congestion is presented in [2-3]. At first System operator (SO) may adopt cost-free means that are adjustment of transformer taps, phase shifters and altering parameters of Flexible AC Transmission System (FACTS) devices. Under some operating states SO may adopt non-cost free means, for instance, generator rescheduling and load shedding.

For managing network congestion and achieving optimal power balance a novel control scheme employing nodal prices in proposed in [4]. Finney et al. [5] presented an approach that provides the breakup of spot prices and unveils congestion cost component in a pool model. In [6] a method is proposed that offer elements of nodal price such as generations, transmission congestion, voltage limitations. This extensive idea of nodal prices helps to manage network congestion and offer economic signals for transmission investment. Seeley et al. [7] presented an integrated auction scheme that linked market clearing with congestion management. In [8] a novel method is presented that examines the share of each loads and generators in transmission line flows for transmission charge allocation. In [9] a model is presented for congestion management that includes determination of the optimal location of FACTS devices and optimal control of device parameters. The scheme for phase shifter optimization is presented in [10] and applied for the purpose of security constrained scheduling. In [11] authors presented the congestion management scheme for hybrid power system that considers probabilistic wind generation model and linear piece-wise hydro model. An approach considering UPFC for the purpose of congestion management is described in [12]. Hajforoosh et al. [13] proposed the placement and sizing of UPFC for managing network congestion considering load variations. Yousefi et al. [14] proposed coordination of both FACTS device controller and demand response to mitigate congestion using TCSCs and static VAR compensators. In [15] authors presented that load shedding performs important task from operations viewpoint as it assist in overload alleviation and also prevents the voltage instability. In [16-18] generation rescheduling based approach for managing network congestion is utilized. In this approach, the portion of power from congested lines is shifted to the non-congested lines. An approach for managing network congestion utilizing particle swarm optimization is presented in [16]. The presented approach manages network congestion with least deviations in scheduled generation value. In [17] a generation rescheduling-based approach for managing network congestion utilizing Firefly algorithm is presented. A simple mechanism employing generation rescheduling and load shedding for managing network congestion is presented in [19]. A multi-objective approach for managing network congestion by means of generation rescheduling and load shedding is presented in [20]. The novelty of this paper is that this paper utilized voltage-dependent load model instead of the constant load model that is generally used. Energy management approach employing generation rescheduling for managing network congestion is presented in [21].

This paper intends to alleviate the transmission congestion by means of rescheduling real power output of generators. To calculate the sensitivities of each power generators to the line power flows of the overloaded lines, generator sensitivity analysis is performed. Obtained information is used for selecting sensitive generators to reschedule their output. An optimal power flow-based problem is formulated to manage the network congestion with minimum congestion cost. It is presented that the considered approach effectively solves the network congestion problem.

The main contributions of this work are as follows:

a) SCA as an optimizing tool has been employed to solve the transmission congestion problem with an objective to minimize the congestion cost.
b) The viability of the considered method has been investigated by implementing it on the modified IEEE 57-bus test system.
c) To demonstrate the effectiveness of employed algorithm obtained results are compared with those available in the literature.

This paper has been structured as follows: The mathematical problem formulation is discussed in Section 2. The solution method has been described in Section 3. Section 4 presents the implementation of the SCA algorithm for congestion management (CM) problem. Section 5 includes the results of implementing the considered approach on standard system followed by the conclusion in the Section 6.

2. Mathematical formulation

2.1. Generator sensitivity

In order to evaluate the sensitivities of each power generators to the line power flows of the overloaded lines, generator sensitivity is formulated based on [22]. This sensitivity is represented as

$$GS_{ij,m} = \frac{\Delta S_{ij}}{\Delta P_{gm}} \quad (1)$$

Where, ΔS_{ij}, signifies the variation in apparent power flow in line connected between bus- i and bus- j and ΔP_{gm}, signifies variation in real power generation of generator connected at bus 'm'.

2.2. Formulation for CM problem

In this section, the mathematical formulation of the CM problem is presented. This work intends to assist the ISO in order to manage network congestion of transmission lines in optimal way. On the basis of bids submitted by GENCOs for CM, the optimal rescheduling values of generators are determined, which affects the cost. Various operating limits that restrict the transfer of power through transmission lines have been added to the formulation as constraints. The following formulation is based on [16]:

$$\text{Minimize } TC_C = \sum_{m=1}^{ng}(C_k \Delta P_{gm}^{+} + D_k \Delta P_{gm}^{-}) \text{ \$/h} \quad (2)$$

Subject to

Equality constraints: These include the basic power balance equations that are required to be satisfied. The constraints mentioned in Eq. (3) and Eq. (4) corresponds to the active and reactive power balance equations respectively characterized by the law of conservation of energy.

$$P_{gm} - P_{dm} = \sum_{n=1}^{nb} V_m V_n Y_{mn} \cos(\delta_m - \delta_n - \theta_{mn}) \quad (3)$$

$$Q_{gm} - Q_{dm} = -\sum_{n=1}^{nb} V_m V_n Y_{mn} \sin(\delta_m - \delta_n - \theta_{mn}) \quad (4)$$

$$P_{gm} = P_{gm}^{c} + \Delta P_{gm}^{+} - \Delta P_{gm}^{-} \quad ; m = 1, 2 \ldots\ldots ng \quad (5)$$

$$P_{dm} = P_{dm}^{c} \quad ; m = 1, 2 \ldots. nd \quad (6)$$

Inequality Constraints:The real and reactive power generation capacities of generating units are limited by upper and lower limits. The constraints corresponding to Eq. (7) and Eq. (8) represents limits on the real and reactive generation capacity of the generators respectively.

$$P_{gm}^{min} \le P_{gm} \le P_{gm}^{max}, \forall m \in ng \quad (7)$$

$$Q_{gm}^{min} \le Q_{gm} \le Q_{gm}^{max}, \forall m \in ng \quad (8)$$

$$(P_{gm} - P_{gm}^{min}) = \Delta P_{gm}^{min} \le \Delta P_{gm} \le \Delta P_{gm}^{max} = (P_{gm}^{max} - P_{gm}), \forall m \in ng \quad (9)$$

The voltage limit at each bus is set by the constraint represented in Eq. (10), which makes certain the system voltage stability because; both over-voltage and under-voltage have severe consequences on the system stability. The MW flow limit of the transmission line is represented in Eq. (11)

$$V_m^{min} \le V_m \le V_m^{max} \quad (10)$$

$$P_k \le P_k^{max} \quad (11)$$

3. Sine cosine algorithm

The sine cosine algorithm [23] is governed by forming the initial population consisting of random solutions which are made to oscillate inward or outward the optimal solution by creating a mathematical model based on sine and cosine functions. The randomly generated set of candidate solutions is estimated repeatedly through an objective function and updated by the set of rules. Since the population-based techniques are aimed at obtaining the optimum solution for an optimization problem stochastically, it is quite uncertain to determine a solution in a single run. However, with the large population size and multiple iterations, the possibility of obtaining the global optimum solution is quite high. Generally, the optimization process involves two stages i.e. exploration and exploitation. In the exploration stage, the set of randomly generated solutions is combined with a high rate of randomness to determine the useful regions of search space whereas in case of exploitation, the random variations in the solution set are comparatively less than that of the exploration stage. In the present work, the positions are updated using the following equations:

$$X_i^{t+1} = X_i^t + r_1 \times \sin(r_2) \times \left| r_3 P_i^t - X_{ii}^t \right| \quad (12)$$

$$X_i^{t+1} = X_i^t + r_1 \times \cos(r_2) \times \left| r_3 P_i^t - X_{ii}^t \right| \quad (13)$$

Where X_i^{t+1} is the position of current solution in the i^{th} dimension at t^{th} iteration, r_1, r_2, r_3 represents the random numbers, P_i is position of the destination point in the i^{th} dimension, and $| \; |$ indicates the absolute value. The two equations combined to be used as follows:

$$X_i^{t+1} = \begin{cases} X_i^t + r_1 \times \sin(r_2) \times \left| r_3 P_i^t - X_i^t \right| , & r_4 < 0.5 \\ X_i^t + r_1 \times \sin(r_2) \times \left| r_3 P_i^t - X_i^t \right| , & r_4 \geq 0.5 \end{cases} \quad (14)$$

Where, r_4 is a random number in range [0, 1]

As per the above equations, there are four major parameters in SCA: r_1, r_2, r_3, and r_4. The parameter r_1 denotes the direction of movement of the particle lying within or outside the search space. The distance of movement towards or away from the destination is defined by parameter r_2. The random weight for the destination is generated by parameter r_3. The parameter r4 oscillates within the sine and cosine component as represented in Eq.(14). The inherent cyclic profile associated with sine and cosine function makes possible the positioning of one solution around the other which guarantees the exploitation of the search space defined within the two solutions. During the exploration stage, the solutions are moved towards the region lying between the corresponding destinations which can be obtained by varying the range of sine and cosine functions. For the purpose of balancing exploration and exploitation, the range of sine and cosine in Eq. (14) is varied adaptively with the following equation:

$$r_1 = a - a\frac{t}{T} \quad (15)$$

Where t is the current iteration, T is the maximum number of iterations, and a is a constant.

The flowchart of the SCA is illustrated in Fig. 1.

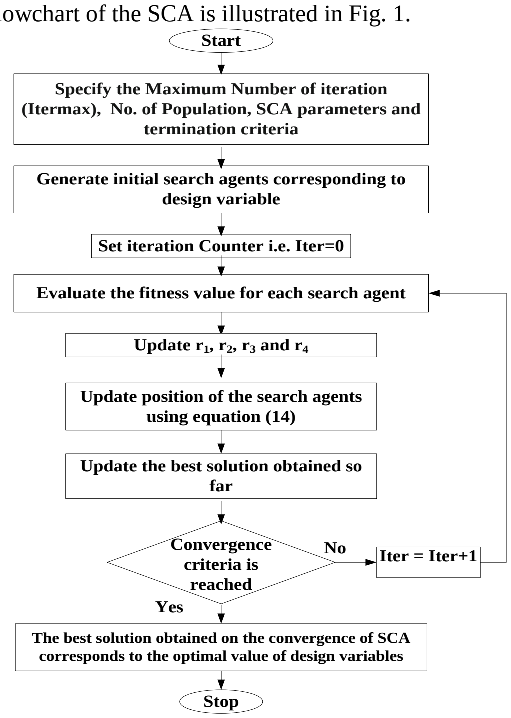

Fig.1: Flowchart of the SCA.

4. Application of SCA algorithm for CM problem

i) Read the system data, GENCOs offered bids and generator information.
ii) Create the network contingency.
iii) Carry out load flow study and check for the constraints violation if any.
iv) Perform sensitivity analysis to select generators for rescheduling their real power output.
v) Initialize with the randomly generated population that represents amount of rescheduling needed for managing network congestion.
vi) For each member of the population, load flow study is carried out and the objective function is applied to assess the fitness value. During the run constraints, violations are checked simultaneously.
vii) The population is updated using equation (14) and the old population members are replaced with the updated ones.
viii) The termination criteria is checked, if satisfied the search process is stopped else go to step vi.

5. Results and discussion

In order to present the usefulness of the technique considered in this paper, it has been executed on the modified IEEE 57-bus test system. The data for this system has been accessed from [16] and the parameters of generating units are mentioned in Table 1. The system includes 7 power generators with 80 transmission lines providing the total active power of 1250.8 MW to feed the load. The bus voltage limit has been considered to be [0.9 - 1.01].
The CM problem is formulated in the same manner as discussed in Section-2 and the solution is achieved through the proposed method. Several trial runs of the proposed algorithm have been carried out and the best obtained results are presented. The population size of 25 and a maximum number of 200 iterations are considered. To perform the required computation, a computer with Intel Core i3 processor, 1.8 GHz, 4GB RAM has been utilized to execute computation. Table 1 presents the price bids submitted by the GENCOs for alleviating congestion. To introduce congestion in the system, contingencies are created. Information regarding different considered cases is presented in Table 2.

Table 1: Submitted Price Bids by Generating Companies for Modified IEEE 57-Bus Test System

Bus Number	Increment ($/MWh)	Decrement ($/MWh)
1	44	41
2	43	39
3	42	38
4	43	37
5	42	39
6	44	40
7	44	41

Table 2: Test Cases Considered

Cases	Contingency Type	Congested Lines	Line Power Flow (MW)	Percentage Overloading	Total Power Violation (MW)
Case-1	Diminishing the power carrying capacity of line 2-3 from 85 MW to 20 MW.	2-3	36.66	83.3	16.66
Case-2	Diminishing the power carrying capacity of line 5-6 from 200 MW to 175 MW and line 6-12 from 50 MW to 35 MW.	5-6 6-12	195.45 49.17	11.68 40.48	34.62

5.1. Case-1

In case1, congestion is introduced with decreasing the power carrying capacity of transmission line connecting bus-2 and bus-3 (Line 2). As a consequence of this, transmission line connecting buses 2-3 turn out to be overloaded. The numbers regarding line flow of congested line and amount of overloading are illustrated in table 2.

To mitigate the network congestion and ensuring network safety from mentioned abnormal situations corrective actions are required. Hence, corrective actions are taken in the form of evaluating generator sensitivity and then based on sensitivity information rescheduling output of selected generators optimally.Consequently, first generator sensitivities are determined using equation (1) corresponding to congested lines and the obtained information is presented in Fig. 2. It can be observed from figure 1 that generator connected at bus -2 and bus -3 are more sensitive to the congested line in case-1. So these generators along with slack bus generator are selected for performing rescheduling in order to manage congestion. Slack bus generator is also included to provide system loss. In order to minimize the scheduling cost SCA algorithm is employed. The results obtained with the application of SCA for solving the CM problem are presented in table 3.

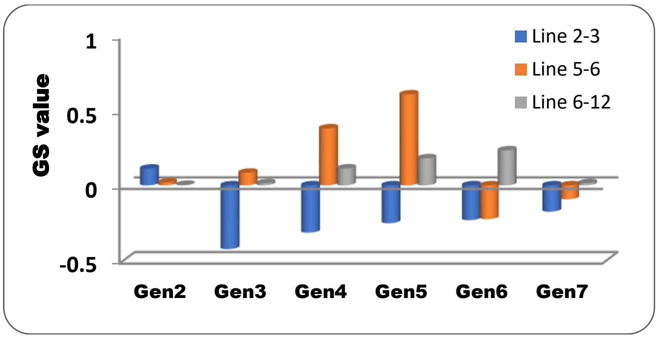

Fig. 2: GS Value of Generators for Different Overloaded Lines.

Table 3: Obtained Results and Its Comparison for Case-1

Parameters	Algorithms				
	PSO [16]	RSM [16]	SA [16]	FF [18]	SCA
ΔP_{g1} (MW)	NR	NR	NR	+0.3704	-1.09
ΔP_{g2} (MW)	NR	NR	NR	-27.5084	-27.91
ΔP_{g3} (MW)	NR	NR	NR	+31.6294	+28.09
ΔP_{g4} (MW)	NR	NR	NR	+0.3308	0
ΔP_{g5} (MW)	NR	NR	NR	-2.2549	0
ΔP_{g6} (MW)	NR	NR	NR	-1.9354	0
ΔP_{g7} (MW)	NR	NR	NR	-0.5101	0
Total Power Rescheduled (MW)	76.314	89.32	97.88	64.5393	57.09
Total Congestion Cost ($/h)	3117.6	3717.9	4072.9	2618.1	2312.96

NR means not reported in the referred literature.

In order to assess the effectiveness of SCA for the considered problem, solutions reported in the literature from other optimization algorithms are also included in table 3. Study of table 3 reveals that the considered approach is able to mitigate network congestion and SCA offers the improved result as 2312.96 $/h. A graphical demonstration of the solutions offered by different algorithms with respect to performance parameters is presented in Fig.3 and Fig.4.

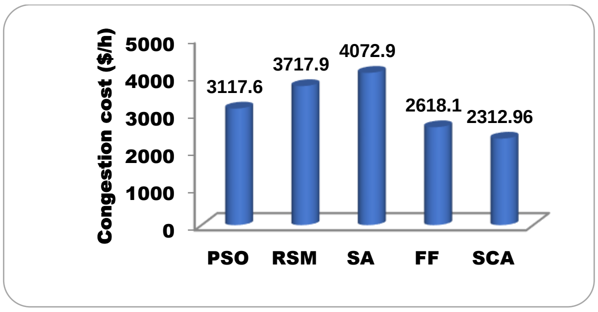

Fig. 3: Total Congestion Cost Achieved by Different Algorithm for Case-1.

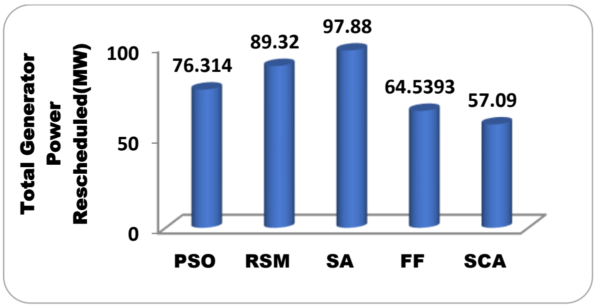

Fig. 4: Total Generator Power Rescheduled for Case-1.

5.2. Case-2

In case2, congestion is introduced with decreasing the power carrying capacity of transmission line 5-6 from 200 MW to 175 MW and line 6-12 from 50 MW to 35 MW. Hence, these transmission lines become overloaded. The numbers regarding line flow of congested line and amount of overloading are illustrated in table 2. The results obtained with the application of the SCA algorithm are presented in Table 4.

Table 4: Obtained Results and Its Comparison for Case-2

Parameters	Algorithms				
	PSO [16]	RSM [16]	SA [16]	FF [18]	SCA
ΔP_{g1} (MW)	+23.13	+59.268	+74.49	+5.635	+39.86
ΔP_{g2} (MW)	+12.44	0	0	+2.523	0
ΔP_{g3} (MW)	+7.493	+37.452	-1.515	+0.509	0
ΔP_{g4} (MW)	-5.385	-47.391	+9.952	+0.107	0
ΔP_{g5} (MW)	-81.21	-52.125	-85.92	-39.151	-42.16
ΔP_{g6} (MW)	0	0	0	-35.112	-30.09
ΔP_{g7} (MW)	+39.03	0	0	+62.193	28.92
Total Power Rescheduled (MW)	168.70	196.23	171.87	145.227	141.03
Total Congestion Cost ($/h)	6951.9	7967.1	7114.3	6050.1	5874.16

Study of table 4 reveals that considered approach is able to mitigate network congestion and SCA offers the improved result as 5874.16 $/h. A graphical demonstration of the solutions offered by different algorithms with respect to performance parameters is presented in Fig.5 and Fig.6

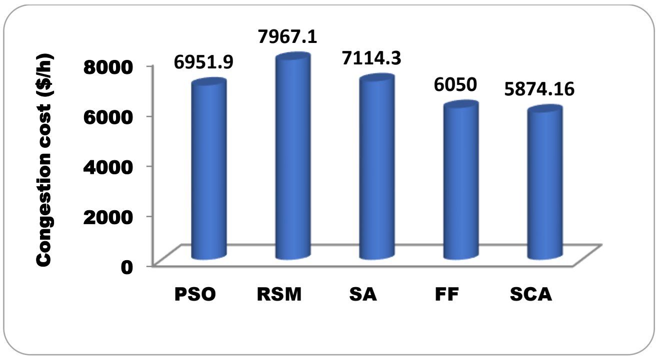

Fig. 5: Total Congestion Cost Achieved by Different Algorithm for Case-2.

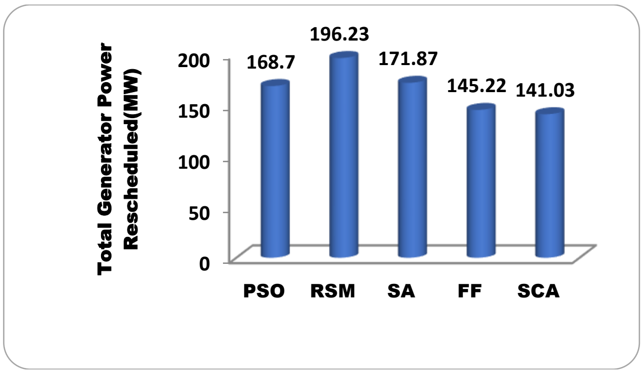

Fig. 6: Total Generator Power Rescheduled for Case-2.

6. Conclusion

This paper discusses the generators rescheduling based approach for solving the power network congestion problem under the deregulated environment. In this regard, a mathematical formulation of the considered problem is presented. This work takes into consideration generators sensitivities to choose suitable generator for rescheduling real power generation. Contingency such as reduction in power carrying capacity of lines is used to create congestion. Sine Cosine Algorithm has been employed to solve the CM problem.The efficacy of the proposed approach is validated by implementing it on the modified IEEE 57-bus test systems. System variables such as congestion cost and the amount of power rescheduled are examined for different cases. Comparison of results with those presented in literature has been prepared. Obtained results ensure that considered approach successfully solve the network congestion problem with minimum congestion cost.

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Appendix

Nomenclature

m, n	Index for buses in network
k, g	Index forline k and generating unit g respectively
nl, ng, nb, nd	Total number oflines, generators, buses, and loads respectively
V_m, δ_m	Magnitude of voltage and voltage phase angle at bus m
P_{gm} ,Q_{gm}	Active power generated and reactive power generated at bus

	m
P_k,	Active power flow in line k
ΔP_{gm}	Variation in real power generation at bus-m
C_k , D_k	Increment and decrement bids submittedby generating companies ($/MWh)
TCc	Total congestion cost in $/h
GS	Generator Sensitivity
Y, G, B, θ	Admittance, conductance, susceptance and admittance angle
P_{dm} ,Q_{dm}	Active power demand and reactive power demand at bus m
$P_g^{\max}$, $P_g^{\min}$	Higher and lower limits of active power generation at unit g
$Q_g^{\max}$, $Q_g^{\min}$	Higher and lower limits of reactive power generation at unit g
$V_m^{\max}$, $V_m^{\min}$	Higher and lower limits of voltage magnitude at bus m
$\delta_m^{\max}$, $\delta_m^{\min}$	Higher and lower limits of voltage phase angle at bus m
$P_k^{\max}$	Maximum limits of active power flow in line k
PSO	Particle Swarm Optimization
SA	Simulated Annealing
FFA	Firefly Algorithm