Optimal Rescheduling of Real Power to Mitigate Congestion with Incorporation of Wind Farm Using Gravitational Search Algorithm in Deregulated Environment

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Abstract- In deregulated power system environment, the congestion is considered as one of the vital issues concerning the system's security and reliability. The Independent System Operator (ISO) bears the task to manage the congestion in the open access electricity market. This article puts forward an efficient Congestion Management (CM) technique with the embodiment of wind farm as a renewable resource alongside the implementation of an efficient and reliable meta-heuristic technique. The proposed CM approach is established contemplating the Bus Sensitivity Factor (BSF) and the Generator Sensitivity Factors (GSF). The positioning of the wind farm is optimally achieved considering the BSF. The GSF values are computed to sort out the most sensitive generators for participating in the CM problem. The Gravitational Search Algorithm (GSA) is introduced in order to optimally minimize the active power yield of the generators taking part in the process of CM. The GSA is one of the latest meta-heuristic algorithms based on the Newton's Laws of gravitational forces. The result obtained by GSA is contrasted with the outcomes reported in the past literatures. Modified 39-bus New England system is considered for the implementation of the potency of the proposed approach of CM with the inclusion of wind farm as a renewable resouce.

Keywords Congestion Management, Gravitational Search Algorithm, Optimization, Wind farm, Renewable Resource.

1. Introduction

The dawn of the deregulation in the power sector led to the unbundling of the vertically integrated utilities. The Generating Company (GENCO), Transmission Company (TRANSCO) and the Distribution Company (DISCO) started functioning as separate entities. The independent operation of these entities ensures an arduous responsibly for the ISO to manage them under one umbrella [1]. In the electricity market, which is deregulated in nature, all the market players interact with each other in a way to maximize their own profit leading to the functioning of the transmission networks beyond their operational limits.

The power demand has increased all over the globe due to the intense competition in the electricity market caused by deregulation. Thus, to ensure a safe functioning of the power system network the transfer limits must be taken care while transferring power from one point to the other. The transfer limits are designated by the thermal limits, voltage limit and the stability limits [2]. The congestion in the transmission network is said to occur when there is a violation of any of the transfer limits. The procedure of preserving the transfer limits by governing the transmission network is termed as the CM. Some of the potential causes that are responsible for the congestion are sudden outage of the generator, tripping of the existing transmission lines, hike in the power demand etc. The responsibility of ISO lies in managing the congestion so that power system stability and the electricity market efficiency is maintained at an optimum level [3].

2. Literature Survey

The literature survey puts forward that a number of techniques have been embraced to solve the issues related to CM. A numerous number of techniques related to the CM has been discussed in literatures [4,5,6,7]. CM problem considering the voltage stability limits in hybrid system has been proposed by Sagwal and Kumar in [8]. Sarwar et al. [9] reported a Locational Marginal Pricing (LMP) approach for CM problem, which sorted out the most congested area for the placement of distribution generations. An Optimal Power Flow (OPF) based technique with Photovoltaic (PV) have been presented by Silaja and Ravi to limit the congestion [10]. İn 2015, Hooshmand et al. have put forward a hybrid algorithm based on Bacterial Forging and Nelder Mead for the solution OPF problem to mitigate congestion [11]. In [12], the effect of the power flow on the congested line is reviewed considering the combine influence of renewable energy sources and FACTS devices.

Kumar et al. proposed a zonal model for the CM issue depending on the ac load flow and the sensitivity values of each buses are taken into consideration [13]. The choice of the generators depending on the sensitivity analysis on the congested lines and the generator bids has been proposed by Talukdar et al. [14]. The Relative Electrical Distance (RED) perception is adopted for the attenuating the excess flow of power in the overloaded line by rescheduling the generator's real power output. The RED helps to select genertors participating in CM problem [15].

Vieira et al. [16] discussed the importance of the wind energy in the electrical power system. The modeling of the wind farm and the impact on the power system power flow is analyzed in [17]. The CM problem is analyzed considering the LMP along with the conventional and renewable energy sources [18]. The generators participating in CM issue on the basis of GSF and optimizing their real power output using Particle Swarm Optimization (PSO) has been reported by Dutta and Singh in [19]. The rescheduling of the generators with the incorporation of the FACTS devices such as SSC, UPFC and STATCOM is reported in [20] for the CM problem. Gope et al. [21] has introduced small hydro units to take care of CM problem with the rescheduling of generator's real power output. Mizuno et al. introduced linear programming to optimaly schedule the power of the critical generators supplying the residential hospitals [22]. In [23] Zadeh et al. used PSO to optimally schedule the hydrothernal wind eneergy system.

GSA proposed by Rashedi et al. is a meta-heuristic algorithm inspired from the Newton's laws of gravity and the implementation of this algorithm for the optimization purpose is increasing in almost all fields of research [24]. With the purpose of solving the optimal reactive power dispatch issue, Chen et al. proposes an improved GSA based algorithm to handle the constraints by conditional selection strategy [25]. The optimal power flow has been solved by GSA in [26]. Li and Zhou [27] used GSA for the optimal parameters identification in case of hydraulic turbine governing system. GSA has been used to simultaneously design the damping controller for the power system stabilizers and thyristor control series capacitor [28]. The minimization of the real power loss has been carried out by Chen et al. [29] utilizing GSA. The outcome of the work has been compared with Differential Evolution (DE) algorithm, Self Adaptive Real Coded Genetic Algorithm (SARGA) and Seeker Optimization (SO) algorithm and it was noticed that the results reported with GSA has a better impact than the others. In another work, Bhattacharaya and Kumar has alleviated congestion utilizing FACTS devices using GSA. The results reported with GSA seemed to be better when compared to Genetic Algorithm (GA) and PSO [30]. Shaw et al. used GSA to analyse optimal reactive power dispatch and found that optimal solution achieved with GSA is better when compared to the results reported with Adaptavive GA and Biogeography Based Optimization (BBO) [31]. İn 2015, Kumar et al. [32] used GSA to find out the optimal location of UPFC considering the enhancement in stability limits and the results obtained with GSA were superior to Artificial Bee Colony (ABC) algorithm. In another research work, Wong et al. optimized the sizing of the battery for photovoltaic distribution generation and found that GSA performs better than Firefly Algorithm (FA) [33]. In the view of the above facts that the GSA gives better result in all the refered cases, it is comprehended that the solution of the CM problem proposed in this paper using GSA will give better and efficient result.

In this paper, the wind farm as one of the renewable resources is introduced to analyze the CM problem in the power system network along with the optimal rescheduling of the generator's active power output using GSA to mitigate congestion. It is observed that there is an enhancement in the voltage profile along with the reduction in the real power losses due to the inclusion of renewable resource i.e. wind farm at the maximum clogged bus. The BSF is utilized for the selection of the buses for the placement of the wind farm. The generators participating in the CM problem is sorted on basis of the GSF and the optimum rescheduling of the active power delivered by those generators taking part in the CM issue are obtained with the help of GSA. The proposed method in this article is compared with results obtained in the literature [15], [19].

3. Motivation

The literature survey suggests that the researchers have implemented several techniques for the CM problem. Most of the optimization techniques lack to function efficiently for nonlinearity and multimodality issues. The present interest is to take care of these issues with the implementation of the meta-heuristic algorithm with renewable resource and it has been manifested that these meta-heuristic algorithms are quite productive. The GSA is influenced from the Newton's

Laws of gravitational force. In GSA, different masses are assigned to different agents who are in turn considered as objects. The gravitational force acting between the agents causes their movements. The movements of the agents are initiated due to the gravitational force acting between them. Moreover, the movements of the agents are initiated such that the agents are attracted towards the agent with heavier masses.

The work projected in this article proposes GSA as one of the optimization approaches for solving the CM issue by introducing the wind farm in the power system network. The main inspiration of the proposed work in this article is to aid ISO to mitigate congestion of the lines in an excellent manner. In this paper GSA is implemented on modified 39-bus New England power system frameworks to fathom the CM problem under selected contingency.

The primary commiment of the proposed work are to:

- Extend the implementation of the wind farm as a major renewable resource and utilize GSA as a powerful and enhancing optimization technique for the minimization of the rescheduling cost under the selected contingency for the modified 39-bus New England framework.
- Viably expel the over-burden in the transmission lines created by the considered possibility with the smallest deviation in the generation schedule.
- Reduce the aggregate rescheduling amount and losses for the considered case.
- Show the viability of the proposed GSA with renewable resource over the others methods for this particular application.

4. Proposed Method

4.1. Wind Farm Model

The Fixed Speed Wind Turbine Generating Unit (FSWTGU) model of power flow is evaluated in order to determine the power injected for FSWTGU. In the induction machine the positioning of the capacitors are done on the terminals of the stator, during its functioning as induction generator, which is self energized in spite of the fact that power electronic converters are at times utilized. The capacitors are connected at times for the purpose of improvement in the power factor and minimize the losses when addition of real power or withdrawal of the reactive power is done by the induction machine from the grid respectively. Fig. 1 shows the wind farm model which represents the generator's steady state model [17]. In case of the wind farm the induction generator parameters are taken as: Rated voltage = 660V, R_s = 0.00708Ω, X_1 = 0.07620Ω, X_m = 3.4497Ω, X_2 = 0.23297 Ω and R_R = 0.00760 Ω.

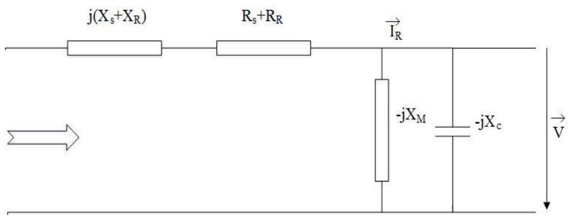

Fig. 1. Representation of wind farm model.

The equation for the consumption of reactive power in case of wind farm can be represented as [17]:

$$Q = V^2 \frac{X_c - X_m}{X_c X_m} + X \frac{V_2 + 2RP}{2(R^2+X^2)} - X \frac{\sqrt{(V^2+2RP) - 4P^2(R^2+X^2)}}{2(R^2+X^2)} \quad (1)$$

$$Q = V^2 \frac{X_c - X_m}{X_c X_m} \; \frac{X}{V^2} P^2 \quad (2)$$

V: rated voltage.

P : injected active power in the grid.

X : stator and rotor leakage reactances in total.

X_c : capacitor bank reactances.

R : summation of both the reactances of stator and rotor.

The real power of FSWTGU is given by [17],

$$P = \frac{1}{2} \rho A U^3 C_P \quad (3)$$

where the area of the rotor is represented by A, air density is designated as ρ, U represents the speed of the wind and C_P is designated as the power co efficient.

4.2. Gravitational Search Algorithm

The GSA is one of the latest meta-heuristic algorithms proposed by Rashedi et al. in the year 2009. The GSA is influenced from the Newton's laws of gravity and motion. The agents in GSA are designated as the objects and their masses are taken into consideration for the measurement of their performances. The gravitational force attracts the objects toward each other and this leads to the overall drifting of the object in the direction of the heavier mass object. The point by point depiction of GSA on how to solve issue is as per the following.

Taking into account that agents N are distributed in the region of the search space D. The i^{th} agent's position is represented in the equation (4).

$$X_i = (x_i^1, \ldots\ldots, x_i^d, \ldots\ldots, x_i^D) \qquad i=1, 2, 3, \ldots, N \quad (4)$$

where x_i^d represents the i^{th} agent position in the search space of D dimension.

Each agent position is updated with every iteration. The computation of the velocity, position and acceleration of the i^{ih} agent in the consecutive iteration is achieved with the help of the following equations:

$$v_i^d(k+1) = Rand(v_i^d(k) + a_i^d(k)) \quad (5)$$

$$x_i^d(k+1) = v_i^d(k+1) + x_i^d(k) \quad (6)$$

$$a_i^d(k) = F_i^d(k) / M_i(k) \quad (7)$$

where $v_i^d(k)$, $x_i^d(k)$ and $a_i^d(k)$ are designated as velocity, position and the acceleration respectively in the k^{th} iteration for the agent i in the D^{th} dimension. Rand signifies the distribution of a random number between (0,1). $F_i^d(k)$ is termed as the overall force exerted by the other agents on the agent i. $M_i(k)$ is designated as the the mass at the k^{th} iteration for agent i, which is calculated depending on the fitness of the current agents. The equation of $F_i^d(k)$ and $M_i(k)$ are given below:

$$F_i^d(k) = \sum_{j \in k_{best}, j \neq i}^{N} Rand_j F_{ij}^d(k) \quad (8)$$

$$F_i^d(k) = G(k)\frac{M_i(k)M_j(k)}{R_{ij}(k)+\varepsilon}(x_j^d(k) - x_i^d(k)) \quad (9)$$

$$G(k) = G_0 e^{-\alpha k / k_{max}} \quad (10)$$

where k_{best} in the equation (8) is considered as the best fitness value for the group of first K agents, which is taken as the function whose value reduces from the initial value K_0 with the increase in the iteration. $F_{ij}^d(k)$ denotes the amount of force exerted by j^{th} agent on the i^{th} agent which is calculated based on the gravitation laws; ε acts as a small constant which is used to prevents the denominator being equal to zero. The Euclidian distance $R_{ij}(k)$ is defined as the distance between the i^{th} and the j^{th} agent the value of which is designated as $R_{ij}(k) = \left\| x_i^d(k), x_j^d(k) \right\|_2$, The gravitational constant G(k) which gets decreased from the initial value G_0 with the iteration k.

$$M_i(k) = \frac{m_i(k)}{\sum_{j=1}^{N} m_j(k)} \quad (11)$$

$$m_i(k) = \frac{Fit_i(k) - F_{worst}(k)}{F_{best}(k) - F_{worst}(k)} \quad (12)$$

$Fit_i(k)$ signifies the i^{th} agent's fitness value at the k^{th} iteration. From the group of N agents the values corresponding to the best and the worst fitness at the k^{th} iteration are defined as $F_{best}(k)$ and $F_{worst}(k)$ which are represented as follows:

$$F_{best}(k) = \min_{i \in [1,....,N]} Fit_i(k) \quad (13)$$

$$F_{worst}(k) = \max_{i \in [1,....,N]} Fit_i(k) \quad (14)$$

In the proposed approach the value of G is set using equation (10) and the value of G_0 is set to 100 and the value of α is assigned as 20. The maximum number of iterations is taken as 160 in this case. The pseudo code and the flow chart for the GSA is shown in the Fig.2 and Fig.3 respectively.

```
Step1. Search space identification, t=0;
Step2. Random initialization, Xi(t);
       For i=1,........N
Step3. Fitness evaluation of objects
Step4. Update the parameters of G(t), best(t), worst(t) and M(t)
       For i=1,.........N
Step5. Calculation the force on each object
Step6. Calculation of the velocity and acceleration of each object
Step7. Update the position of the agent by (6) to yield Xi(t+1);
Step8. Repeat step 3 to 7 until the stop criteria is reached
Step9. End
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Fig. 2. Pseudocode for GSA

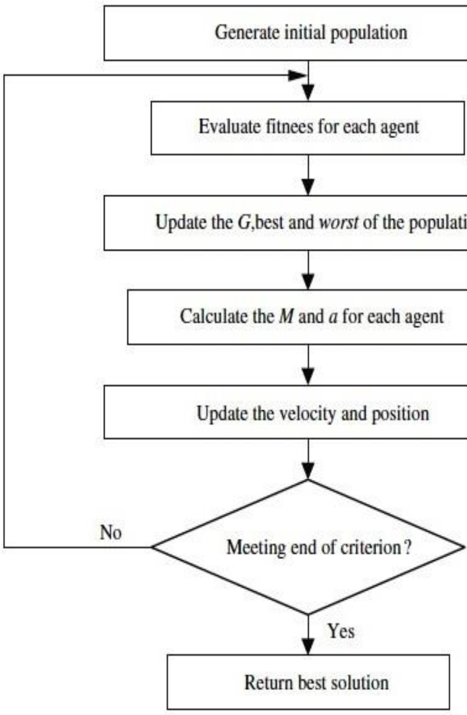

Fig. 3. Flow chart for GSA

4.3. BSF and GSF Calculations

For the k^{th} transmission line situated between the i^{th} and the j^{th} bus the expression for real power P_{ij} is given by:

$$P_{ij} = -|V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_i) - V_i^2 Y_{ij}\cos\theta_{ij} \quad (15)$$

where V_i and Θ_i are designated as the magnitude of the voltage and angle of the i^{th} bus. Y_{ij} and Θ_{ij} are the magnitude and angle respectively of the ij^{th} element of the Y_{BUS} matrix.

4.3.1. BSF Calculations

The BSF is defined as the adjustment in the active power flow in the k^{th} line which is designated as the congested line, located between the buses i-j to the injection of real power ΔP_n at bus n. The BSF can be mathematically shown by:

$$BSF_n^k = \Delta P_{ij} / \Delta P_n \tag{16}$$

ΔP_{ij} is the k^{th} line flow of real power and BSF_n^k signifies the change in the quantity of the flow of real power in line k due to the injection of real power ΔP_n at the bus n. For the overloaded line k, the expression for BSF can be represented as:

$$BSF_n^k = a_{ij} m_{in} + b_{ij} m_{jn} \tag{17}$$

A step by step derivation of the BSF can be found in the reference [21].

4.3.2. GSF Calculations

The GSF is termed as the ratio of change in the flow of the real power in the transmission line k to change in the real power output of the g^{th} generator P_{Gg}. In case of a congested line k the GSF is represented as:

$$GSF_n^k = \Delta P_{ij} / \Delta P_{G_g} \tag{18}$$

where ΔP_{ij} signifies the alteration in the amount of the power flow through the congested line k. The g^{th} generator's real power output is designated as P_{Gg}

$$GSF_n^k = \frac{\partial P_{ij}}{\partial \delta_i} \cdot \frac{\partial \delta_i}{\partial P_{G_g}} + \frac{\partial P_{ij}}{\partial \delta_j} \cdot \frac{\partial \delta_j}{\partial P_{G_g}} \tag{19}$$

Where,

$$\alpha_{ij} = \frac{\partial P_{ij}}{\partial \delta_i} = V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i)$$

$$\beta_{ij} = \frac{\partial P_{ij}}{\partial \delta_i} = -V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) = -\frac{\partial P_{ij}}{\partial \delta_i}$$

The detail derivation of GSF can be found in the reference [19]. Depending on the values of the sensitivity indices, the generators exhibiting non uniform sensitivity indices are sorted out for the participation in the CM problem.

5. Problem Formulation

The aggregate rescheduling amount contributed by the generators participating in the CM problem is obtained by:

$$Minimize \sum_{g \in N_g} C_g(\Delta P_{Gg}) * \Delta P_{Gg} \tag{20}$$

ΔP_{Gg} is the adjustment in the g^{th} bus's real power; C_g represents the price offers put forward by the associating generators in the CM problem. The amounts of rescheduling for the participating generators are subjected to the following constraint:

GSF constraint is given by:

$$\sum_{g=1}^{Ng} ((GSF_g) * \Delta P_g) + F_k^0 \le F_k^{max} \tag{21}$$

The Ramp limit:

$$P_g - P_g^{min} = \Delta P_g^{min} \le \Delta P_g \le \Delta P_g^{max} = P_g^{max} - P_g \tag{22}$$

Power balance:

$$\sum_{i=1}^{Ng} \Delta P_{Gi} = 0 \tag{23}$$

P_g^{min} and P_g^{max} corresponds to the limits of the generator g's minimum and maximum active power generation.

F_k^0 corresponds to the flow of the power in the k^{th} transmission line resulted due to all the contacts requesting the transmission service.

F_k^{max} corresponds to the MVA flow limit of the transmission line k joining the buses i and j.

6. Result and Discussion

In this article, application of wind farm as a renewable resource along with GSA is implemented for CM problem, employing MATLAB version 2013a software on a 4GB RAM system which is accompanied with an Intel Core i5, 2.4 GHz clock speed processor. 39-bus New England System which has 10 generators and 29 load buses has been used to analyze the viability of the proposed CM problem in this article. The framework for the 39-bus New England is shown in Fig. 4.

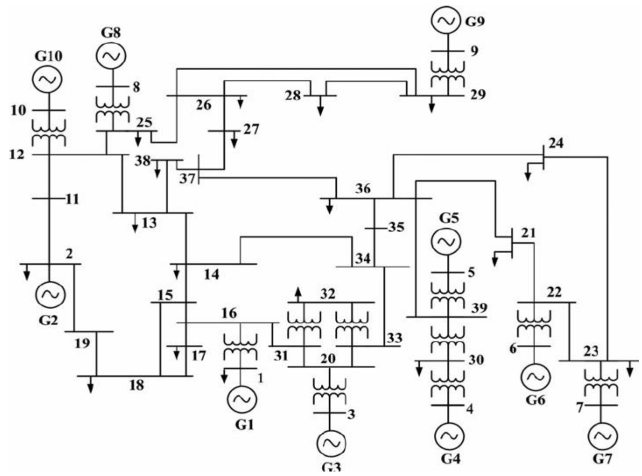

Fig. 4. New England 39-bus Test framework

The essential parameters needed for the wind farm are obtained from [17]. The outage of the line 14-34 is considered in the framework to establish congestion in the line 15-16. Table 1. shows the computed values of BSF due to the outage of line 14-34 and the installation of the wind farm is optimally placed at bus 14 which is the most sensitive bus. It is observed that the flow of power decreases from a higher level to lower level in the congested line 15-16, when the ratings of the wind farm are varied from 30MW to 100MW, aiding the ISO to lessen the number of generators participating in the CM problem.

From the values of BSF represented in Table 1, it is observed that the BSF values corresponding to bus 14 and bus 34 are significantly high. The positioning of the wind farm is done on bus 14 as it signifies most negative BSF, leading to the reduction of flow in the congested line.

Table 1. BSF values with different wind farm power level with outage of line 14-34.

Bus Sensitivity Factor Values				
Bus No	Without Wind farm	With Wind Farm (30MW)	With Wind Farm (50MW)	With Wind Farm (100MW)
1	0	0	0	0
8	-0.0199	-0.0206	-0.0197	-0.0194
9	0.0296	0.0289	0.0292	0.0290
10	-0.0398	-0.0387	-0.0384	-0.0380
12	-0.0399	-0.0379	-0.0374	-0.0370
14	-0.2572	-0.2496	-0.2494	-0.2491
16	-0.0051	-0.0024	-0.0021	-0.0020
19	-0.0337	-0.0295	-0.0292	-0.0289
25	-0.0218	-0.0213	-0.0210	-0.0204
27	0.0488	0.0498	0.0511	0.0516
34	0.4176	0.4244	0.4251	0.4302
38	0.0205	0.0234	0.0236	0.0240

In Table 2. the values of GSF corresponding to wind farm of different power level for the congested line 15-16 are shown. The GSF values corresponding to the generators 2, 8, 4, 5, 6 and 7 are uniform with different values of wind power. This suggests that the impact contributed on the flow of power in the congested line by these generators is similar. In fact, these generators also display similar effect as there is a negligible change in their GSF values due to the addition of the wind farm in the framework. Moreover, it is analyzed that even the wind farm inclusion in the framework, non-uniform flow of sensitivity values are shown by the generators 3, 9, and 10 on the congested line. Therefore, in order to minimize the transmission cost, these three generators are taken to participate in CM problem for the rescheduling purpose. The method proposed in this article led to the participation of less number of generators for CM problem as compared with the resulted presented in [15],[19].

Table 2. GSF values with different wind farm power level with outage of line 14-34

Generator Sensitivity Factor				
Bus No	Without Wind farm	With Wind Farm (30MW)	With Wind Farm (50MW)	With Wind Farm (100MW)
1	0	0	0	0
2	-0.5621	-0.5561	-0.5552	-0.5521
3	-0.0787	-0.0823	-0.0814	-0.0792
4	-0.4077	-0.4192	-0.4189	-0.4162
5	-0.4102	-0.4110	-0.4181	-0.4172
6	-0.4134	-0.4146	-0.4138	-0.4118
7	-0.4112	-0.4119	-0.4117	-0.4196
8	-0.5524	-0.5528	-0.5518	-0.5589
9	-0.5029	-0.5048	-0.5034	-0.5020
10	-0.5948	-0.5951	-0.5889	-0.5881

The real power flow in the congested line 15-16 due to the outage of line 14-34 has resulted in 628MVA power flow in the congested line 15-16. The placement of the wind farm in the framework significantly lessens this flow of the power in the congested line. The impact on the power flow in the congested line is represented in Table 3. resulted due to the ramification of the wind farm at different power levels.

Table 3. Power Flow in the Congested line 15-16

	Without wind farm	With wind farm at different power level		
		30 MW	50 MW	100 MW
Power flow (MVA)	628	603	587	548

In the current research, the proposed CM problem is analyzed with the incorporation of 30MW wind farm. The proposed method concentrates on the influence of the wind farm in the CM problem. The wind farm with a higher rating will also mitigate the congestion and reduce the cost of rescheduling but a considerable large area is required for the installation of a wind farm with higher rating along with high cost of installation. The robustness of the proposed method along with the GSA is implemented to 39-bus New England system. It is noticed from Table 4. that the proposed approach using GSA not only decreases the participating generators in numbers for CM but also minimizes the total amount of real power rescheduling when compared with

[15],[19]. İt is also seen that the total rescheduling amount acheived with ABC and FA are reported to be 530.62 and 527.77 MW respectively [21]. Therefore, the proposed CM method in this manuscript with GSA is superior to ABC and FA considering that the rescheduling amount and the rescheduling cost is also minimum.

Table 4. Amount of Rescheduling

Gen No.	Amount of Rescheduling (MW)		
	Result reported in [15]	Result reported in [19]	30MW wind farm using GSA
1	-99.59	-149.1	-117.23
2	98.75	65.6	Not Participated
3	-159.64	-129	-32.713
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	Not Participated
9	12.34	52.1	49.15
10	49.38	83.0	100.85
Total Amount (MW)	518.45	554.2	299.94

The proposed approach for the CM problem with the implementation of GSA shows a reduction in the active power loss when compared with [15], [19] is shown in Table 5. Furthermore the adopted method for the CM problem using 30MW wind farm along with the implementation of GSA after rescheduling also results in the improvement in the system minimum voltage profile leading to a more stable system as compared with [15], [19].

Table 5. Real Power Loss and System Minimum Voltage Level

Param-eters	Pre-Rescheduling		Post rescheduling		
	With-out wind farm	With wind farm 30 MW	Result reported in [15]	Result reported in [19]	Proposed method with 30 MW wind farm
Ploss (MW)	59.9	58.8	58	57.31	56.94
V min	0.935	0.9464	0.9320	0.945	0.9563

Fig. 5 shows the outcome of the proposed approach with the placement of 30 MW wind farm in the system compared with the result proposed in [15], [19]. The generator 1, which is the slack bus generator, is re-scheduled to minimize the real power losses. Besides this, comparing with the result reported in [15], [19] without wind farm, the rescheduling amount of generator 1 and generator 10 in the proposed method are quite significant.

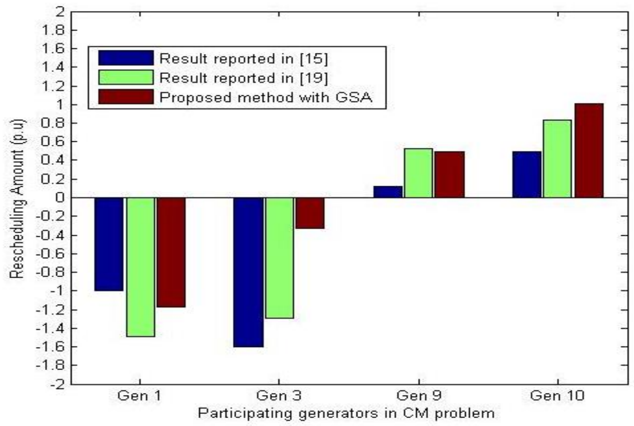

Fig. 5. Comparison for the amount of active power rescheduling for CM problem.

The comparison in the flow of the power in a few critical lines with the proposed approach is shown in Table 6. It is noticed that with the existence of wind farm the power flow in some lines diminished beneath the normal flow limits while fewer lines also show small augmentation in the line flows post rescheduling. The flow of the power in line 26 which is designated as the congested line is reduced below its flow limit and the lines 30, 32, 40, 41 show the increment in the power flow post rescheduling. The critical lines power flow decreases to normal line flow limit. The implementation of the wind farm not only just lessens the line flow in the congested line, but it also additionally decreases the flow of the power also in other basic lines. With the presence of 30 MW wind farm there is a reduction in the amount of the power flow in the congested line and henceforth reduces the real power output of the participating generators when compared with the others.

Table 6. Power flow in some critical lines in case of Pre and Post Rescheduling

Lines connected between the buses	Line Number	Actual Power Flow MVA			Line Flow Limit (MVA)
		Before Rescheduling	Pre rescheduling with 30MW wind farm	Post rescheduling with 30 MW wind farm	
L_{39-5}	36	519.1	517.33	517.0	1200
L_{22-6}	43	683.63	680.91	680.9	1200
L_{23-7}	42	575.51	574.35	574.3	1100
L_{25-8}	41	539.46	540.23	539.7	1100
L_{29-9}	40	825.85	826.18	827.0	1100
L_{12-13}	32	431.99	416.26	523.5	600
L_{13-14}	30	250.68	217.39	293.1	600
L_{15-16}	26	628.6	603.06	491.2	500
L_{21-22}	17	614.72	612.78	612.8	1200

The price bids for the generators are given in Table 7. Table 8. shows the comparisons in the cost of rescheduling for the CM problem. It is observed that the rescheduling cost achieved with the proposed method with GSA is minimum when compared with the cost reported in [15], [16].

Table 7. Generator price bids for 39-bus New England Test System (Rs/MW-h)

Generator No.	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
Bids (Rs/MW-h)	15	20	17	16	12	17	13	11	14	19

Table 8. Comparisons of Rescheduling cost for CM problem

	Result reported in [15]	Result reported in [19]	30MW wind farm using GSA
Total cost of Rescheduling (Rs/h)	8635.09	8874.4	4918.836

The convergence characteristic has been represented in Fig.6. From Fig.6, it is observed that the minimization of the cost for rescheduling involved in congestion mitigation is achieved with the increase in the number of iterations.

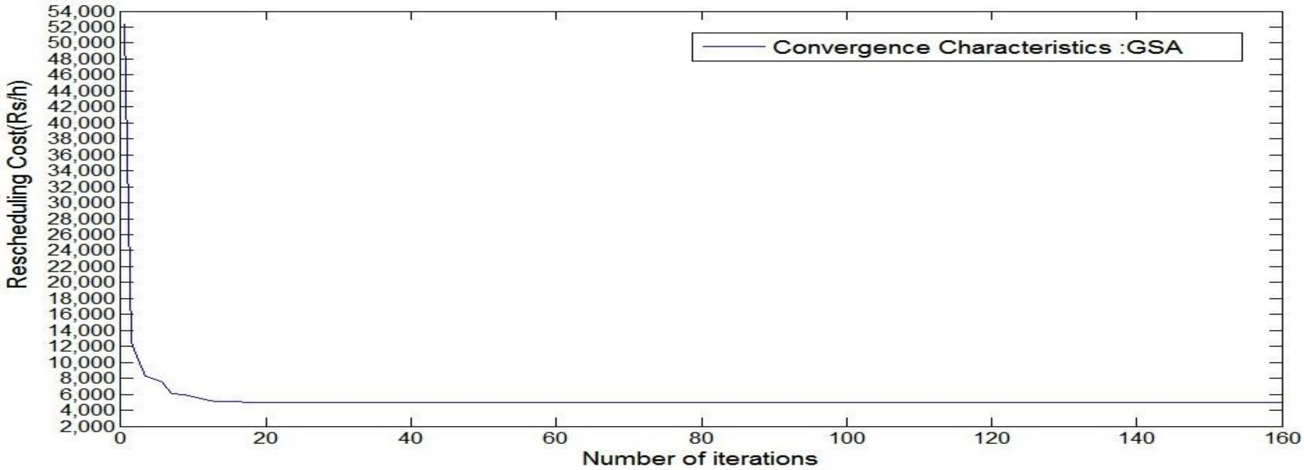

Fig. 6. Convergence profile for GSA based approach with wind farm.

7. Conclusion

This article exhibits the implementation of a meta heuristic optimization technique to alleviate the congestion by introducing wind farm as the renewable resource in the open access electricity market. In this paper the wind farm is included in the power system network to solve the CM problem. Though high rating of wind farm is favourable for CM problem but from the technical aspect a lower rating of the wind farm is chosen. The current adopted approach for CM problem portrays better results as compared with the previous literatures. The proposed approach is implemented and investigated on 39-bus New England System. The rescheduling cost involved in the alleviation of congestion is minimized using GSA. The outage of the line is taken as the contingency in this work. In the test system, the optimal values of the control variable are achieved by proper implementation of the proposed approach. When compared with the other techniques, the adopted approach with GSA successfully reduces the congestion. The rescheduling cost achieved with GSA is more economical than the cost reported in [15], [19]. Furthermore, the proposed approach in this paper also helped to reduce the amount of the active power rescheduling and the losses.

It may be observed from the simulated cases that GSA acts as an efficient tool in solving the non linear and multimodal problem with the incorporation of the wind farm. Moreover, it may be concluded that the approach adopted in this work provides a better utilization and application of the renewable resources along with GSA as a powerful and efficient tool to solve the CM problems, in the deregulated power system network.

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