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Optimal location and sizing of Unified Power Flow Controller (UPFC) to improve dynamic stability: A hybrid technique

B. Vijay Kumar [a,*], N.V. Srikanth [b]

[a] National Institute of Technology, Warangal, India
[b] Department of Electrical Engineering, National Institute of Technology, Warangal, India

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ABSTRACT

In this paper a hybrid technique based optimal location and sizing of UPFC to improve the dynamic stability is proposed. Here, the maximum power loss bus is identified at the most favorable location for fixing the UPFC, because the generator outage affects the power flow constraints such as power loss, voltage, real and reactive power flow. The optimum location has been determined using the Artificial Bees Colony (ABC) algorithm. Depending on the violated power flow quantities the Gravitational Search Algorithm (GSA) optimizes the required quantity of the UPFC to recover the initial operating condition. Then the proposed work is implemented in the MATLAB/simulink platform and the performance is evaluated by using the comparison, at different techniques like ABC and GSA. The comparison results demonstrate the superiority of the proposed approach and confirm its potential to solve the problem.

Introduction

Around the world, Electric power systems have been compelled to work to more or less their full capacities owing to the environmental and economic constraints to erect novel generating plants and transmission lines [2,3]. By safety and steadiness constraints, the amount of electric power that can be passed on among two positions through a transmission network is restricted [1]. Power flow in the lines and transformers should not be permitted to raise to a level where a random event could cause the network fall down as cascaded outages [4,5]. The system is said to be dammed when such a limit reaches. Managing congestion to reduce the limitations of the transmission network in the aggressive market has, therefore, turn into the central movement of systems operators [6]. It has been scrutinized that the inadequate management of transactions could raise the congestion cost which is a surplus burden on customers [7].

For controlling the power transmission system, Flexible Alternating Current Transmission System (FACTS) is a stationary tool that is used [8,9]. FACTS is identified as "a power electronic based system and other stationary tool that offer control of one or more AC transmission system parameters to improve controllability and amplify power transfer capability" [10]. The different kinds of FACTS tools accessible for this purpose comprises Static Var Compensator (SVC), Thyristor controlled series Capacitor (TCSC), Static Synchronous series compensator (SSSC), Static Synchronous Compensator (STATCOM), Unified Power Flow Controller (UPFC) and Interlink Power Flow Controller (IPFC) [12]. UPFC is one of the FACTS tools among them, that can manage the power flow in transmission line by inserting active and reactive voltage component in series with the broadcasting line [11,13].

Novel opportunities for controlling power and improving the utilizable capacity of surviving transmission lines are released by the appearance of FACTS devices [14]. An optimal location of UPFC tool permits to control its power flows for a meshed network and as a result the system load ability is raised [15]. On the other hand, a limited number of tools, beyond which this load ability can never be enhanced [16]. The optimal location and optimal capacity of a specified number of FACTS in a power system is a setback of combinatorial study [18,19]. Dissimilar kinds of optimization algorithm have been applied to work out this sort of problem, such as genetic algorithms, simulated annealing, and tabu search [17,20]. However, hybridization of more than one algorithm has been proven from basic general problems [24] to power system issues, for its outstanding performance [20,26].

In this paper a hybrid technique based optimal location and sizing of UPFC to improve the dynamic stability is proposed. Here, the maximum power loss bus is identified at the most favorable location for fixing the UPFC, because the generator outage affects the power flow constraints such as power loss, voltage, real and reactive power flow. The optimum location has been determined using

* Corresponding author.
E-mail address: bvijaykumar0478@gmail.com (B. Vijay Kumar).

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the Artificial Bees Colony (ABC) algorithm. Depending on the violated power flow quantities the Gravitational Search Algorithm (GSA) optimizes the required quantity of the UPFC to recover the initial operating condition. The rest of the paper is organized as follows: the recent research works is analyzed in 'Recent research work: a brief review'; the proposed work brief explanation is explained in 'Problem formulation'; the suggested technique achievement results and the related discussions are given in 'Results and discussion'; and the paper ends in 'Conclusion'.

Recent research work: a brief review

Numbers of associated works are obtainable in literature, which is based on enhancing the power transfer competence of power system. A few of them are assessed here. For improving the safety of power systems under single line contingencies, the efficiency of the optimal location of UPFC has been examined by Shaheen et al. [21]. Based on the emergency choice and ranking process, determinations of the severest contingency scenarios were executed. One of the latest computational intelligence methods, namely: DE has been effectively employed to the problem under concern. Maximization of power system security was regarded as the optimization principle. The presentation of DE was compared with that of GA and PSO. Moreover, they were carried out as two case studies by means of an IEEE 14-bus system and an IEEE 30-bus system.

Under single line contingencies, to detect the optimal placement and parameter setting of UPFC for improving power system security, a strategy based on differential evolution method has been offered by Shaheen et al. [22]. Initially, to find out the most rigorous line outage contingencies regarding line overloads and bus voltage limit violations as a performance index, they execute a contingency study and ranking procedure. Secondly, they use different evolution method to detect the optimal location and parameter setting of UPFC under the decided contingency scenarios. They carry out simulations on an IEEE 14-bus and an IEEE 30-bus power systems. They attained results point out that installing UPFC in the location optimized by DE could considerably improve the safety of power system by removing or minimizing the overloaded lines and the bus voltage limit violations.

To get the optimal location of UPFCs for attaining minimum total active and reactive power production, cost of generators and minimizing the installation cost of UPFCs, the requests of hybrid immune algorithm has been offered by Taher et al. [23]. The UPFC can supply control of voltage magnitude, voltage phase angle and impedance. As a result, it was employed successfully in this document to raise power transfer capability of the existing power transmission lines and diminish operational and investment costs. UPFC furthermore presents a mechanism that might assist traditional congestion mitigation techniques and in some cases might avert generators to run in and out of merit order and hence may prevent load shedding or curtailment that was generally necessary to sustain system security. They were executed simulations on IEEE 14-bus and 30-bus test system.

Nireekshana et al. [25] have examined the exploit of FACTs tools, like SVC and TCSC, to take full advantage of power transfer transactions during normal and contingency conditions. ATC was computed by means of Continuation Power Flow (CPF) technique regarding both thermal limits and voltage profile. To find out the location and control-ling parameters of SVC and TCSC, Real-code Genetic Algorithm (RGA) was applied as an optimization device. The proposed methodology was experimented on IEEE 14-bus system and as well on IEEE 24-bus dependability test system for usual and dissimilar contingency cases.

Using Fuzzy logic and Real Coded Genetic Algorithm, an approach for appointment and sizing of shunt FACTS controller has been suggested by Phadke et al. [26]. A blurry presentation index based on distance to encumber node bifurcation, voltage profile and capacity of shunt FACTS controller is suggested. In order to find the most efficient location, the suggested method can be applied and optimal size of the shunt FACTS tools can be used. The suggested strategy has been used on IEEE 14-bus and IEEE 57-bus test systems.

Ravia et al. [27] have suggested an Improved Particle Swarm Optimization (IPSO) was advised for optimizing the power system presentation. Lately, to work out power engineering optimization problems giving improved results than classical techniques, the Particle Swarm Optimization (PSO) technique has been used. Owing to unhurried convergence and local minima, particle swarm optimization fails to offer global results. For optimal sizing and distribution of a Static Compensator (STATCOM) and diminish the voltage variations at all the buses in a power system, they give the application of enhanced particle swarm optimization to overcome these disadvantages. This algorithm gets an optimal settings for current infrastructure with optimal locations, sizes and control settings for Static Compensator (STATCOM) units.

A novel strategy for optimal placement of PWM based Series Compensator (PWMSC) in huge power systems have been brought in by Safari et al. [28]. This strategy was based on the Selective Modal Analysis (SMA) and dynamics index to soggy out the inter-area fluctuation modes. Consequently, primary, SMA was applied to compute the low frequency modes of oscillation and then Most Dominant Line (MDL) Table based on the dynamic index was suggested which demonstrates the pressure of active power flows of the transmission lines on inter-area modes of the power system. The parameters of the PWMSC damping controller were planned by optimization based strategy for the purpose of damping inter-area oscillations in practical system. Optimal PWMSC placement was authenticated by comparing dissimilar candidate appointments based on the total damping that they offer for system.

The heavily loaded lines, sustain the bus voltages at desired levels and enhance the stability of the power network are increased at uncontrolled exchanges in power systems. For that reason, power systems need to be supervised in sequence to make use of the obtainable network competently. FACTS devices depends on the advance of semiconductor technology released positive latest prospects for controlling the power flow and expanding the loadability of the accessible power transmission system. Among the FACTS devices, the UPFC is one of the most promising FACTS devices for load flow control seeing as it can either concurrently manage the active and reactive power flow alongside the lines in addition to the nodal voltages. As per the characteristics of the UPFC, scheduling the implementations, it has some practical concern for finding the optimal location. In practical, the optimal location of UPFC tends not by randomly, and the matching methodical exploration is not frequently adequate. Several researches have put effort to solve the optimal location of UPFCs with respect to different purposes and methods. For determining the optimal location, the operating condition of UPFC must be pre-assigned which can be taken as simultaneously. Some of the optimization algorithms are introduced to determine the location and size of UPFC such as genetic algorithm, particle swarm optimization, and differential evaluation. This cannot be utilized to find the capacity and location at the same time so that the hybrid approach is needed. The proposed method is briefly described in the following section.

Problem formulation

Power flow studies of UPFC

The UPFC is one of the FACTS devices, which provides independent control of the real and reactive power flows, voltage magnitude and enhances the dynamic stability of the system. The UPFC consists of two switching converters like series converter and shunt converter operated from a common DC link. The converters are connected to the power system via coupling transformers. The shunt converter is connected to the sending end node whereas the series converter is connected between the sending and receiving end, which injects an AC voltage with controllable magnitude and phase angle in series with the transmission line. When the active power loss is neglected, the UPFC cannot generate or absorb the active power and the active power in the two converters must be balanced via the DC link. However the converters generate or absorb the reactive power and provide the independent shunt reactive compensation for the line. The UPFC structure is described in the following Fig. 1.

The above figure shows the structure of the UPFC; the Generator G is connected with the buses m and n. Here the converters are connected via transformer. It includes the impedances of the converter such as series impedance Z_{se}, shunt impedance Z_{sh}, Generator side impedance Z_G and load impedance Z_L. The converters are connected with the DC link capacitor C_{dc} with voltage V_{dc} capacity. These can be incorporated to the UPFC power flow equations [29], which are required to solve the power system affected quantities like equality and inequality constraints. It may occur due to the outage of generators presented in the power system, because the utilization side needs demand satisfaction at all times. The disturbed quantities are briefly described in the following section.

Equality constraints

The power system mainly contributes to the satisfaction of total demand of the utilities. Here, the system generators must satisfy the total demand of the consumers as well as power loss of the transmission lines. It is denoted as the equality constraints or power balance condition of the power system. The generators presented in the system get outage; it may increase the power loss and affect the dynamic stability environment. The required power balance condition is described in the following Eq. (1).

$$\sum_{i=1}^{N_G} P_G^i = P_D + \sum_{j=1}^{N_G}\left(P_L^j + jQ_L^j\right) \quad (1)$$

where P_G^i represents the power generated in the ith bus, P_D, the demand, P_L^j and Q_L^j, the real and reactive power losses of the jth bus, which are calculated by the following Eqs. (2) and (3).

$$P_L^j = |V_i||V_j||Y_{ij}|\sum_{n=1}^{N}\cos(\alpha_{ij} - \delta_i - \delta_j) \quad (2)$$

$$Q_L^j = |V_i||V_j||Y_{ij}|\sum_{n=1}^{N}\sin(\alpha_{ij} - \delta_i - \delta_j) \quad (3)$$

where V_i and V_j represent the voltage of the buses i and j, Y_{ij}, the bus admittance matrix, α_{ij}, the angle between the buses i and j, δ_i and δ_j, the load angles of i and j. Similarly, the inequality constraints are described in the following section.

Inequality constraints

This section describes the inequality constraints like voltage, and real and reactive power flows, which are affected due to the protest of the generation unit. These constraints are briefly explained as follows: The power system dynamic stability mainly considers the voltage stability of every node. The stable power flow needs the voltage at each bus at the range of 0.95–1.05 pu. The change in voltage is described in the following Eq. (4).

$$\Delta V_i = \frac{1}{\sqrt{l}}\sqrt{\sum_{i=1}^{l}\left(V_i^k\right)^2} \quad (4)$$

$$\text{where, } V_i^k = V_{slack} - \sum_{i=1}^{n} Z_i\left(\frac{P_i - jQ_i}{V_i}\right) \quad (5)$$

With V_{slack} represents the slack bus voltage, ΔV_i, the voltage stability index of the bus i, V_i, voltage of the bus, where $i = 1, 2, 3\ldots n$, Z_i, the impedance of the ith bus, P_i and Q_i, the real and reactive powers of bus i and j, the number of nodes. The bus voltage lies between the limits, i.e., $V_i^{\min} \le V_i \le V_i^{\max}$. The real and reactive powers of the particular bus are described in the following Eqs. (6) and (7).

$$P_i = |V_i||V_j|\sum_{n=1}^{N_B}(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}) \quad (6)$$

$$Q_i = |V_i||V_j|\sum_{n=1}^{N_B}(G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij}) \quad (7)$$

where V_i and V_j symbolize the voltage of i and j buses respectively, N_B, the total number of buses, δ_{ij}, the angle between i and j buses respectively, G_{ij} and B_{ij}, the conductance and susceptance values respectively. Depending on these constraints, the optimum location and the UPFC have been determined using the proposed hybrid technique. It is briefly explained in the following Section Overview of the hybrid technique.

Overview of the hybrid technique

In the paper, optimal location and sizing of UPFC to improve dynamic stability based on a hybrid technique are proposed. Initially, the IEEE standard bench mark, systems normal power flow and the stability condition are analyzed. Afterwards the generation faults are introduced in the bus system. Here, the maximum power

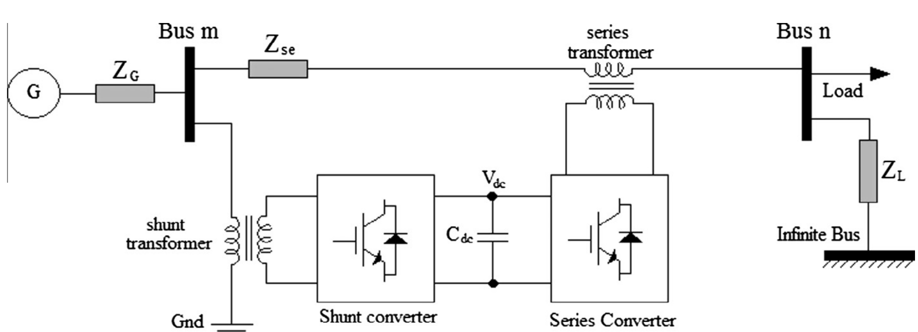

Fig. 1. Structure of the UPFC.

loss bus is determined by the ABC technique, and is identified as the most favorable location for fixing the UPFC. Depending on the affected parameters, the finest capacity of the UPFC is identified using the GSA algorithm. It is used to recover the normal operating condition and enhance the dynamic stability. The ABC algorithm based optimal location determination is explained in the following section.

ABC based optimum location determination

In the proposed hybrid technique, the first stage involves the optimum location identification of the UPFC. Here, the power flow terms such as voltage, real and reactive power flows and power losses have already been determined using the Newton–Raphson (N–R) method. Then the generator fault is performed at the generator buses, which causes instability at the system. So the maximum power loss bus and the corresponding affecting parameters are attained using the ABC technique. The algorithmic steps to optimize the location are given in the following section.

Algorithm.

Step1: Initialize the population of the line power loss and voltage (X_i) at all the buses.

$$X_i = \left[(V_1, P_{L1})^{B1}, (V_2, P_{L2})^{B2}, (V_3, P_{L3})^{B3} \dots (V_n, P_{Ln})^{Bn}\right]$$

where $(V_1, P_{L1})^{B1}$ are the voltage and the power loss of the $B1$ bus.

Step 2: Generate the random number of population input voltage and the power loss.

Step 3: The employ bee phase evaluates the fitness of the population and the required fitness function is given in the following Eq. (8).

$$\Phi = Max\left\{|V_i||V_j||Y_{ij}|\sum_{n=1}^{N}\cos(\alpha_{ij} - \delta_i - \delta_j)\right\} \tag{8}$$

Step 4: Set the iteration count as 1, i.e., iteration I = 1.

Step 5: Repeat

Step 6: The onlooker bee attains the elite fitness function of the bus system and improves the velocity of the populations using the following Eq. (9).

$$V_{i,j} = x_{i,j} + \Phi_{i,j}(x_{i,j} - x_{k,j}) \tag{9}$$

where k signifies the solution the neighborhood of i, Ψ, a random number in the range [−1, 1], $k = (1, 2, 3 \dots n)$ and $j = (1, 2, 3 \dots n)$, the randomly chosen index and $V_{i,j}$, the neighborhood solution of X_i.

Step 7: Apply the selection process to find the better fitness of the new solutions and determine the probability.

$$probability = \frac{\Phi}{\sum_{i=1}^{n}\Phi} \tag{10}$$

Step 8: If better solutions are not achieved, abandon the solutions and produce the random number of scout bee solution using the following Eq. (8).

$$x_i^j = x_{\min}^j + rand[0, 1]\left(x_{\max}^j - x_{\min}^j\right) \tag{11}$$

Step 9: Memorize the best solution achieved so far.

Step 10: Check the iteration range, if the iteration has not achieved the maximum range, increase the iteration count $I = I + 1$, or else terminate the process.

Once the above process is finished, the system is ready to produce the maximum power loss bus at the specified generator bus fault condition. The optimum capacity of the UPFC is selected as per the following section.

UPFC sizing prediction using GSA

This section describes the second stage of the proposed hybrid technique, which involves the prediction of the finest capacity of the UPFC. It may be attained by optimizing the power flow quantity of the UPFC. Here, the difference between bus system normal voltage and the generator fault time voltage is reduced. Then the optimized voltage is used to develop the finest capacity of the UPFC. By using the optimum capacity of the UPFC the dynamic stability of the system is enhanced. The steps to achieve the optimum capacity of the UPFC are explained in the following section.

Algorithm.

Step 1: Identify the search space and initialize the voltage limit of the IEEE bench mark system and the UPFC power flow equations, which are assumed as the agents. We consider the proposed system which consists of N agents (masses) and the position of the ith agent is given by

$$Y = (y_i^1, \dots, y_i^d, \dots y_i^n) \quad \text{where, } i = 1, 2, \dots n$$

Step 2: Involves random generation of the input voltage and formation of the fitness function; the proposed system considers the fitness function as the minimization of the voltage deviation between normal bus voltage and fault time bus voltage. The fitness function is given in the following Eq. (12).

$$\Psi = Min\sum_{i=1}^{N_B}\left(V_{Normal} - V_i^F\right) \tag{12}$$

Step 3: Identify the fitness of the agents using above Eq. (12).

Step 4: Update the gravitational constant $G(t)$, best fitness $F(B)$, worst fitness $F(W)$ and mass of the agents $M_i(t)$. The gravitational search constant $G(t)$ is initialized at the beginning and it will reduce with time to control the search accuracy. The gravitational constant is given by the following expression: $G(t) = G(G_0, t)$, the best fitness $F(B)$, worst fitness $F(W)$ and mass of the agents $M_i(t)$ are described by the following Eqs. (15)–(17).

$$F(B) = \underset{j\in\{1\dots N\}}{Max}\ Fitness_j(t) \tag{13}$$

$$F(W) = \underset{j\in\{1\dots N\}}{Min}\ Fitness_j(t) \tag{14}$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)} \tag{15}$$

where, $m_i(t) = \frac{F_i(t) - F(B)_t}{F(B)_t - F(W)_t}$, with $F_i(t)$ represents the fitness values of the ith agent at time t.

Step 5: Determine the total force of the agents at different directions, total force is described by the following Eq. (18).

$$force_i^d(t) = \sum_{j\neq i} rand_j\left(force_{ij}^d(t)\right) \tag{16}$$

where $force_{ij}^d(t) = G(t)\frac{M_{pi}(t)^* M_{aj}(t)}{R_{ij}+\varepsilon} * \left(y_j^d(t) - y_j^d(t)\right)$, $R_{ij} = \|Y_i(t), Y_j(t)\|_2$ is the Euclidian distance between two agents i and j, $rand_j$ is the random values, i.e., [0, 1], is a small constant, M_{aj} and M_{pi} active and passive gravitational masses related to agent i and j.

Step 6: Calculation of the acceleration and velocity: the acceleration is determined by using the following Eq. (17).

$$Acceleration\ a_i^d(t) = \frac{force_i^d(t)}{M_i(t)} \tag{17}$$

Step 7: Update the agent's position, using the following velocity Eq. (18)

$$V_i^d(t+1) = rand_i \cdot \left[V_i^d\right] + a_i^d(t) \tag{18}$$

The above velocity function is used to develop the new agents, which is described in the following Eq. (19).

Table 1
Power flow analysis of single generator problem using the proposed method.

Generator bus no.	Best location		Power flow					
			Normal		During fault		After connecting UPFC	
	From bus	To bus	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
2	12	15	19.675	7.796	19.797	7.755	20.457	7.715
6	5	7	23.744	13.825	24.763	14.248	21.010	17.652
13	10	22	4.047	6.617	4.044	6.581	1.316	7.105
22	12	15	19.675	7.796	19.797	7.755	20.015	7.222
27	10	22	4.047	6.617	4.044	6.581	1.704	8.118

Table 2
Power loss of single generator problem using the proposed method.

Generator bus no	Best location		Power loss in MW		
	From bus	To bus	Normal	During fault	With UPFC
2	12	15	10.809	12.768	9.222
6	5	7		12.552	8.367
13	10	22		12.795	8.345
22	12	15		11.883	8.669
27	10	22		11.903	9.233

Table 3
Power flow analysis of double generator problem using the proposed method.

Generator bus no.	Best location		Power flow					
	From bus	To bus	Normal		During fault		After connecting UPFC	
			P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
2 and 6	10	22	1.047	6.617	4.044	6.581	4.035	6.468
2 and 13	5	7	23.744	13.825	24.763	14.248	21.940	13.076
6 and 13	2	5	72.803	2.549	71.715	2.681	78.743	1.915
22 and 27	12	15	19.675	7.796	19.797	7.755	22.474	6.499
13 and 27	10	22	1.047	6.617	4.044	6.581	2.387	6.889

$$Y_i^d(t+1) = Y_i^d(t) + V_i^d(t+1) \quad (19)$$

Where, $V_i^d(t)$ and $Y_i^d(t)$ are the velocity and position of an agent at t time and d dimension, $rand_i$ is the random number in the interval [0, 1].

Step 8: Check the fitness of the new agents and memorize the best solutions.

Step 9: Repeat the procedure from step 3 to 7 until it reaches the stop criteria.

Step 10: Terminate the process.

Once the process exits, the system is ready to enhance dynamic stability. Then, the proposed system is implemented in the MATLAB platform and its performance is checked with various operating conditions. It is given in the following section.

Results and discussion

The proposed hybrid model is implemented in MATLAB 7.10.0 (R2010a) platform. The numerical results of the proposed method is presented and discussed in this section. The obtained results are compared with various operating environments. Here, the hybrid technique is applied to the IEEE standard bench mark system like IEEE 30 bus system and IEEE 14 bus system. The discussions about the two systems are given as follows.

Validation of IEEE 30 bus system

The dynamic stability of IEEE 30 bus benchmark system, which consists of six generator bus, 21 load bus and 42 transmission lines, is analyzed in this section. Initially, the system load flow analysis is done by the standard Newton–Raphson (N–R) method. Here, the IEEE 30 bus system standard details are used. Afterwards, the generators are turned off at different intervals and the corresponding stability is tabulated. Table 1 illustrates UPFC location and the capacity identification during the single generator off condition by using the proposed method. From this, we observed that the best line is optimized by the ABC algorithm and the capacity of the UPFC selection is made by the GSA technique. Similarly, power loss at different environment has been described in Table 2. Then the power flow and the corresponding power loss during double generators at turned off conditions are explained in Tables 3 and 4. Here, it also provides the information about the power loss at normal condition, during the generator off time and the proposed hybrid method. Finally, the proposed method is compared with different techniques like ABC and GSA and the obtained results are illustrated in Tables 5 and 6. The power losses in IEEE 30 bus

Table 4
Power loss of double generator problem using the proposed method.

Generator bus no.	Best location		Power loss in MW		
	From bus	To bus	Normal	During fault	With UPFC
2 and 6	12	15	10.809	14.73	9.212
2 and 13	5	7		15.017	8.999
6 and 13	10	22		14.833	9.602
22 and 27	12	15		13.051	8.706
13 and 27	10	22		14.005	9.901

Table 5
Power flow comparison using different techniques.

Technique	Fault generator bus no.	Best location		Power flow during normal condition		Power flow during fault condition		Power flow after fixing the UPFC	
		From bus	To bus	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
ABC	2	5	7	21.850	13.825	24.763	14.248	22.639	16.538
GSA	2	5	7					22.638	19.572
Hybrid	2	5	7					21.850	16.320

Table 6
Power loss comparison of single generator problem using different techniques.

Fault generator bus no.	Power loss in MW			
	Normal	ABC	GSA	Hybrid
2	10.809	9.858	9.542	9.498

Table 7
Power loss comparison of double generator problem using different techniques.

Fault generator bus no.	Power loss in MW			
	Normal	ABC	GSA	Hybrid
22 27	10.809	9.662	9.221	8.706

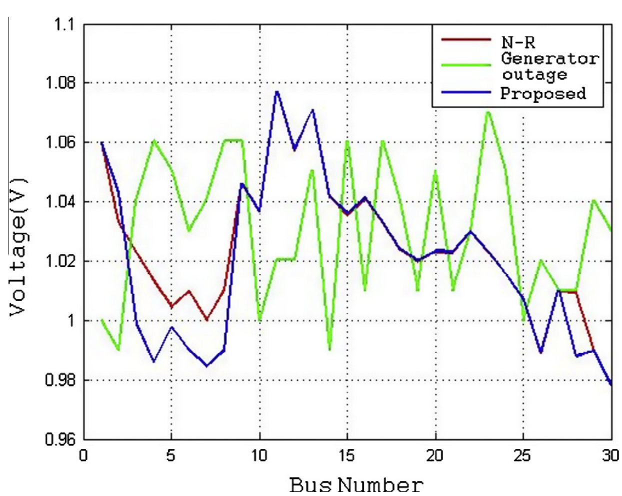

Fig. 2. Voltage profile during generator outage at 2nd bus.

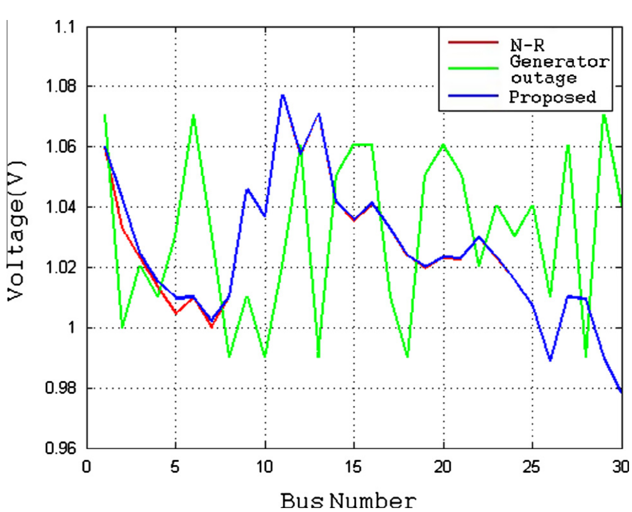

Fig. 3. Voltage profile during generator outage at 6th bus.

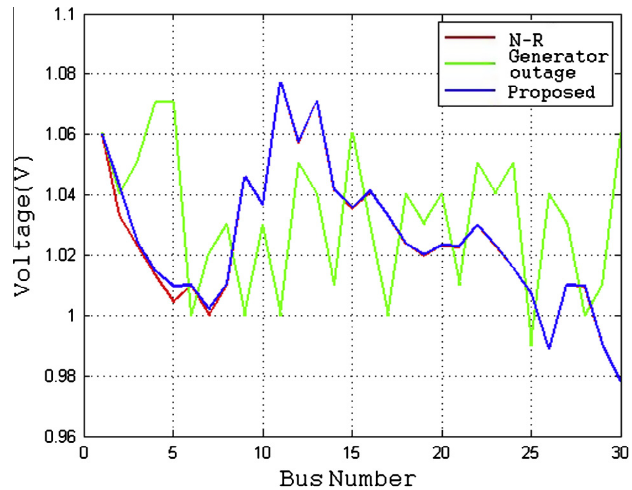

Fig. 4. Voltage profile during generator outage at 13th bus.

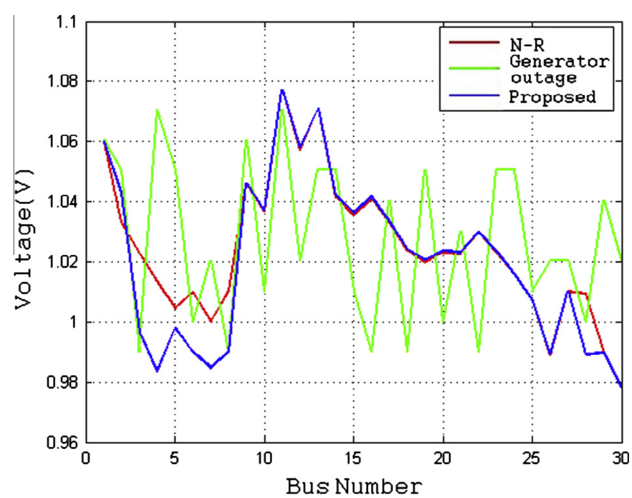

Fig. 5. Voltage profile during generator outage at 22nd bus.

system during double generator problem using different techniques are explained in Table 7 followed by graphical analysis.

The voltage profile variation in IEEE 30 bus system at single generator problem is described in Figs. 2–6. Here, the bus system generators are turned off in the sequence: 2nd bus, 6th bus, 13th bus, 22nd bus and 27th bus. The voltage profile is identified for N–R method, during the generator off time and the proposed method. From the voltage profile analysis, we found that the voltage profile at each bus is collapsed at the generator shutdown period, but at the same time the proposed method is used to enhance the voltage profile normal condition using the UPFC. The power loss obtained during this instant is mentioned in Fig. 7. It shows

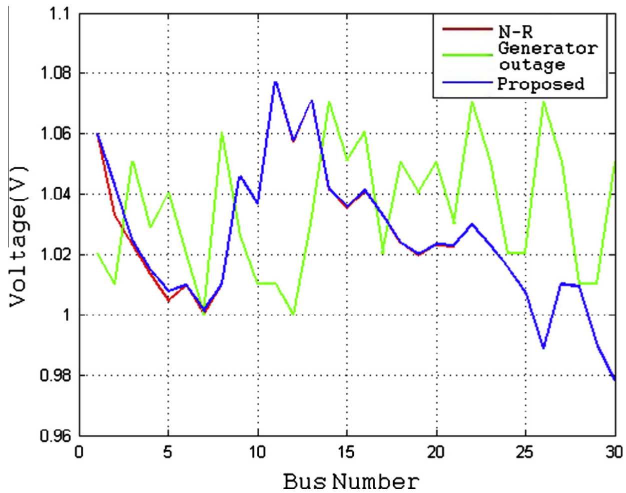

Fig. 6. Voltage profile during generator outage at 27th bus.

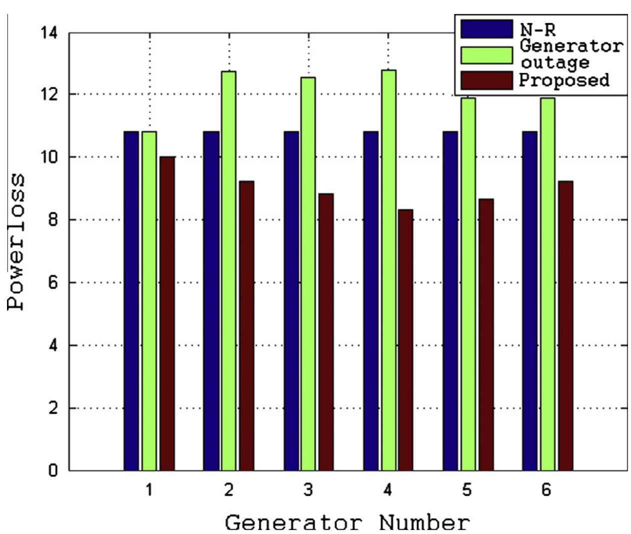

Fig. 7. Power loss at single generator problem.

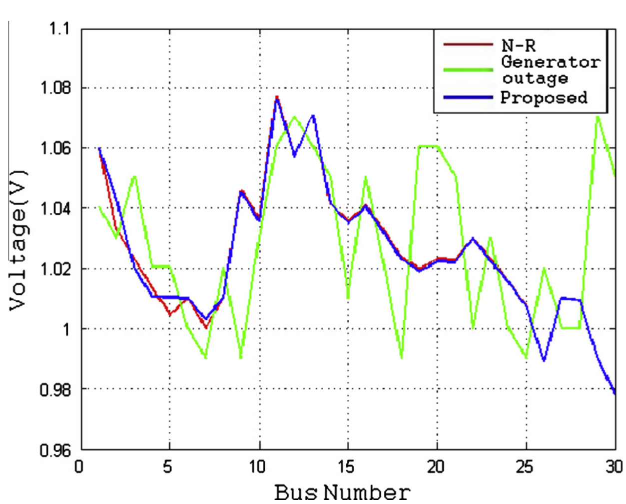

Fig. 8. Voltage profile during generator outage at buses 2 and 6.

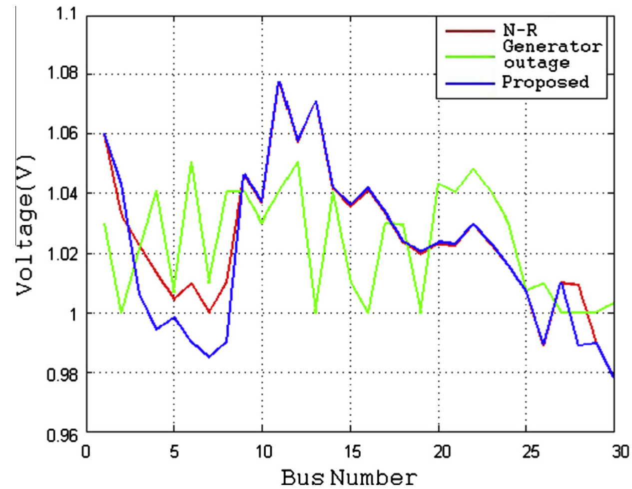

Fig. 9. Voltage profile during generator outage at buses 2 and 13.

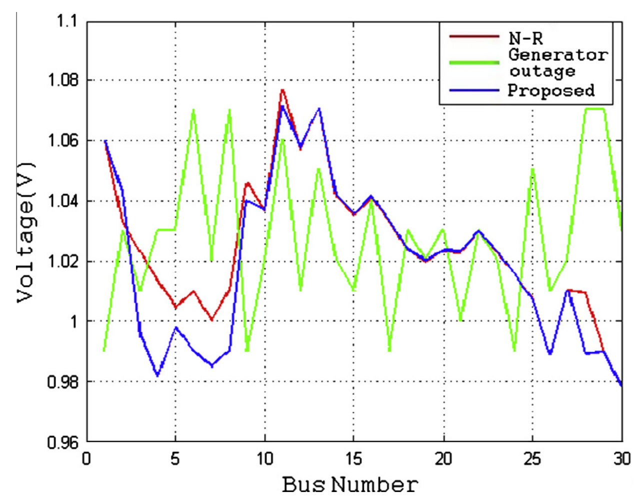

Fig. 10. Voltage profile during generator outage at buses 6 and 13.

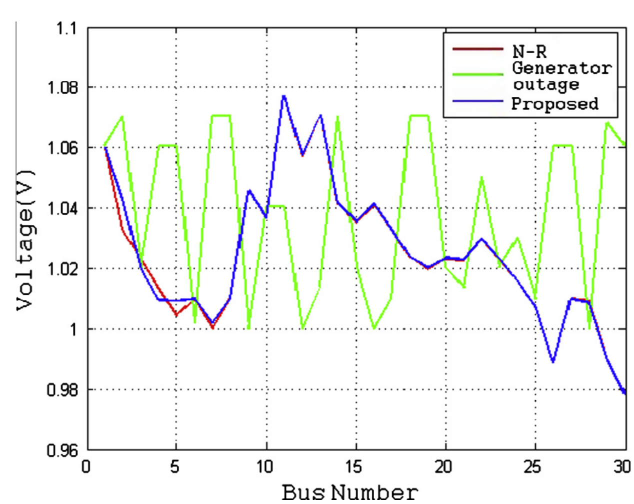

Fig. 11. Voltage profile during generator outage at buses 22 and 27.

the power loss using N–R method, during the generator off time and the proposed method, in which the power loss is much more reduced after using the proposed hybrid technique. Similarly, the stability condition is analyzed at double generator source problem condition. Figs. 8–12 describe the Double generator problem like (12, 15), (5, 7), (10, 22), (12, 15) and (10, 22), respectively. During these generator shutdowns condition, the power flow problem affects the dynamic stability, which can be resolved by the proposed hybrid technique. Then the power loss reduction using proposed method at the double generator source problem is described in Fig. 13. Finally the effectiveness of the proposed method is proved by Figs. 14 and 15. It shows that the proposed hybrid method has reduced power loss and voltage profile, when compared with ABC and GSA techniques. The IEEE 30 bus system voltage during double generator problem using different techniques like ABC, GSA and proposed technique are illustrated in Fig. 16. Here, the normal voltage profile is collapsed during the generator outage condition, which can be recovered using the ABC, GSA and proposed techniques. From the comparison results, we can

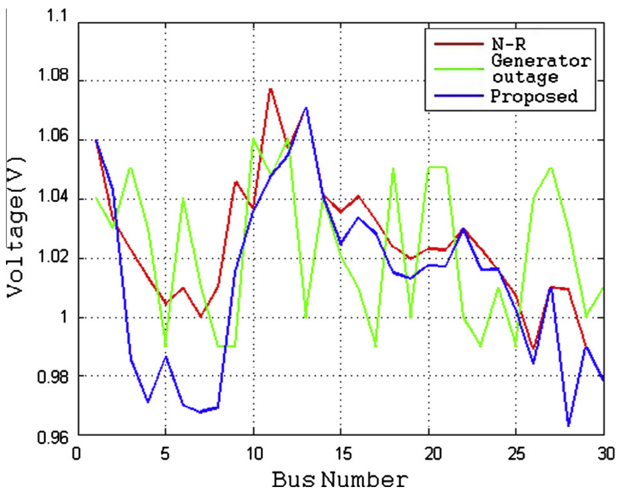

Fig. 12. Voltage profile during generator outage at buses 13 and 27.

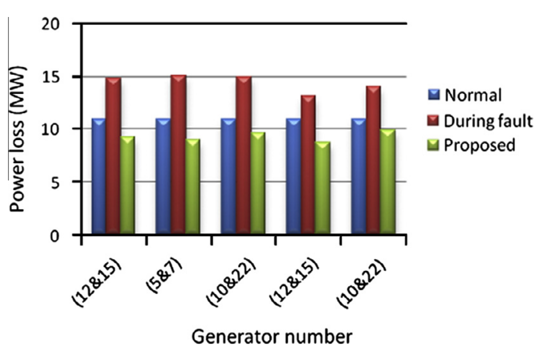

Fig. 13. Power loss at double generators problem.

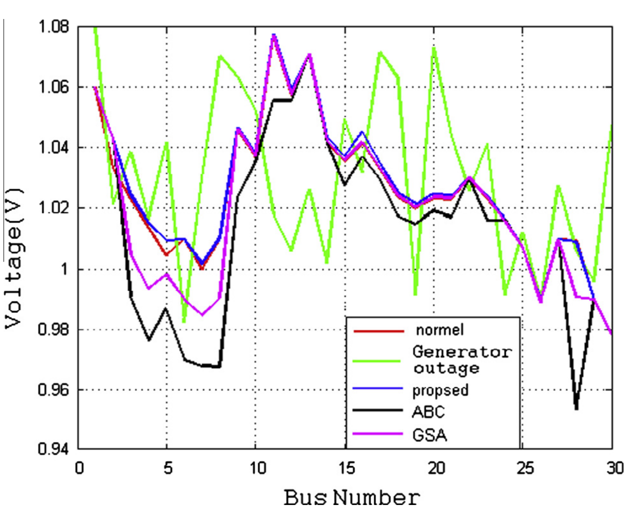

Fig. 14. Voltage profile comparison during generator problem at 2nd bus.

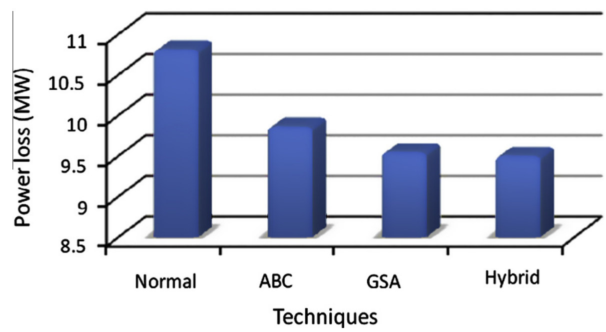

Fig. 15. Power loss comparison during generator problem at 2nd bus.

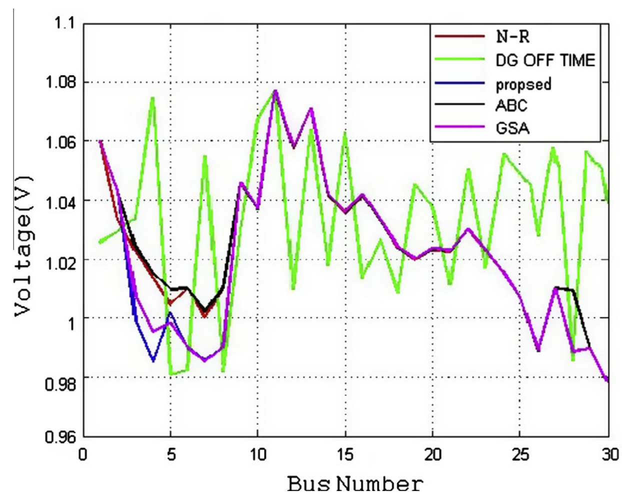

Fig. 16. Voltage profile comparison during double generator problem.

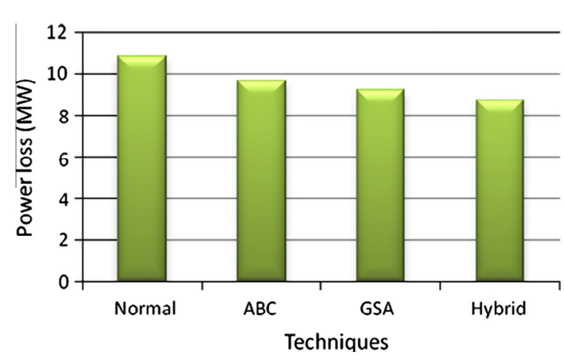

Fig. 17. Power loss comparison during double generator problem.

Table 8
Power flow comparison using different techniques.

Technique	Fault generator bus no.	Best location		Power flow during normal condition		Power flow during fault condition		Power flow after fixing the UPFC	
		From bus	To bus	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
ABC	2	4	5	59.585	11.574	62.894	14.208	56.287	9.827
GSA	2	4	5					58.654	10.931
Hybrid	2	4	5					54.852	9.319

Table 9
Power loss comparison using different techniques.

Fault generator bus no.	Selected lines		Power loss in MW			
	From bus	To bus	Normal	ABC	GSA	Hybrid
2	4	5	13.592	11.765	12.979	11.175

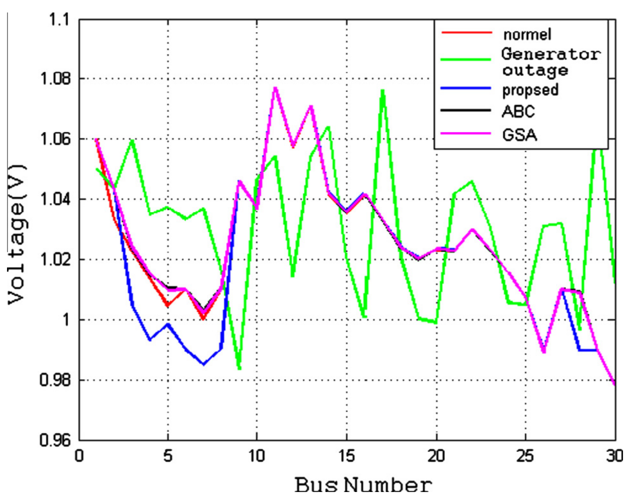

Fig. 18. Voltage profile comparison during generator outage at 2nd bus.

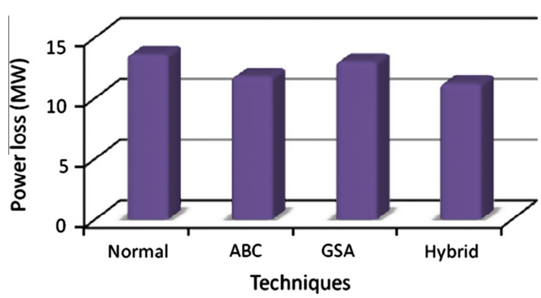

Fig. 19. Power loss comparison during generator outage at 2nd bus.

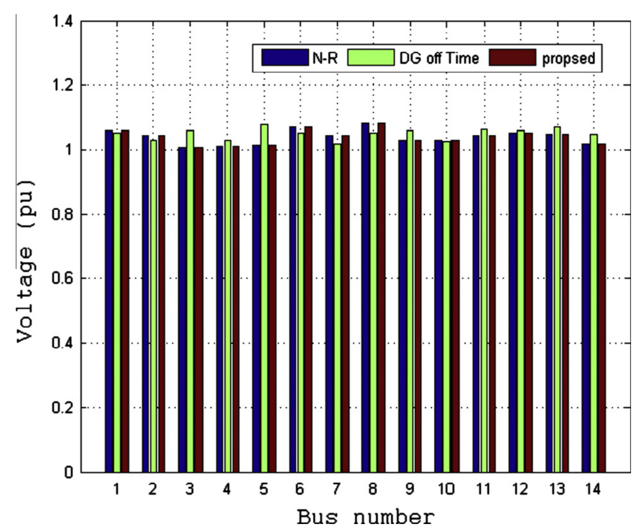

Fig. 20. Voltage profile comparison in bar chart.

Table 10
Performance evaluation of the proposed method.

Techniques	RA in (%)
ABC	8.795
GSA	11.721
Proposed	19.456

understand that the proposed method is effectively maintaining the voltage profile within the stability limit, when compared with other techniques. Similar type of double generator problem is applied in the IEEE 30 bus system and the power loss has been analyzed in Fig. 17. It was seen that the power loss is much more reduced to 8.706 MW using the proposed method. The effectiveness of the proposed method is also validated using the IEEE 14 bus system, which has been explained in 'Validation of the IEEE 14 bus system'.

Validation of the IEEE 14 bus system

This section describes the effectiveness of the proposed hybrid technique against the IEEE 14 bus benchmark system, which consists of 2 generator buses, i.e., one generator in slack bus and another one in 2nd bus. Initially, the power flow of the bus system is identified using the N–R method. Afterwards, it performs the generator outage at the required bus and analyzes the stability condition using our proposed method. Here, IEEE 14 bus system power loss, best location and optimum quantity of the UPFC are compared with ABC and GSA, which can be described in Tables 8 and 9, followed by graphical analysis.

Fig. 18 illustrates the voltage profile variation of the IEEE 14 bus system at ABC algorithm, GSA technique and the proposed hybrid method. Here, it can be achieved by turning off the 2nd bus generator. In this, the collapsed voltage during the generator off time is recovered into the normal condition using the proposed method. Also, the power loss is described in Fig. 19 in which the power loss is reduced using the proposed hybrid technique due to the optimization process. The Fig. 20 illustrated about the bus voltage profile comparison between different techniques like N-R method, DG off time and proposed method. Here, the proposed method effectively maintains the voltage profile within the mentioned limit (0.95–1.05 pu). From the obtained results, the Results Accuracy (RA) is determined for all the techniques using Eq. (20).

$$RA = \frac{BP - NP}{NP} \times 100 \tag{20}$$

where BP and NP are the best minimum power loss and normal power loss respectively, the RA for different techniques are described in the Table 10. From Table 10, we have to find the percentage accuracy of the results during the optimization process in the IEEE 30 bus system. The effectiveness is identified by the high RA values. Here, the ABC has 8.795% RA value from both the best minimum power loss and normal power loss, whereas GSA has slightly higher RA value than other techniques i.e., 11.721%. But the proposed hybrid technique provides high RA value in the optimization process, i.e., 19.456%. From that, we can observe that the proposed method contains reduced power loss during the fault conditions. Finally, we concluded that, the proposed system well effectively identify the optimum location and optimum capacity of the UPFC, which proves the superiority of the proposed method.

Conclusion

In this paper, the effectiveness of the optimal location and sizing of UPFC to enhance the dynamic stability is proposed. The advantage of the proposed method is effective searching ability to find the optimum solutions and accuracy. Here, the proposed method was applied to the IEEE 30 and 14 benchmark system and the effectiveness is tested against different generator faults. Initially the single generator problem is performed at different ways in the bus system and afterwards double generator problem was introduced. In these conditions, the voltage profile and the power loss is analyzed at normal condition, ABC algorithm, GSA algorithm and proposed hybrid technique. From the presented analysis, we concluded that the proposed system effectively enhanced the dynamic stability of the system due to the selection of optimum location and optimum quantity of the UPFC and was competent over the other techniques.

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