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A hybrid approach for optimal location and capacity of UPFC to improve the dynamic stability of the power system

B. Vijay Kumar[a,*], N.V. Srikanth (Associate Professor)[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 document, the Firefly Algorithm (FA) and Cuckoo Search (CS) algorithm based on optimal location and the capacity of UPFC to improve the dynamic stability of the power system are proposed. The novelty of the proposed method is exemplified in the improved searching ability, random reduction and reduced complexity. In this regard, the generator fault affects the system dynamic stability constraints such as voltage, power loss, real and reactive power. Here, the FA technique optimizes the maximum power loss line as the suitable location of the UPFC. The affected location parameters and dynamic stability constraints are restored into secure limits using the optimum capacity of the UPFC, which in turn, has been optimized with reduced cost by using the CS algorithm. The attained capacity of the UPFC has been located in the affected location and the power flow of the system analyzed. The proposed method is implemented in the MATLAB/Simulink platform and tested under IEEE 30 and IEEE 14 standard bench mark system. The proposed method performance is evaluated by comparison with those of different techniques such as ABC-GSA, GSA-Bat, Bat-FA and CS algorithms. The comparison results invariably prove the effectiveness of the proposed method and confirm its potential to solve the related problems.

1. Introduction

Electric power systems have been forced to work to more or less their full capacities around the world due to the environmental and economic limitations to upright new generating plants and transmission lines [2,3]. The amount of electric power by safety and steadiness restraints, that can be passed on between two positions via a transmission network is limited [1]. Power flow in the lines and transformers should not be allowed to increase to a level where an arbitrary incident could cause the network fall down as cascaded outages [4,5]. The system is assumed to be blocked when such a limit attains. Managing obstruction to decrease the restrictions of the transmission network in the forceful market has, thus, turn into the central movement of systems operators [6]. It has been analyzed that the insufficient management of dealings could increase the congestion cost which is an extra burden on customers [7].

For managing the power transmission system, Flexible Alternating Current Transmission System (FACTS) is a fixed device that is applied [8,9]. FACTS is recognized as "a power electronic based system and other fixed device that present control of one or more AC transmission system parameters to develop controllability and magnify power transfer capability" [10]. The different types of FACTS devices available for this purpose includes 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 devices among them, that can administer the power flow in transmission line by including active and reactive voltage component in chain with the transmission line [11,13].

New opportunities for controlling power and enhancing the utilizable capacity of surviving transmission lines are discharged up by the look of FACTS tools [14]. An optimal location of UPFC device allows to control its power streams for an interconnected network, and as a result to increase the system load ability [15]. Alternatively, a limit number of devices, away from which this load ability can in no way be improved, has been analyzed [16]. The optimal location and optimal capacity of a particular number of FACTS in a power system is a hinder of combinatorial revise [18,19]. Different types of optimization algorithm have been used to effort out this kind of problem, such as genetic algorithms, reproduced annealing, tabu search and etc [17,20].

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

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This paper the Firefly algorithm and Cuckoo Search (CS) algorithm based optimal location and the capacity of UPFC to improve the dynamic stability of the power system is proposed. Here, the FA technique optimizes the maximum power loss line as the suitable location of the UPFC. The affected location parameters and dynamic stability constraints are restored into secure limits using the optimum capacity of the UPFC, which in turn, has been optimized with reduced cost by using the CS algorithm. The attained capacity of the UPFC has been located in the affected location and the power flow of the system analyzed. Rest of the paper sorted by the following: the recent analysis works is usually reviewed throughout Section 2; the proposed work elaborate the evidence is usually described throughout Section 3; the suggested techniques approach good results effects as well as the related discussions receive throughout Section 4; as well as Section 5 finishes the paper.

2. Recent research work: a brief review

Numbers of related works are available in literature, which based on improving the power transfer capability of power system. Some of them are reviewed here. Shaheen et al. [21] has been scrutinized the competence of the optimal location of UPFC for enhancing the safety of power systems under single line contingencies. Fortitudes of the severest possibility scenarios were performed based on the emergency option and ranking process. One of the newest computational intelligence techniques, namely: DE has been successfully used to the problem under distress. Maximization of power system security was considered as the optimization rule. The appearance of DE was compared with that of GA and PSO.

Shaheen et al. [22] has presented an approach based on differential evolution technique under single line contingencies, to identify the optimal placement and parameter setting of UPFC for enhancing power system security. At first, to detect the most accurate line outage contingencies considering line overloads and bus voltage limit violations as a presentation index, they implement an emergency study and ranking process. Secondly, they employ differential evolution technique to identify the optimal location and parameter setting of UPFC under the decided contingency scenarios.

Seyed Abbas Taher et al. [23] have presented the demands of hybrid immune algorithm to get the optimal location of UPFCs for accomplishing minimum total active and reactive power production cost of generators and minimizing the installation cost of UPFCs. The UPFC can provide control of voltage magnitude, voltage phase angle and impedance. Accordingly, it was utilized effectively in this paper to increase power transfer capability of the presented power transmission lines, and reduce operational and investment costs. UPFC in addition offers a mechanism that might help traditional congestion mitigation methods and in some cases might turn away generators to run in out of merit order, and thus may stop load shedding or restriction that was commonly required to maintain system security.

Nireekshana et al. [24] have checked the use of FACTs devices, like SVC and TCSC, to take full benefit of power transfer transactions during normal and emergency situations. Using Continuation Power Flow (CPF) technique, ATC was worked out considering both thermal limits and voltage profile. Real-code Genetic Algorithm (RGA) was used as an optimization tool to detect the location and control-ling parameters of SVC and TCSC.

A.R. Phadke et al. have proposed a strategy for engagement and sizing of shunt FACTS controller by means of Fuzzy logic and Real Coded Genetic Algorithm [25]. A fuzzy appearance index based on distance to impede node bifurcation, voltage profile and capacity of shunt FACTS controller is proposed. The proposed technique can be used and optimal size of the shunt FACTS devices in order to discover the most competent location.

Hassan et al. [26] have demonstrated the application of Genetic Algorithm (GA) technique for the simultaneous stabilization of power systems using a Unified Power Flow Controller (UPFC). The GA was applied to find the optimal location of the UPFC and to tune its control parameters under different operating conditions. The problem was formulated as a multi-objective optimization problem which aims at maximizing the damping ratio of the electromechanical modes using different lines fitted with the UPFC.

Hagh et al. [27] have presented a novel method to solve security based optimal placement and parameter setting of unified power flow controller (UPFC) problem based on hybrid group search optimization (HGSO) technique. Firstly, HGSO is introduced in order to solve mix-integer type problems. Afterwards, the proposed method is applied to the security based optimal placement and parameter setting of UPFC problem. The focus of the paper is to enhance the power system security through eliminating or minimizing the over loaded lines and the bus voltage limit violations under single line contingencies.

The discrete multiple facility location problem (DMFLP) is an advance method proposed by Davood et al. [44]. It was mainly describing the location of different multiple facilities and location of customers to be placed on these facilities. In this problem mainly indicating the mathematical model to these facilities and the difficulties to solve the mathematical model, particularly in large scale. For this problem, they proposed a new hybrid algorithm based on tabu search algorithm.

For dynamic optimization problems, Karimi et al. [45] proposed a new hybrid technique with constant search places. In this method used to hybridize efficient features of the particular swarm optimization with a new evolutionary process. In proposed dynamic hybrid PSO (DHPSO) algorithm the swarm size will change in self-regularity method. The particles can replicate infants and the mature one will expire, in the microbial life. Using of quadratic interpolation method, the infants were particularly replicated by high possible particles and situated near the limited optimum points. The algorithm was modified to execute in constant search places, utilizing constant movement of the particles. By using Euclidian norm to describe the locality in the replication process.

The Parallel hybrid intelligence optimization algorithm (PHIOA) based on the qualities of particle swarm optimization with genetic algorithm (GA) proposed by Deng et al. [46]. Based on the fitness values, the projected algorithm separates the individuals into two equation groups. The peak fitness values of the derived group were developed by GAs and the further derived group was developed by the PSO algorithm. The finest number was chosen as a global optimum at every movement which gives improved outcome than both PSO and GAs. It also develops the complete process of the algorithm. To optimize the formation and parameters of the fuzzy neural network was used by PHIOA. The PHIOA could develop the fault accuracy whereas speeding up the convergence method and efficiently remove the early convergence to evaluate with the obtainable processes.

Deng et al. [47] have explained a book two-stage hybrid swarm intelligence optimization algorithm called GA-PSO-ACO algorithm that integrats the developed thoughts of the genetic algorithms, particle swarm optimization and ant colony optimization based on the return for solving the roaming salesman criteria. The complete procedure of hybrid algorithm separated into two ways. On the first way, they formulate use of the randomness, swiftness and integrity of the genetic algorithms and particle swarm optimization to find the substandard resolutions to regulate the allotment of smell in the ACO. On the second way, they formulate use of this compensation of the aligned, clear response and high accuracy of result to apply solving of complete problem.

To develop the active stability, Vijaya kumar et al. [48] have proposed a hybrid method based best location and allocation of UPFC. In this place, the greatest power loss bus was recognized at the most agreeable place for fixing the UPFC, because the generator outage disturbs the power flow force constraints such as power loss, real and reactive power flow. The Artificial Bees Colony (ABC) algorithm used for to decide the optimum place. Rely upon on the violated power flow quantities, to improve the initial operating condition; the Gravitational Search Algorithm (GSA) optimizes the necessary amount of the UPFC.

In power systems, the heavily loaded lines maintain the bus voltage at preferred level, and improve the consistency of the power are amplified uncontrolled interactions. For that cause, the power system requires to be directed in sequence to make use of the available network effectively. FACTS device depends on the advance of semiconductor technology released optimistic newest forecast for maintaining the power flow and extending the load ability of the available power transmission system. Between the FACTS devices, the UPFC is one of the most capable FACTS devices for load flow control considering as it can either simultaneously handle the active and reactive power flow besides the lines in nodal voltage. Some of the uniqueness of the UPFC is, preparing the implementation, it has some realistic responsibilities for discovering the optimal location. In reality, the optimal location of UPFC tends not by erratically, and the matching methodical exploration is not regularly enough. A number of researches have attempt to resolve the optimal location of UPFCs with respect to different intensions and methods like differential evaluation(DE) technique, genetic algorithm(GA), real coded genetic algorithm, hybrid group search optimization(HGSO) method, dynamic hybrid PSO (DHPSO) algorithm, parallel hybrid intelligence optimization algorithm (PAIOA), Artificial bee colony (ABC), Algorithm and gravitational search algorithm(GSA) etc. However, GA has raised one of the important methods for solving the optimization problems but unfortunately, it fails to solve some variant optimization problems. This problem mainly occurs due to ineffectively known fitness functions, it produces awful chromosome blocks even though that only good chromosome blocks traverse. There is no complete proof that GA will get the global optimum. Besides, the PSO technique undergo from the drawbacks of weak local search and slow convergence problem. In addition, ABC techniques need a large number of iterations to make more perfect solutions by that leading to increase the computational cost. The hybridization of ABC algorithm includes computational complexity and unreasonable random generation in that way consuming extended time and getting only low level of accuracy. These mentioned methods cannot be applying to get the quantity and location at the same time for that the hybrid approach is needed. The projected method is explained briefly in the Section 3.

3. Proposed methodology

3.1. UPFC model and power flow equation

In two machine system, Fig. 1 displays the conceptual representation of UPFC. The UPFC contains two switching converters, which are activated from a common dc link offered by a dc storage capacitor [28]. The power flow for a two-bus system depends on the magnitude of bus voltages, their phase difference and the impedance of the transmission line in a power system. At the UPFC terminals the UPFC permits concurrent control of the active and reactive power flow and voltage magnitude. On the other hand, the controller may be placed to control one or more of these parameters in any combination or to control none of them [29]. In Fig. 1, the UPFC is connected between the buses i and j, where shunt converter and series converters are connected to the transmission line via shunt and series transformers. By the shunt converter through the common DC link, the real power demanded by the series converter is delivered from the AC power system. The shunt converter is proficient to deliver or absorb controllable reactive power in both operating modes (i.e., inverter and rectifier) [30]. At a specified value, the independently controlled shunt reactive compensation can be applied to sustain the shunt converter terminal AC voltage magnitude. The equivalent circuit of the UPFC is described in the following Fig. 2.

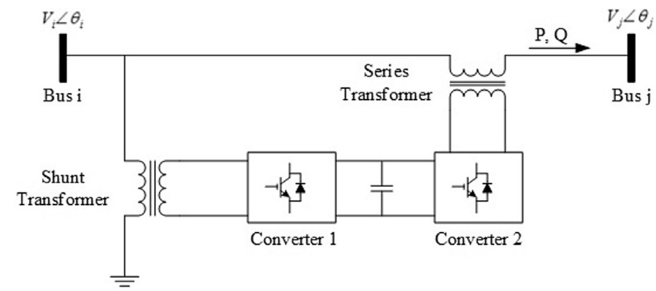

Fig. 1. UPFC installation between the buses.

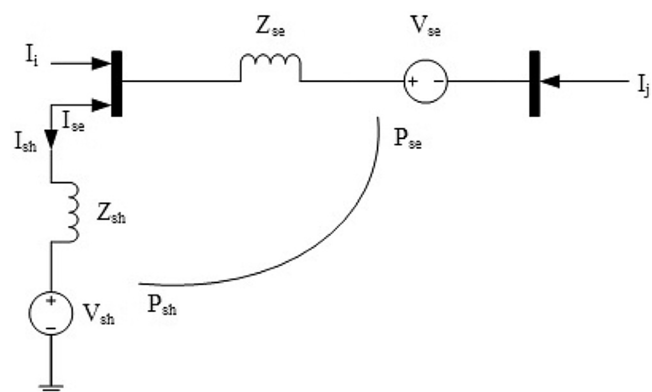

Fig. 2. UPFC equivalent circuit model.

As shown in Fig. 2, based on the equivalent circuit, the active and reactive power equations are described in the following Eqs. (1) and (2). Using the power flow equations, the power injection at each node can be obtained from the equivalent circuit model. The power flow equations from node i to j and j to i are described in the following equations [31,32].

Power flows from i to j:

$$\begin{aligned} P_{ij}(t) = {} & \left(V_i^{2(t)} + V_{kl}^{2(t)}\right) G_{ij}^{(t)} + 2V_i^{(t)} V_{kl}^{(t)} G_{ij}^{(t)} \cos(\alpha_{kl} - \phi_j) \\ & - V_j^{(t)} V_{kl}^{(t)} \left[G_{ij}^{(t)} \cos(\alpha_{kl} - \phi_j) + b_{ij}^{(t)} (\sin\alpha_{kl} - \phi_j)\right] \\ & - V_i^{(t)} V_j^{(t)} \left(G_{ij}^{(t)} \cos\phi_{ij} + b_{ij}^{(t)} \sin\phi_{ij}\right) \end{aligned} \tag{1}$$

$$\begin{aligned} Q_{ij}(t) = {} & -V_i^{(t)} I^{(t)} - V_i^{2(t)} (b_{ij}^{(t)} + B/2) \\ & - V_i^{(t)} V_{kl}^{(t)} \left[G_{ij}^{(t)} \sin(\alpha_{kl} - \phi_i) + b_{ij}^{(t)} (\cos\alpha_{kl} - \phi_i)\right] \\ & - V_i^{(t)} V_j^{(t)} \left(G_{ij}^{(t)} \sin\phi_{ij} - b_{ij}^{(t)} \cos\phi_{ij}\right) \end{aligned} \tag{2}$$

Where, $G_{ij} + jb_{ij} = \frac{1}{R_{ij} + jX_{ij}}$; V_i and V_j are the voltage of the buses i and j respectively and V_{kl} is the voltage of the compensating device, similarly the real and reactive power flow from the bus j to i is given by the following Eqs. (3) and (4) [33].

Power flows from j to i:

$$P_{ji}(t) = V_j^{2(t)} G_{ij}^{(t)} - [V_j^{(t)} V_{kl}^{(t)} G_{ij}^{(t)} \cos(\alpha_{kl} - \phi_j) - b_{ij}^{(t)} G^{(t)} \sin(\alpha_{kl} - \phi_j)] - V_i^{(t)} V_j^{(t)} \left(G_{ij}^{(t)} \cos\phi_{ij} - b_{ij}^{(t)} \sin\phi_{ij} \right) \quad (3)$$

$$Q_{ji}(t) = -V_j^{2(t)} (b_{ij}^{(t)} + B/2) - V_j^{(t)} V_{kl}^{(t)} \left[G_{ij}^{(t)} \sin(\alpha_{kl} - \phi_j) - b_{ij}^{(t)} (\cos\alpha_{kl} - \phi_j) \right] + V_i^{(t)} V_j^{(t)} \left(G_{ij}^{(t)} \sin\phi_{ij} - b_{ij}^{(t)} \cos\phi_{ij} \right) \quad (4)$$

The UPFC power flow equations are used to find the capacity of the UPFC, which is based on the affected location requirements. The UPFC location and capacity selection depends on the dynamic stability constraints or control variables such as power balance condition, voltage stability, power loss, UPFC cost, real and reactive power flow equations. Because the dynamic stability is achieved by maintaining the dynamic stability constraints at secure limits. The required dynamic stability constraints are described as follows [40].

3.3. Power balance equation

The demand of the system and the power loss should get assured by the power generated from the power system. The generators existing in the system may get outage, which means the power loss of the buses is raised, which breaks the power balance condition. In the Eq. (5), the necessary power balance condition is described.

$$\sum_{i=1}^{N_G} P_G^i = P_D + \sum_{j=1}^{N_L} (P_L^j + jQ_L^j) \quad (5)$$

Where, P_G^i is the power generated in the i^{th} bus; P_D is the demand; N_L is the total number of transmission lines; N_G is the total number of generators; P_L^j and Q_L^j are the real and reactive power loss of the jth line. The generators generation limits and demand of the system are described in the following Eqs. (6) and (7) [33].

$$P_G^{i(\min)} \le P_G^i \le P_G^{i(\max)} \quad (6)$$

$$P_D^{(\min)} \le P_D \le P_D^{(\max)} \quad (7)$$

Where, $P_G^{i(\min)}$ and $P_G^{i(\max)}$ are the minimum maximum range of the generators generation limits, $P_D^{(\min)}$ and $P_D^{(\max)}$ are the minimum maximum range of the load demand limits. The bus power loss constraint is discussed in the following section.

3.4. Power loss equation

By the subsequent Eqs. (8) and (9) [33], the real and reactive power loss can be devised.

$$P_L^j = |V_i||V_j||Y_{ij}| \sum_{j=1}^{N_L} \cos(\alpha_{ij} - \delta_i - \delta_j) \quad (8)$$

$$Q_L^j = |V_i||V_j||Y_{ij}| \sum_{j=1}^{N_L} \sin(\alpha_{ij} - \delta_i - \delta_j) \quad (9)$$

Where, $V_i$andV_j are the voltage of the buses i and j; Y_{ij} is the bus admittance matrix; α_{ij} is the angle between the buses i and j; δ_i and δ_j are the load angle of i and j. The real and reactive power flow between the buses is calculated in the following Section 3.3.

3.5. Real and reactive power flow

The real and reactive power at bus $i$can be described by the following Eqs. (10) and (11) [33].

$$P_i = |V_i||V_j| \sum_{n=1}^{N_B} \left(G_{ij} \cos\delta_{ij} + B_{ij} \sin \delta_{ij} \right) \quad (10)$$

$$Q_i = |V_i||V_j| \sum_{n=1}^{N_B} \left(G_{ij} \sin\delta_{ij} - B_{ij} \cos \delta_{ij} \right) \quad (11)$$

Where, V_i and V_j are the voltage of i and j buses respectively; N_B is the total number of buses; δ_{ij} and δ_{ij} are the angle between $i$and $j$buses respectively; G_{ij} and B_{ij} are the conductance and susceptance values respectively. The voltage stability constraint is described in the following Section 3.4.

3.6. Voltage stability

The voltage stability of each bus is the main factor of the dynamic stability, which can be described by the following Eq. (12) [33].

$$\Delta V_i = \frac{1}{\sqrt{l}} \sqrt{\sum_{i=1}^{l} \left(V_i^k\right)^2} \quad (12)$$

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

With,V_{slack} is the slack bus voltage, ΔV_i is the voltage stability index of the bus i, V_i is voltage of the bus, where $i = 1, 2, 3\ldots n$, Z_i is the impedance of the ith bus, P_i and Q_i are the real and reactive power of bus i and$j$ is the number of nodes. The UPFC cost constraint is explained in the following.

3.7. UPFC cost equation

The UPFC cost can be determined by the following Eq. (13) [34].

$$C_{UPFC} = 0.0003S^2 - 0.269S + 188.22\ (\$/KVAR) \quad (13)$$

Where, S is the operating range of the facts devices in MVAR. For making out the optimum location of the UPFC and CS algorithm the suggested hybrid technique is employed into two categories such as FA algorithm for finding the optimum capacity of the UPFC at decreased cost. The FA algorithm based on optimum location of the UPFC determination is briefly described in the following Section 3.6.

3.8. Optimization of UPFC location using FA technique

FA is invented by Xin-She Yang for solving multimodal optimization problem, which works based on the flashing behavior of fireflies [35,36]. The IEEE standard bench mark system load flow analysis has been done by using the Newton Raphson (N-R) method [48]. Initially the normal power flow of the system is analyzed. Then different types of generator fault are introduced in the generator bus, which ensures the dynamic stability constraints away from the secure limit. Meanwhile this state, the FA technique optimizes the position to put the UPFC based on the pointing function, i.e., maximum power loss line. In this method, the maximum loss line is the mainly appropriate line to situate the UPFC. The FA method gets the best position of the UPFC using the input voltage and power loss parameters of the bus system. At the commencement, the input fireflies like voltage at each bus and the power loss are initialized, which is demonstrated in the subsequent Eq. (14).

$$M_i^d = [(V_i, P_{Li})^d], \quad i = 1, 2 \ldots n \tag{14}$$

Where, M_i^d is the input firefly; the input bus voltage is randomly generated with the required n dimensions search space (In every firefly assign the light absorption coefficient γ). The objective function is evaluated for every firefly, using the following Eq. (15).

$$\Phi = Max\left\{|V_i||V_j||Y_{ij}|\sum_{n=1}^{N}\cos(\alpha_{ij} - \delta_i - \delta_j)\right\} \tag{15}$$

According to the objective function, the best fireflies are chosen. After that the solution can be optimized by reorganizing the firefly location by means of the subsequent updating Eq. (16) [37,38].

$$x_i^{t+1} = x_i^t + \beta_o e^{-\gamma v_{ij}^2}(x_i^t - x_j^t) + \alpha\sigma_i^t \tag{16}$$

Where, $\beta_o$is the attractiveness at $v = 0$, the first term is the old firefly position, second term is due to attraction, third term is randomization with vector of random variables σ_i being drawn from a Gaussian distribution, α is the random movement factor and distance between two fireflies i and j at x_i and x_j be a Cartesian distance$v_{ij} = ||x_i - x_j||$. Here, initially α_o and β_o is varied from 0.1 to 1.0 with a step increase of 0.1, γ is varied from 0.01 to 100 with a step increase of 0.01 up to 1 and then 5 up to 100 [38]. The algorithm steps to find the optimum location of the UPFC is described in the following.

Steps to find the optimum location

Step 1: Initialization of the fireflies.

Step 2: Input fireflies are randomly generated at n dimension. Here, the bus voltage and line losses are the input fireflies.

Step 3: Evaluate the fitness function for the random number of the fireflies.

Step 4: Into two groups the solutions are divided, the first groups have the least good solutions and one more group has maximum best solutions.

Step 5: According to the objective function the best solution could be found out and accumulate the current population.

Step 6: Arbitrarily revise the current firefly's population to update position vector and velocity vector of the micro-bats.

Step 7: Assess the objective for the novel firefly's population and among the solution choose the best solution.

Step 8: Find the power loss, voltage, real and reactive power flow of the best solution.

Step 9: Check the termination criterion. If it is satisfied terminate or else go to step 10.

Step 10: Generate the new agents to generate new solutions. Go to Step 3.

Once the above process is over the system is to provide the optimum location of the UPFC at the corresponding generator fault conditions [41]. The affected location parameters were analyzed using the N-R load flow analysis. Based on the optimum location parameters the UPFC capacity is selected using the CS algorithm, which is briefly described in the following Section 3.7.

3.12. UPFC capacity optimization using CS algorithm

In 2009 [37], Xin-She Yang and Suash Deb proposed a CS algorithm which is an optimization algorithm. On the basis of cuckoo's behavior, it functions and the mechanism of Levy flights [38,39] have guided to design searching of optimal solutions. The UPFC capacities at various generator faults conditions with reduced cost are optimized by using the CS algorithm with the help of an objective function. The minimum voltage deviation and UPFC cost is measured as the ideal function for best capability problem. At different fault conditions, the CS algorithm optimization process is allocated on the best position load flow parameters. The CS algorithm produces the different UPFC capacities and those capacities implemented into the best position. The promising capacity for fulfilling the purpose of the function is elected as the best capacity. By using the optimized UPFC capacity is used to restore the dynamic stability constraints at a secure limi [42]. The steps for optimization of UPFC capacity is described in the following.

Steps to find the optimum capacity

Step1: Initialize the input host nest and cuckoo parameters such as power flow equation of the UPFC and bus system voltage.

Step 2: Generate the random population of n host nests using the following Eq. (17).

$$X_i = [X_1, X_2 \ldots X_n] \tag{17}$$

Step 3: Set the iteration count k = 1.

Step 4: Evaluate the objective function for each parameters using the following Function (18).

$$Fitness = \{f_1, f_2\} \tag{18}$$

Where, $f_1 = \sum_{i=1}^{N_B}\left(V_{Normal} - V_i\right)$ and $f_2 = C_{UPFC}$

With $V_i$is the voltage of the bus and V_{Normal} normal voltage.

Step 5: Determine the maximum and minimum fitness of the initial population. From the solutions minimum values are selected as the best solutions [43].

Step 6: Generate the new solution X_i^{t+1} for cuckoo i using levy flight, which can be represented as follows

$$X_i^{t+1} = X_i^t + \alpha \oplus Levy(\lambda) \tag{19}$$

Where, $\alpha > 0$ is the step size, which should be related to the scale of the problem of interest, and the product $\oplus$ means entry-wise multiplication. In this work, we consider Levy flight in which the step-lengths are distributed according to the following probability distribution

$$Levy(\lambda) = t^{-\lambda}, \quad 1 < \lambda \le 3 \tag{20}$$

Step 7: Find the worst nests based on the probability (p_a) and replace the worst nests by new set of solutions.

Step 8: Check the termination criteria. If it is met, then go to step 9, otherwise go to step 3.

Step 9: Terminate the process.

Once the process is completed the network is ready to give the optimum UPFC capacity according to the generator fault. The structure of the proposed hybrid method for optimizing the UPFC location and capacity is described in Fig. 3. The proposed technique is tested in the MATLAB/simulink platform and the results are analyzed in Section 4.

4. Results and discussion

The proposed hybrid method is implemented in MATLAB/Simulink 7.10.0 (R2012a) platform, 4GB RAM and Intel(R) core(TM) i5. The proposed method is tested under different IEEE benchmark systems such as IEEE 30 bus system and IEEE 14 bus system. The effectiveness of the proposed method is observed from a comparative analysis between GSA-Bat, Bat-FA and CS techniques. The FA [51] implementation process consists of following parameters settings like number of fireflies is 5, maximum generation is 100, light absorption coefficient (γ) is 0.5, attractiveness (β) is 0.2 and step size (α) is 0.5. The CS algorithm [53] consists of the following parameters like nest population size is 50, Maximum generation is 100 and the levy flight search constant (λ) is 1. The ABC algorithm [50] modeled based on the parameters like number of bees are 20,

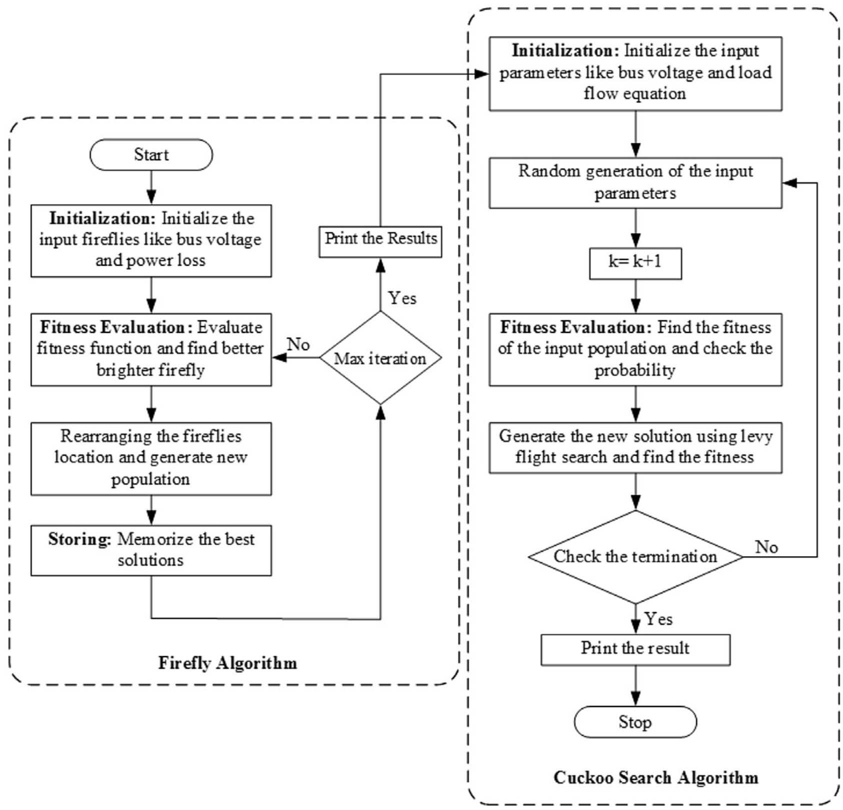

Fig. 3. Structure of the proposed method.

population size is 50 and maximum generation is 100. The GSA [52] parameters are defined like population size is 30, Initial gravitational constant (G_o) is 30 and Constant (β) is 10. The Bat-inspired algorithm [54] parameters are defined like maximum generation is 100, population size is 50, minimum constant value (L_o) is 0, Large constant value (L_m) is 1, Minimum frequency ($f_{\min}$) is 0, Maximum frequency ($f_{\max}$) is 100, Constant (β) is 0.9 and Positive constant (γ) is 0.9. The proposed method is applied in the IEEE 30 bus system and discussed in the following Section 4.1.

4.1. Validation under IEEE 30 bus system

In the section, the performance analysis of proposed method when applied in IEEE 30 bus system is discussed. Fig. 4 gives the layout of the IEEE 30 bus system. It consists of 6 generator buses, 21 load buses and 42 transmission lines. Initially, normal load flow in the IEEE 30 bus system is investigated using N-R load flow analysis. Consequently, generator outages such as single generator problem and double generator problem are arbitrarily introduced in the generator buses, 1, 2, 6, 13, 22 and 27. Such generator faults lead the IEEE 30 bus system to lose its dynamic stability. Load flow analysis can be used to determine the degree of loss of dynamic stability occurs due to generator outage. Table 1 gives the details of power flow induced by the proposed method after the occurrence of single generator problem. The power loss and the cost of UPFC at required capacity are given in Table 2.

Fig. 5 illustrates the normal bus voltage profile of the IEEE 30 bus system. It was obtained from the bus system using N-R method at normal condition. The bus voltage profiles at normal condition obtained after introducing the second bus generator outage and proposed method are illustrated in Fig. 6. This states that N-R method is able to maintain the bus voltage at the stability margin while the power flow constraint is normal. However, instability occurs when there is an issue in the generator. Hence, the proposed

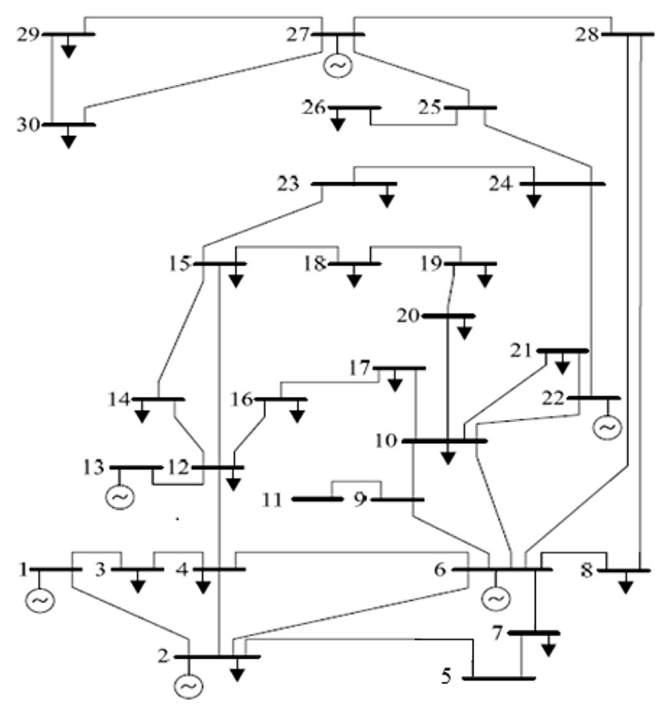

Fig. 4. IEEE 30 bus system structure.

method is used to determine the optimal location and capacity for UPFC to minimize the voltage instability. Fig. 7 illustrates the bus voltage profile after the generator outage in bus 13, when the proposed method is employed. It shows the efficacy of the proposed method in maintaining the voltage profile at the stability margin. Further, the total power loss of the IEEE benchmark system

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

Generator bus no.	Best location		Power flow					
	From bus	To bus	Normal		Generator outage		Proposed method	
			P(MW)	Q(MVAR)	P(MW)	Q(MVAR)	P(MW)	Q(MVAR)
2	2	4	27.410	3.121	26.387	3.708	27.702	4.219
6	8	28	2.971	1.398	1.963	1.3691	5.103	0.841
13	12	16	9.529	4.077	5.564	4.766	10.837	9.411
22	24	25	1.453	3.584	1.380	1.404	3.184	6.9699
27	10	22	4.046	6.617	0.6402	4.803	4.357	8.552

Table 2
Power loss and UPFC cost at single generator problem using the proposed method.

Generator bus no.	Best location		Power loss in MW			UPFC cost($/KVAR)
	From bus	To bus	Normal	Generator outage	Proposed method	
2	2	4	10.809	13.912	6.446	184.9449
6	8	28		13.724	6.433	187.0702
13	12	16		12.795	6.461	189.6639
22	24	25		13.119	6.399	189.9507
27	10	22		13.211	6.446	182.1467

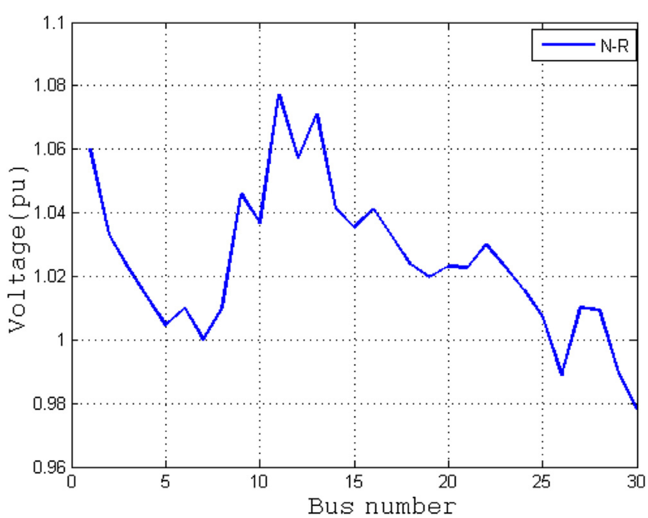

Fig. 5. Normal bus voltage profile.

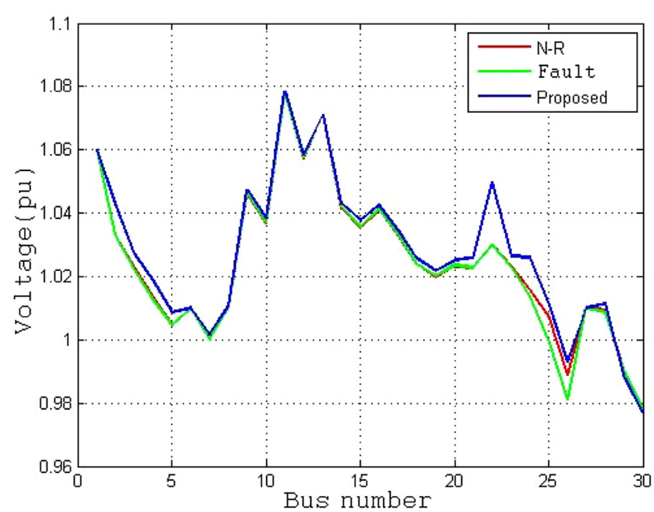

Fig. 7. Voltage profile under 6th bus generator outage.

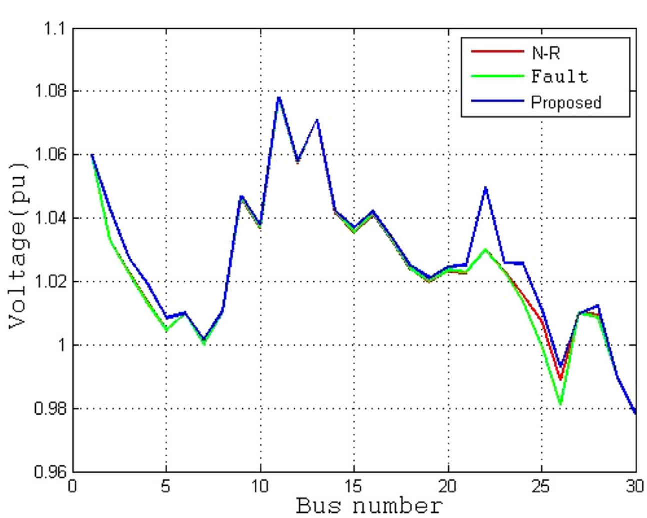

Fig. 6. Voltage profile under second bus generator outage.

is determined in identical generator outage environments. Similarly, outages are introduced in other generators of the bus system and the corresponding outcomes are plotted in Figs. 8–10.

Power losses in IEEE 30 bus system at different conditions such as normal condition, fault condition and with proposed method are described in Fig. 11. It shows the dominating performance of the proposed method. The proposed method effectively reduces the single generator fault power loss. Subsequently, double generator problem is introduced in the IEEE 30 bus system. At this juncture, the power flow of the bus system is affected because of occurrence of generator problems at different instants of time. Table 3 gives the details of double generator problem with proposed method and Table 4 gives the power loss and cost of UPFC with required capacity, when the proposed method is implemented in the bus system having double generator problem.

At various conditions of double generators outage, the voltage profile variation in the bus system with proposed system is determined and plotted in Figs. 12–16. Comparison is made between the voltage profiles of the system with proposed method and fault conditions. The occurrence of double generator fault leads the normal bus voltage profile of the bus system to increase beyond the stability margin. According to the fault range, the proposed method

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

Generator bus no.	Best location		Power flow					
	From bus	To bus	Normal		Generator outage		Proposed method	
			P(MW)	Q(MVAR)	P(MW)	Q(MVAR)	P(MW)	Q(MVAR)
2 and 6	6	7	47.479	2.110	44.327	1.292	46.898	3.715
2 and 13	12	15	19.674	7.796	14.813	8.708	24.454	7.528
6 and 13	12	15	19.674	7.796	16.202	8.216	20.936	3.666
22 and 27	10	20	7.665	3.278	6.801	3.866	8.722	3.762
13 and 27	5	7	23.744	13.824	17.948	11.419	26.427	20.810

Table 4
Power loss and UPFC cost at double generator problem using the proposed method.

Generator bus no.	Best location		Power loss in MW			UPFC cost($/KVAR)
	From bus	To bus	Normal	Generator outage	Proposed method	
2 and 6	6	7	10.809	16.015	6.4548	194.5189
2 and 13	12	15		15.017	6.4317	185.7369
6 and 13	12	15		16.107	6.4693	187.1121
22 and 27	10	20		14.367	6.7082	193.3527
13 and 27	5	7		15.264	6.4313	176.8064

Table 5
Power loss comparison at single generator problem using different techniques.

Fault Generator bus no.	Best location		Power loss in MW						
	From bus	To bus	Normal	Generator outage	Firefly	ABC-GSA	GSA-Bat	Bat-FA	FA-CS
2	12	15	10.809	14.005	9.884	9.498	8.718	7.3961	6.646

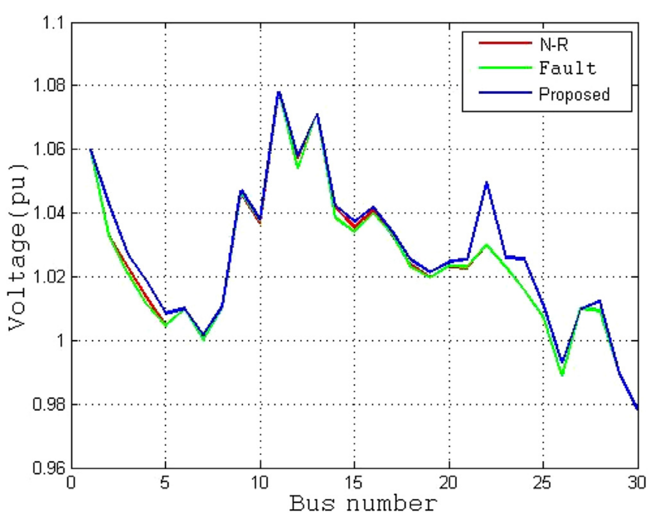

Fig. 8. Voltage profile under 13th bus generator outage.

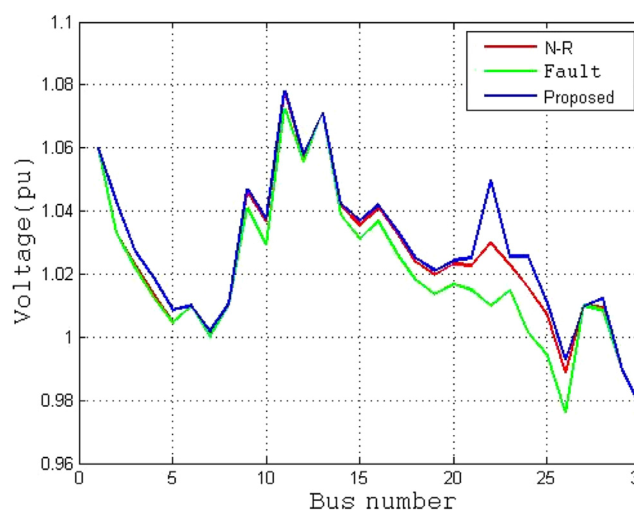

Fig. 9. Voltage profile under 22nd bus generator outage.

identifies the location and the capacity of the UPFC with reduced cost. The approach has been used to resolve the voltage instability problem. The power loss of the IEEE 30 bus system at fault condition and using proposed method is explained in Fig. 17. In the figure, normal power loss of the IEEE 30 bus system is observed as 10.809 MW. It may rise to 16.107 MW, when there is a double generator outage problem. The increased power loss can be mitigated by selecting the optimal capacity and location for UPFC at reduced cost using the proposed method, i.e. 6.4313 MW with 176.8064 $/KVAR. Then the effectiveness of the proposed method is analyzed by comparing its numerical results with the techniques such as ABC-GSA, GSA-Bat, Bat-FA, CS and FA. The power losses in IEEE 30 bus system, while using different techniques, are described in Table 5.

Diverse methods such as ABC-GSA, GSA-Bat, Bat-FA and CS are applied in IEEE 30 bus system with single generator problem. The voltage profiles and power losses are obtained and compared in Figs. 18 and 19, respectively. From the graphs, we come to know that the proposed technique efficiently chooses the optimum location and capacity of the UPFC in relation to the other optimization methods. By preserving the dynamic stability, the proposed technique maintains the voltage profile of the IEEE 30 bus system at the stability margin and reduces its power loss, almost to 6.646 MW. The efficiency of the proposed is also demonstrated in IEEE 14 bus system and it is discussed in Section 4.2.

4.2. Validation of IEEE 14 bus system

The section details the employment of proposed technique in IEEE 14 bus system, which has two generator buses. One among the two generators is in slack bus and the remainder is in the second

Table 6
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)
Bat-FA	2	6	11	8.287	8.898	8.232	7.928	6.265	7.856
Proposed	2	2	3	73.396	5.9362	72.6441	0.82124	77.7233	5.5308

Table 7
Power loss comparison using different techniques.

Fault Generator bus no.	Best location		Power loss in MW						
	From bus	To bus	Normal	Fault	Firefly	ABC-GSA	GSA-Bat	Bat-FA	FA-CS
2	4	5	13.592	15.428	12.924	11.175	10.275	9.623	8.720

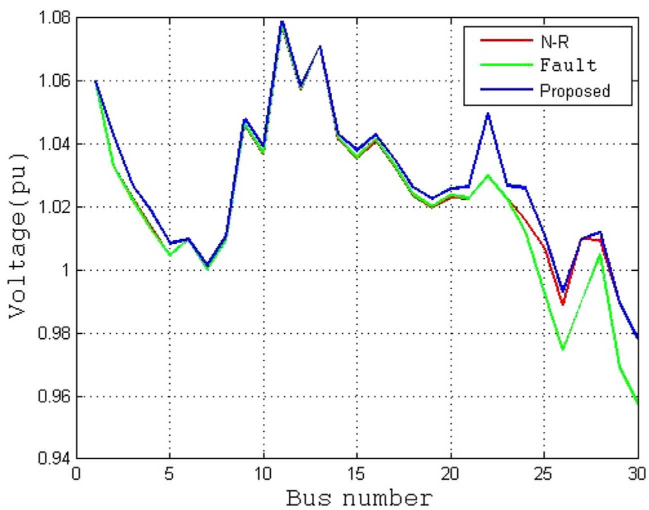

Fig. 10. Voltage profile under 27th bus generator outage.

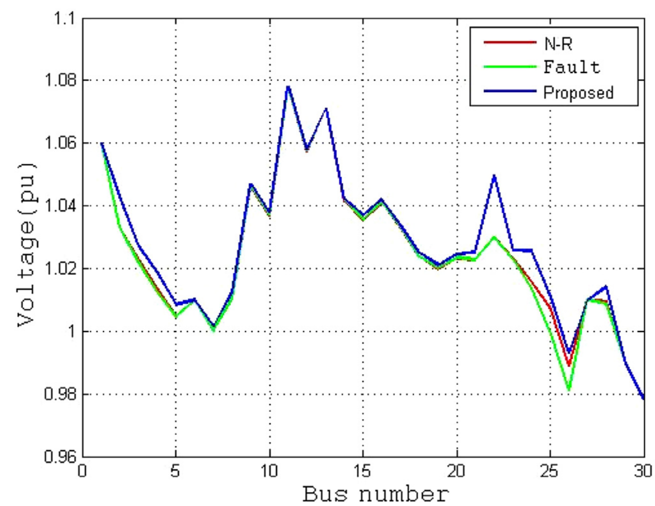

Fig. 12. Voltage profile during generator outage at buses 2 and 6.

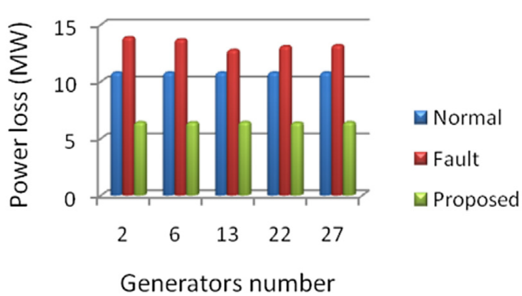

Fig. 11. Power loss comparison at single generator outage.

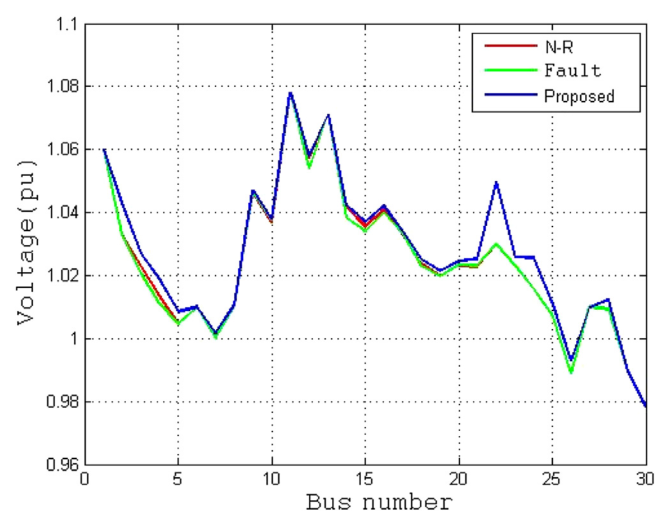

Fig. 13. Voltage profile during generator outage at buses 2 and 13.

bus. Fig. 20 illustrates the structure of IEEE 14 bus test system. The load flow solution at normal condition is estimated by means of N-R load flow analysis, which recognizes the entire system load flow parameters and the dynamic stability constraints. The single generator problem is introduced in the IEEE 14 bus system. This increases the complexity of the system power flow and control variables and so voltage instability and increased power loss occur. However, the problem can be overcome by identifying the fault location and by connecting UPFC with appropriate capacity. Table 6 compares the power flow using different techniques, when single generator problem is introduced. The single generator problem power loss comparison is tabulated in Table 7.

The normal voltage profile of IEEE 14 bus system obtained using N-R load flow analysis is illustrated in Fig. 21. The voltage profile of the IEEE 14 bus system at single generator problem under different type of topology is described in Fig. 22. In the figure, voltage profile from the proposed method is compared with the ABC-GSA, GSA-Bat, Bat-FA and CS techniques. It is clearly shown that the novel technique considerably enhances the voltage profile from the normal value. The power loss by means of the proposed technique is analyzed with the different techniques such as ABC-GSA, GSA-Bat, Bat-FA and FA shown in Fig. 23. The figure demonstrates that the proposed technique preserves the voltage profile at the dynamic stability margin, when compared with the conventional

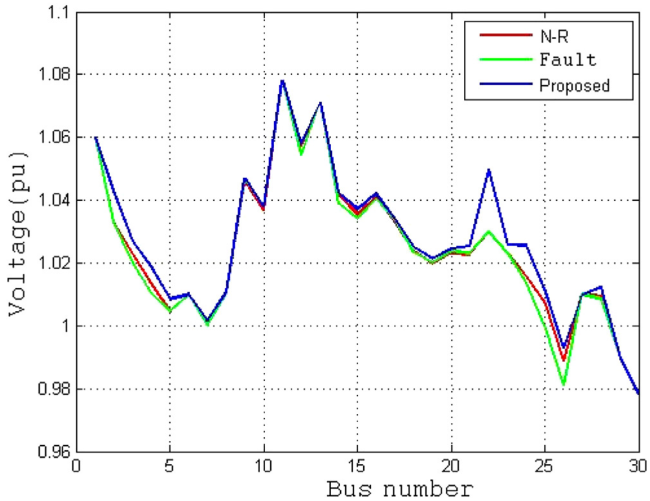

Fig. 14. Voltage profile during generator outage at buses 6 and 13.

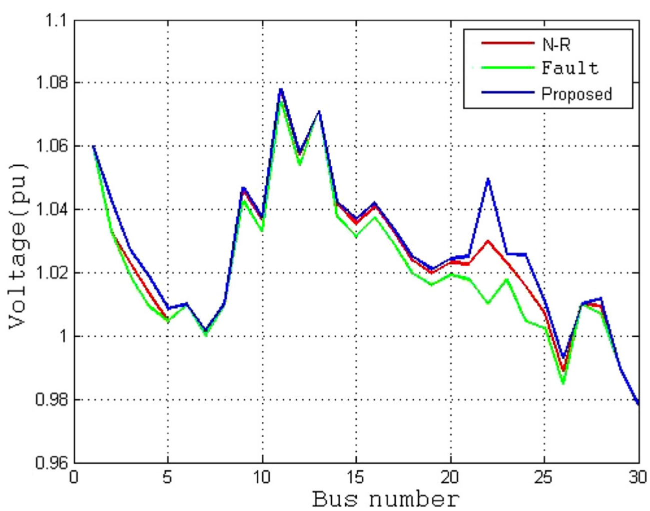

Fig. 15. Voltage profile during generator outage at buses 13 and 27.

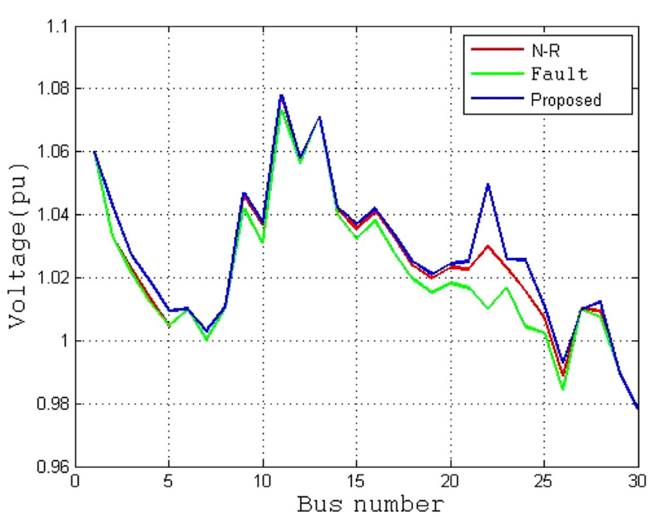

Fig. 16. Voltage profile during generator outage at buses 22 and 27.

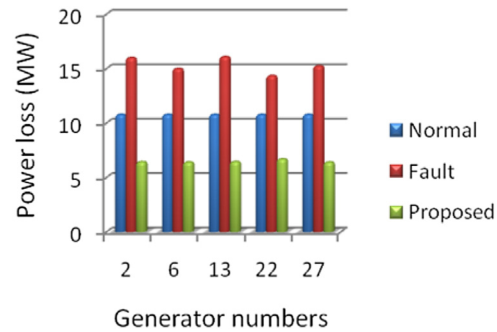

Fig. 17. Power loss comparison at double generator outage.

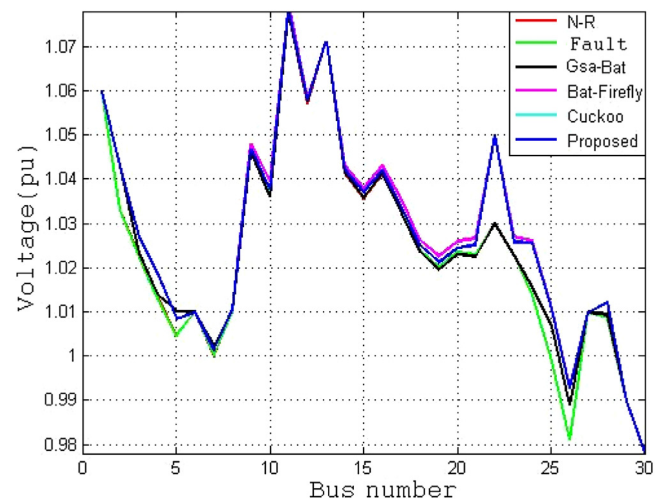

Fig. 18. Voltage profile comparison at single generator problem.

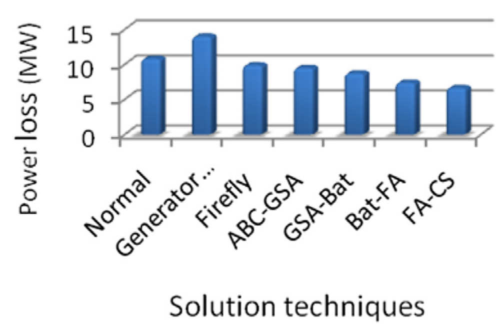

Fig. 19. Power loss comparison at single generator problem.

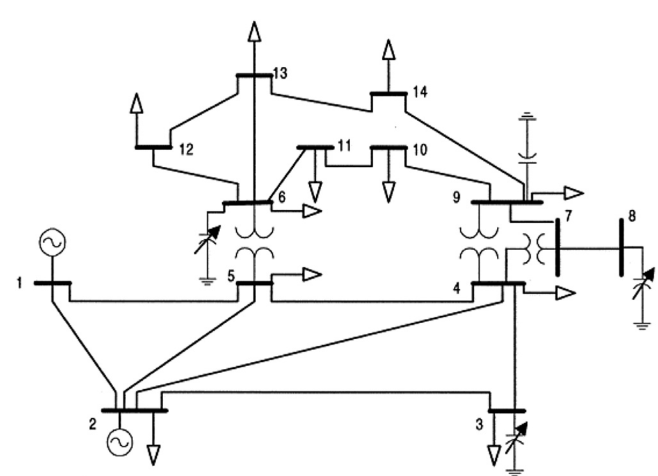

Fig. 20. IEEE 14 bus system structure.

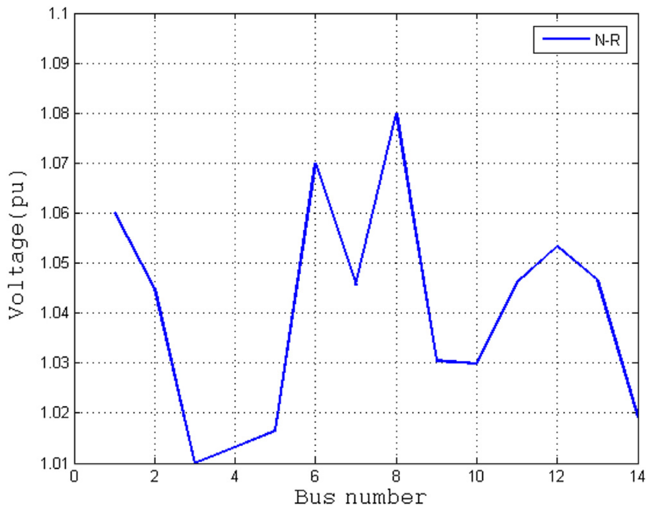

Fig. 21. Normal bus voltage profile.

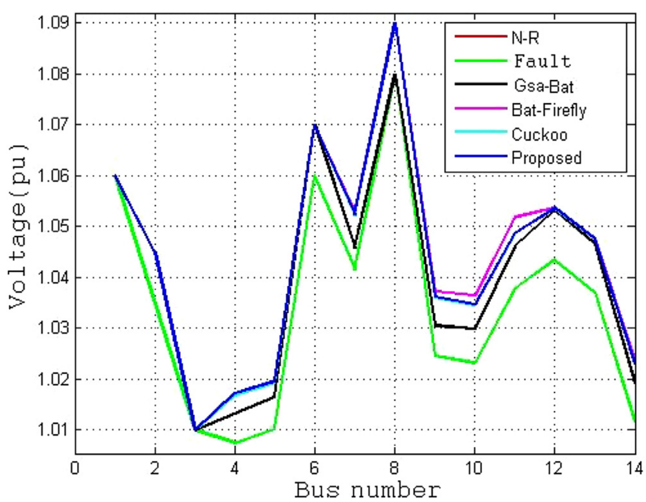

Fig. 22. Voltage profile comparison at single generator problem.

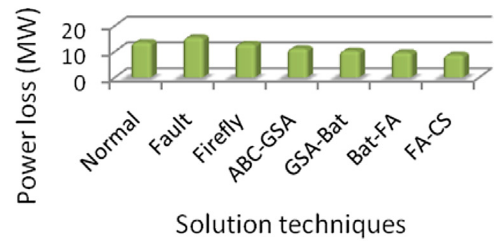

Fig. 23. Power loss comparison at single generator outage problem.

Table 8
Performance evaluation of the proposed method.

Techniques	RA in (%)
Bat-GSA	9.665
Bat-FA	11.995
CS	10.721
Proposed	20.115

techniques. The proposed technique decreases the power loss of IEEE 14 bus system to 8.720 MW. It is relatively better than GSA and Bat algorithms. The voltage graphs dataset given in Figs. 18 and 22 are utilized to find the Voltage Deviation Percentage (VDP) of the techniques. The voltage stability performance of different techniques is calculated using the following Eq. (21).

$$VDP(i) = \frac{V_N(i) - V_{ST}(i)}{V_N(i)} \times 100, \quad i = 1, 2, 3 \ldots N_B \tag{21}$$

Where, $VDP(i)$ is the voltage deviation percentage of bus i; $V_N(i)$ is the normal voltage of the bus i and $V_{ST}(i)$ is the solution technique voltage of the bus$i$. Based on the VDP calculation, Figs. 24 and 25 are plotted.

The calculating time and the recital of the projected algorithm are better that those of the Bat-GSA, Bat-Firefly and CS technique for these two criteria, which are describes in Fig. 26. The Bat-GSA has high number of calculated time between the illustrated optimization algorithms. The calculated time of the Bat-FA algorithm is 8.4412 s and 14.2232 s for IEEE 14 and 30 bus systems simultaneously. The computation time for IEEE 14 bus system as 6.6642 s and for IEEE 30 bus system for 14.2214 s, in CS techniques. In this manner, the projected method shortens the calculated time compared

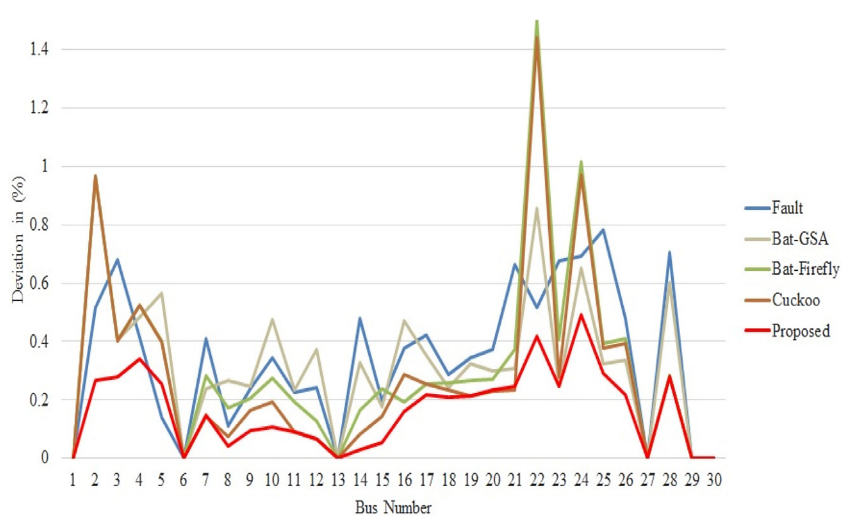

Fig. 24. VDP of IEEE 30 bus system.

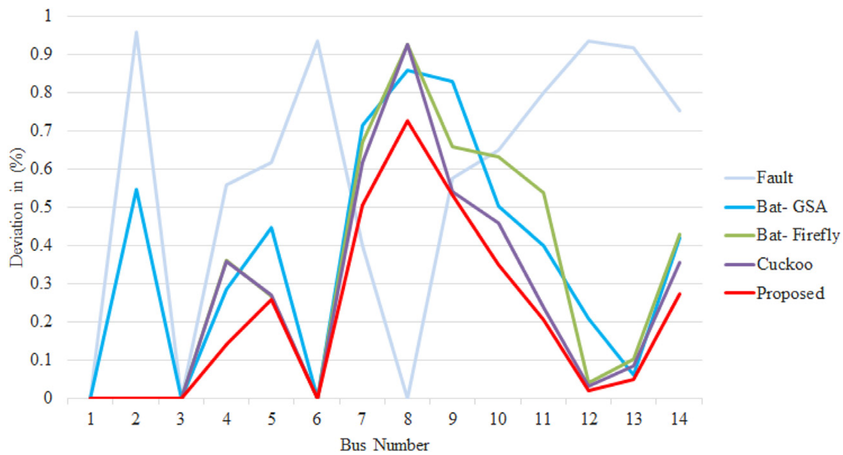

Fig. 25. VDP of IEEE 14 bus system.

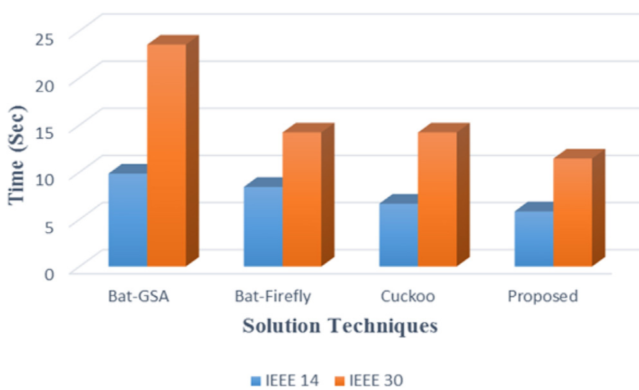

Fig. 26. Computational time comparison.

to the remaining techniques. The calculated reduction time verified the reduced difficulties of the projected method. From the acquired results, the Results Accuracy (RA) is driven for all the techniques using Eq. (22).

$$RA = \frac{ML - NL}{NL} \times 100 \quad (22)$$

Where, *ML* and *NL* are the best minimum power loss and normal power loss simultaneously, the RA for various methods are indicates in the Table 8. In the IEEE 30 bus system, we have to get the fraction correctness of the solutions at the time of optimization process. The usefulness is recognized by the high RA values. In this equation, the Bat-GSA has 9.665% RA value from the best minimum power loss and normal power loss, when in fact Bat-FA has somewhat higher RA value than the remaining techniques i.e., 11.995%. But the projected hybrid technique contributes high RA value in the optimization process i.e., 20.115%. In these things, we can easily examine that the projected method includes minimum power loss at the time of fault situation. It was clearly explaining that the projected method successfully minimizes the fluctuations from the normal condition. The solutions acquired from the comparative analysis confirm the controlling process of the projected techniques over the typical techniques in terms of preserve the vigorous support of power system.

5. Conclusion

The paper proudly proposes the hybrid approach based dynamic stability enhancement of the power system using the UPFC. The advantage of the proposed method was highlighted in the enhanced searching ability and the lesser complexity in achieving the optimal solutions. The IEEE 30 bus and IEEE 14 bus systems were utilized for testing the proposed method performance. In the bus system different types of generator faults were created and the most affected location was determined by using the FA technique. The affected dynamic stability constraints such as voltage, power loss, real and reactive power were restored into secure limits by locating the optimum capacity of the UPFC, which, in turn, was optimized by using the CS algorithm. The dynamic stability specifications were founded by the applying of different experiment bus systems into projected method. The dynamic stability specifications were determined for normal condition, fault condition and projected method. The projected method arithmetical solutions were corrected by the comparison analysis with those of the various techniques like ABC-GSA, GSA-Bat, and Bat-FA and CS algorithms. The VDP calculation also evaluated by the projected hybrid approach dynamic stability enhancement. The comparison analysis confirms that the projected method is a useful technique to elaborate the dynamic stability of the power system and is capable over the remaining techniques.

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Bairu Vijay Kumar was born in Warangal, India, in April 1978. He received the B. Tech degree in Electrical & Electronics Engineering, M. Tech degree in Power Systems Engineering and Ph.D in Electrical Engineering from National Institute of Technology, Warangal, India, in 2002, 2008 and 2015 respectively. His Current research interest includes Enhancement of Power System Stability using FACTS devices and AI techniques. He is a member of the Institution of Engineers, India,

N. V. Srikanth (Nandiraju Venkata srikanth) was born in Vijayawada, India, in 1966. He received the B. Tech degree in Electrical &Electronics Engineering from College of Engineering, Osmania University, Hyderabad, India, in 1988, and his M. Tech and Ph.D degrees in Power Systems Engineering from National Institute of Technology, Warangal, India, in 1999 and 2007, respectively. Currently, he is an Associate professor in the Department of Electrical Engineering, National Institute of Technology, Warangal, India. He has 25 papers in journals, and International/National conferences. His areas of research interests include Fuzzy logic applications in power systems, power system stability& control, HVDC transmission systems, and their impact on power system stability. Dr. Srikanth is an active member in many professional organizations. He is a member of IEEE, a member of the Institution of Engineers, India, and a lifetime member of ISTE.