A Hybrid Ifcsa Approach For Optimal Location And Capacity Of Upfc To Improve Power System Dynamic Stability

T. Jagan Mohan Raju, .G. Tulasiram, Soumya K

Abstract: In this manuscript, the hybrid technique based on optimal location and the capacity of UPFC to improve the dynamic stability of the power system are proposed. The proposed hybrid technique is the joint execution of both the Improved Fruitfly Algorithm (IFA) and Crow Search Algorithm (CSA) and hence it is said to be as IFCSA. Here, the searching behavior of the fruit flies is enhanced by the crossover and mutation technique and hence it is termed as improved FA (IFA) technique. The novelty of the proposed hybrid technique is exemplified in the improved searching ability and reduced complexity. In this regard, the generator fault affects the dynamic stability of the system constraints such as voltage, power loss, real and reactive power. IFA technique optimizes the maximum power loss line as the UPFC suitable location. By using the CSA, the affected location parameters and dynamic stability constraints are restored into secure limits using the UPFC optimum capacity and accordingly the CSA reduces the UPFC cost. The attained UPFC capacity has been located in the affected location and the system power flow is analyzed. The proposed hybrid technique is implemented in the MATLAB/Simulink platform and tested under standard bench mark system. The proposed method performance is evaluated by comparison with various existing techniques such as ABCGSA and FOAPSO algorithms. The comparison results invariably prove the proposed hybrid technique effectiveness and confirm its potential to solve the related issues.

Index Terms: Dynamic Stability, Power loss, real power, reactive power, UPFC, Voltage.

1 INTRODUCTION

In transmission and generation as power demand develops quickly and expansion is confined with the restricted resources accessibility and power systems are today significantly more loaded than before because of the strict environmental constraints [1]. This makes the power systems be worked close to their stability limits. From the previous three decades, the power system engineers met different difficulties in the solidness of the power system [2, 3]. In power systems stability, the significant concern is the voltage stability [4, 5]. To control the reactive power demand it ends up troublesome for that framework when a bulk power transmission network near the utmost of voltage stability [6]. In an interconnected power system network at different locations because of the sag in reactive power is the primary driver of voltage instability [7, 8]. In spite of the fact that the voltage stability issue concerns the whole power system it more often than not has a one basic region inclusion [9]. Small disturbance voltage stable is at a given operating state a power system yet in the event that, following any small disturbance, for example, unbalanced loads and load varieties, voltages near loads are indistinguishable or near the pre-disturbance values. System faults, circuit contingencies or loss of generation to keep up steady voltages following large unsettling influences voltage stability alludes to the system's capacity [10]. At specific focuses prompting voltage sag after such a disturbance may come to the pre-aggravation esteems or not at different purposes of voltages [11].

- T. Jagan Mohan Raju Assistant Professor, EEE Department, University College of Engineering , Kakatiya University, Kothagudem, Telangana, India, E-mail: tjmraju@gmail.com
- Prof .G. Tulasiram, Professor, Electrical and Electronics Engineering, Jawaharlal Nehru Technological University Hyderabad, Kukatpally, Hyderabad, Telangana, India, E-mail: das_tulasiram@jntuh.ac.in
- Soumya K, Associate Professor, Dept of EEE, AKITS, Kothagudem, India

A serious issue is as yet being considered because of weather conditions the line outages caused and reason for power system instability is negligible however in India, power transmission and distribution systems have been centralized. During such circumstances reactive power deficiency and voltage degradation is serious [12]. Here to survey the voltage stability of an interconnected power system influenced by such a contingency there is a need to throw light [13]. Improvement of voltage profile and voltage stability margin of the system is finished by utilizing the FACTS devices [14]. With the broadcasting line by embeddings active and reactive voltage component in series among them that can deal with the power flow in transmission line utilizing UPFC is one of the devices of the facts devices. By the presence of FACTS devices improving the utilizable capacity of surviving transmission line are discharged and the novel open doors can control the power of the system [15]. Accordingly the system load ability is raised by an UPFC instrument optimal location license to control its power flows for a meshed network. Then again, past which this load ability can never be, upgraded amid the set number of tools [16]. In a power system the optimal location and optimal capacity of a predetermined number of FACTS is a setback of combinatorial study [17]. Genetic algorithms, simulated annealing, and tabu search are different sorts of optimization algorithm have been connected to work out this kind of issue [18, 19]. Be that as it may, hybridization of algorithm (more than one) has been demonstrated from general issues to the issues of the power system, for its exceptional execution [20].

2 RECENT RESEARCH WORK: A BRIEF REVIEW

Much research works have already existed in the literature which depended on improving the power transfer capability of power system. A portion of the works is inspected here. B. Kumar et al. [21] have proposed 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. FA enhances the maximum power loss line as the UPFC reasonable location. Utilizing the UPFC optimum capacity the influenced location parameters and dynamic stability constraints were reestablished into secure limits and has been optimized by CS algorithm. In power systems a multi-objective framework for optimal location and parameters setting of an UPFC was utilized by S. Galvani et al. [22]. All the while the system predictability maximization AND minimization of active power loss were considered. Utilizing point estimate technique the load and wind generation uncertainty were displayed. Utilizing NSGA-II the formulated multi-objective issue was understood and utilizing IEEE 57-bus test system was reenacted. In power system to expand damping of the electromechanical oscillations utilizing the system critical modes and residue factor utilizing the placement of multi unified power flow controllers (UPFCs) was introduced by A. Motiebirjandi et al. [23]. Utilizing residue factor their optimal locations were resolved and to decide the number of UPFCs the critical modes were utilized for this reason. Supplementary controller was structured and connected to control the model parameters. Through transmission lines to give flexible power flow control dependent on FLC to beat the issues of the existing UPFC controllers an UPFC control strategy was created by F. Albatsh et al. [24]. Through the power system network on improving the power flow control so as to adequately explore the execution of UPFC, a hardware prototype of UPFC utilizing FLC has been created. N. Nahak et al. [25] have introduced in power system a novel dual optimized controller to damp intra plant and inter area oscillations. By a novel hybrid differential evolution-grey wolf optimizer (DE-GWO) the parameters of controllers were tuned. There by maximizing the efficacy of controller and UPFC the dual optimized controller simultaneously controls two independent variables of UPFC. G. Kannayeram et al. [26] have structured in power systems to improve the damping of low frequency oscillations an adjusted non-dominated sorting genetic algorithm-II (MNSGA-II) based optimal damping control of unified power flow controller (UPFC). Under a wide range of operating conditions subsequently minimizing the integral squared error (ISE) of speed deviation and input control signal (u) the robust damping of UPFC controller design was figured as a multi-objective optimization issue. Through nonlinear time domain simulation and eigen value analysis the viability of the proposed controller was affirmed.

2.1 Background of the Research Work

According to the recent research work, it was verified that several studies have been developed in the reactive power compensation and stability analysis of the power distribution system is an important contribution factor. Since the flow of heavily loaded lines sustain the bus voltages at desired levels and increased the uncontrolled exchanges in power systems. For that reason, power systems need to be supervised in sequence to make use of the obtainable network competently. 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 practically, the optimal location of UPFC tends not by randomly, and the matching methodical exploration is not frequently adequate. Several researches have effort to solve the optimal location of UPFCs with respect to different purposes and methods. Some of the optimization algorithms are introduced to determine the location and size of UPFC such as Firefly algorithm and Cuckoo Search (CS) algorithm, Fuzzy logic controller (FLC), Differential Evolution-Grey Wolf Optimizer (DE-GWO), modified non-dominated sorting genetic algorithm-II (MNSGA-II) and etc. The firefly and cuckoo search algorithms are that they usually have good efficiency for certain problems and require only a small number of iterations. However, one of their main disadvantages is bad accuracy, low convergence rate, and high probability of being trapped in local optima because they are local search algorithms. A fuzzy logic controller based UPFC is designed in order to improve the transient performance. There is a chattering problem associated with the sliding mode controller which affects the accuracy of the controller during power system disturbances. Although many research have been focusing on developing UPFC control, there is a general lack of optimal capacity and location at the same time hence the hybrid approach is needed. In literature very few works are presented to solve this problem and the presented works are ineffective. These discussed drawbacks and problems are motivated to do this research.

3 PROPOSED METHODOLOGY

3.1 UPFC Connected Bus System

One of the FACTS devices is the UPFC which give control of the magnitude of the voltage, flow of real and reactive power and the system dynamic stability is improved [29]. Series and shunt converter are the two switching converters of UPFC which are associated with the common DC link. For coordinating the load voltage through the coupling transformer injecting controlled proportion of voltage the converters are joined. At the point when the series converter is associated in between the node of sending and receiving end the shunt converter is fused with the node of sending end. In series with the transmission line the series converter infuses an AC voltage with controllable magnitude and phase angle. Through the DC interface the active power between the two converters must be adjusted and when the active power is dismissed the UPFC can't create or ingest the active power. Anyway the converters give an autonomous shunt reactive compensation for the transmission line and can produce or retain the reactive power. Fig 1 shows the structure of UPFC.

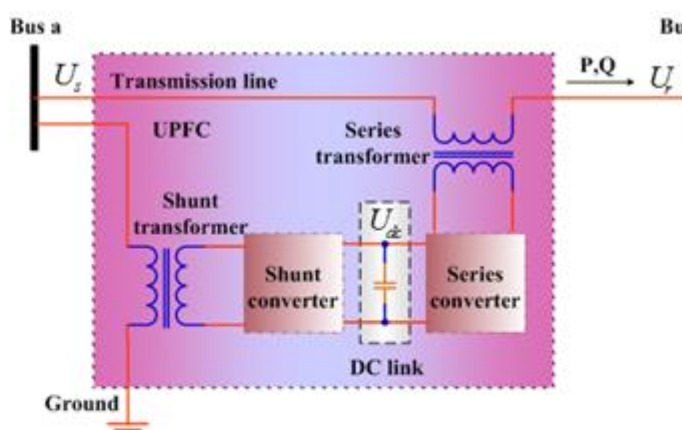

Fig. 1. *Basic Structure of UPFC*

In Fig 1, the UPFC is connected between the buses a and b where converters are connected to the transmission line by means of transformers. From the AC power system the real power demanded by the series converter is conveyed by the shunt converter through the common DC link. In operating modes, for example, inverter and rectifier to convey or retain controllable reactive power the shunt converter are capable [30]. At a predefined value, the freely controlled shunt reactive compensation can be connected to support the shunt converter terminal AC voltage magnitude.

3.2 Power Flow Equation of UPFC

An UPFC can be defined by two voltage sources specifying fundamental components of output voltage waveforms of the two coupling transformers [31]. Fig 2 shows the equivalent model of the UPFC. The equation for the injected voltage into the transmission line by the UPFC is defined as follows,

$U_{inj}^{se} = re^{m\theta}U_a$ (1)

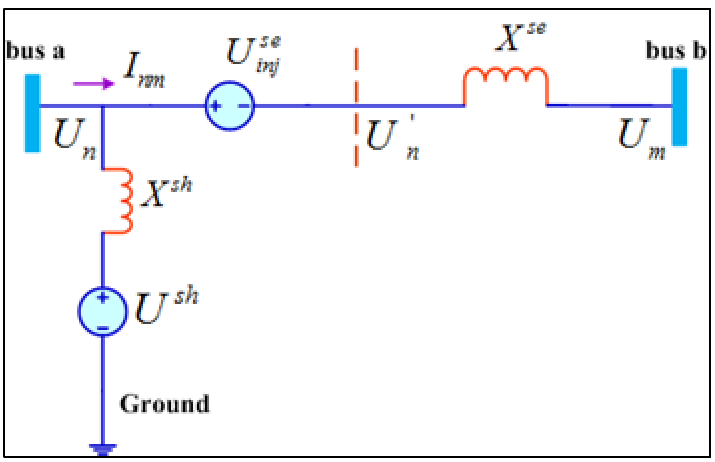

***Fig. 2.** Equivalent model of UPFC*

Here, injected voltage into the transmission line is represented as U_{inj}^{se}, the series voltage source magnitude is indicated as r, the angle of series voltage source is θ and the system voltage can be specified as U_a. The following specified limits for the parameters is given as follows,

$0 \le r \le r_{\max}$ *and* $0 \le \theta \le 2\pi$ (2)

The series injected current in the transmission line is formulated by,

$C_{inj}^{se} = -jm^{se}U_{inj}^{se}$ (3)

Here, series injected current in the transmission line is specified as m^{se}. Then the, $m^{se} = 1/X^{se}$ and C_{inj}^{se} can be formulated by the two auxiliary buses a and b in an injection powers.

$S_a^{se} = U_a(-U_{inj}^{se})$ (4)

$S_b^{se} = U_a(-U_{inj}^{se})$ (5)

Here, injected power can be specified as S_a^{se} and S_b^{se}. The real and imaginary components is represented as follows,

$S_a^{se} = P_a^{se} + jQ_a^{se}$ (6)

Here,

$P_a^{se} = rm^{se}U_a^2 \sin\theta$ (7)

$Q_b^{se} = rm^{se}U_a^2 \cos\theta$ (8)

Similarly, the real and imaginary components of equation (6) is represented as follows,

$S_b^{se} = P_b^{se} + jQ_b^{se}$ (9)

Here,

$P_b^{se} = rm^{se}U_aU_b \sin(\varphi_a - \varphi_b + \theta)$ (10)

$Q_a^{se} = rm^{se}U_aU_b \cos(\varphi_a - \varphi_b + \theta)$ (11)

The apparent power supplied by the series converter can be calculated as follows,

$S^{se} = U_{inj}^{se}C_{ab} = rm^{b\theta}U_a\left(\frac{U_a - U_b}{jX^{se}}\right)$ (12)

Here, the injected current at the two auxiliary buses a and b can be specified as C_{ab}. The active and reactive power is supplied in the series converter and can be equated as follows,

$S^{se} = P^{se} + jQ^{se}$ (13)

Here,

$P^{se} = rm^{se}U_aU_b \sin(\varphi_a - \varphi_b + \theta) - rm^{se}U_a^2 \sin\theta$ (14)

$$Q^{se} = -rm^{se}U_aU_b \cos(\varphi_a - \varphi_b + \theta) + rm^{se}U_a^2 \cos\theta + r^2m^{se}U_a^2 \quad (15)$$

Here, the real part of the apparent power is expressed as P^{se}, the imaginary part of the apparent power provided by the series converter can be specified as Q^{se}. Within the acceptable limits the principle capacity of the reactive power is to keep up the voltage level at bus a. The problem formulation of UPFC is depicted in the accompanying section.

3.3 Problem Formulation

UPFC optimal capacity and location tries to optimize the power system steady state execution regarding an objective function while fulfilling the constraints of the dynamic stability. Optimal power flow is formulated as an optimization problem and which is given by,

$Min\ j(x,u); \frac{1}{m(x,u)}$ (16)

Subject to $n(x,u) = 0\ \ i(x,u) \le 0$

Here, the objective function of the whole generation cost is specified as $j(x,u)$, total network loss and deviation in the voltage can be specified as $m(x,u)$ it is said to be as the objective of maximum power loss in the network, the set of equality constraints for the specified operating condition can be expressed as $n(x,u)$, set of inequality constraints for the specified operating condition at the operating limits of the constraints can be specified as $i(x,u)$, set of control variables and dependent variables of the generator and load buses are expressed as x *and* u. With the help of UPFC power flow equations the capacity of the UPFC is evaluated based on the influenced requirements of location. In the following section the required objective of the dynamic stability and the constraints are explained [32].

3.3.1 Power Balance Constraint

$$\sum_{a=1}^{N_g} P_{gen}^{a} = P_{demand} + \sum_{b=1}^{N_l} (P_l^b + jQ_l^b) \qquad (17)$$

$$P_{gen}^{a(\min)} \le P_{gen}^{a} \le P_{gen}^{a(\max)} \quad (18)$$

$$P_{demand}^{\min} \le P_{demand} \le P_{demand}^{\max} \qquad (19)$$

Here, the generated power in the bus a is specified as P_{gen}^{a}, power demand is the P_{demand}, total number of the transmission lines and generators as N_g and N_l, real and reactive power loss of the bus b is specified as P_l^b and Q_l^b, the minimum and maximum range of generation limits can be indicated as $P_{gen}^{a(\min)}$ and $P_{gen}^{a(\max)}$, the minimum and maximum range of load demand limits as $P_{demand}^{\min}$ and $P_{demand}^{\max}$.

3.3.2 Power Loss Constraint

$$P_l^m = |U_a||U_b||Y_{ab}| \sum_{b=1}^{N_l} \cos(\theta - \varphi_a - \varphi_b) \qquad (20)$$

$$Q_l^m = |U_a||U_b||Y_{ab}| \sum_{b=1}^{N_l} \sin(\theta - \varphi_a - \varphi_b) \qquad (21)$$

Where, the bus admittance matrix is defined as Y_{ab}, the angle between the buses a and b as θ, the load angle of buses a and b is specified as φ_a and φ_b.

3.3.3 Voltage Stability

$$\Delta U_a = \frac{1}{\sqrt{l}} \sqrt{\sum_{a=1}^{l} (U_a^k)^2} \qquad (22)$$

Here, $U_a^k = U_{sl} - \sum_{a=1}^{a} z_a \left(\frac{P_a - jQ_a}{U_a} \right)$

Here, the voltage stability index of the bus a can be specified as ΔU_a, the voltage of slack bus can be represented as U_{sl}, the impedance of the bus a is indicated as z_a, the real and reactive power of buses a and b can be indicated as P_a and Q_a, number of nodes is expressed as j.

3.3.4 Cost Equation

$$Cost_{UPFC} = 0.0003s^2 - 0.269s + 188.22(\$/KVAR) \quad (23)$$

Here, the cost of UPFC is expressed as $Cost_{UPFC}$; the operating range of FACTS devices in MVAR can be specified as s. Fig 3 shows the block diagram of optimal location and capacity of UPFC in the power system.

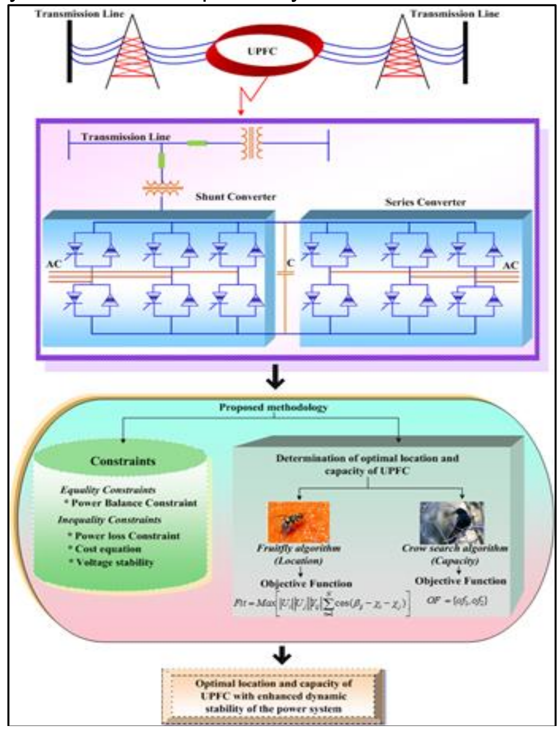

***Fig. 3**. Block diagram of optimal location and capacity of UPFC in the power system using proposed hybrid technique*

3.3 UPFC Location Optimization Using IFA Technique

The Fruitfly Algorithm (FA) is one of the latest meta-heuristic methods which are inspired by the foraging behavior of fruit flies or vinegar flies in finding food [27]. The FA prevails in nonlinear frameworks with high accuracy, which can insert and extrapolate arbitrary information. Here, the FA searching behavior is enhanced by the crossover and mutation operator and hence it is termed as Improved FA (IFA) technique. By using the Newton Raphson (N-R) method the IEEE standard bench mark system load flow analysis has been done [3]. Initially the normal power flow of the system is analyzed. Then in the generator bus different types of fault in the generator are introduced, which ensures the dynamic stability constraints away from the secure limit. Meanwhile this state, based on the objective function the IFA technique optimizes the position to locate the UPFC, i.e., maximum power loss line. In this method, to locate the UPFC the maximum power loss line is the mainly appropriate line. Using the input voltage and power loss parameters of the bus system the IFA method gets the best position of the UPFC. At the commencement, the input fruit flies like voltage at each bus and the power loss are initialized, which is demonstrated in the subsequent equation (24),

$$T_i^d = [(U_i, P_{li})^d],\ i = 1, 2 \ldots a \qquad (24)$$

Here, the input Fruitfly can be specified as X_i^d. Randomly generate R the population of input voltage and the power losses. The equation can be derived as follows,

$$R = \begin{bmatrix} (U_i, P_{Li})^{11} & (U_i, P_{Li})^{12} & \dots & (U_i, P_{Li})^{1b} \\ (U_i, P_{Li})^{21} & (U_i, P_{Li})^{22} & \dots & (U_i, P_{Li})^{2b} \\ \vdots & \vdots & \vdots & \vdots \\ (U_i, P_{Li})^{a1} & (U_i, P_{Li})^{a2} & \dots & (U_i, P_{Li})^{ab} \end{bmatrix} \qquad (25)$$

For every Fruitfly, the objective function is evaluated using the following equation (26),

$$Fit = Max\left[|U_i||U_j||Y_{ij}| \sum_{n=1}^{N} \cos(\beta_{ij} - \chi_i - \chi_j) \right] \qquad (26)$$

The best Fruitfly are picked dependent on the objective function. By reorganizing the Fruitfly location by methods for the consequent updating function utilizing crossover and mutation operator the solution can be optimized. The updating equations are as per the following: Between the two fruit flies which generate a new set of fruit flies, the crossover rate is achieved. The process is performed into the fruit flies fitness value and the new generated fruit flies. The fruit flies are randomly mutated in light of the particular mutation rate in the mutation process. For calculating the crossover and mutation rate of fruit flies are calculated based on the following equations: (27) & (28):

$$X = \frac{N_{GX}}{L_c} \qquad (27)$$

$$M = \frac{M_p}{L_c} \qquad (28)$$

Where, N_{GX} indicates the number of genes crossover, M_p represents the mutation point and L_c indicates the length of chromosome. The steps is described as follows,

Step 1: Initialization of the fruit flies.

Step 2: The input fruit flies were randomly generated in n dimensions. The fruit flies input here are bus voltage and line losses.

Step 3: For the random number of the fruit flies evaluate the fitness function.

Step 4: The solutions are partitioned into two phases. The first phase is said to be as Osphresis foraging phase. In the Osphresis foraging phase, populaces of populace size food sources are created randomly around the present fruit fly swarm area. The second phase is vision foraging Phase. In the vision foraging phase, fruit flies do a greedy choice strategy.

Step 5: As per the objective function as well as could be expected be discovered and gather the current populace.

Step 6: Subjectively amend the current fruit flies populace to refresh position. The updating function is enhanced with the utilization of crossover and mutation operator.

Step 7: Evaluate the objective of the new population of fruit flies and select the best arrangement among the arrangements.

Step 8: Discover the power loss, voltage, real and reactive power flow of the best arrangement.

Step 9: In this section, in the event that the maximum number of iterations is achieved, at that point the procedure is exit else it will do the process of mutation and crossover operation. Here, the best chromosomes of the voltage, cost and power are determined, in light of the fitness values and the network is prepared to give the optimum UPFC capacity as indicated by the generator fault. In the condition, it unmistakably demonstrates that in view of the output combination the best combination of UPFC capacity based on the generator fault. The output is equated as follows,

$$\begin{bmatrix} Fit_{11} & Fit_{12} & \cdots & Fit_{1n} \\ Fit_{21} & Fit_{22} & \cdots & Fit_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ Fit_{m1} & Fit_{m2} & \cdots & Fit_{mn} \end{bmatrix} = \begin{bmatrix} (U_i, P_{Li})_{11}(t) & (U_i, P_{Li})_{12}(t) & \cdots & (U_i, P_{Li})_{1n}(t) \\ (U_i, P_{Li})_{21}(t) & (U_i, P_{Li})_{22}(t) & \cdots & (U_i, P_{Li})_{2n}(t) \\ \vdots & \vdots & \vdots & \vdots \\ (U_i, P_{Li})_{m1}(t) & (U_i, P_{Li})_{m2}(t) & \cdots & (U_i, P_{Li})_{mn}(t) \end{bmatrix} \qquad (29)$$

Step 10: Create the new fruit flies to produce new solutions. Go to Osphresis foraging and vision foraging phases. The system is to give the optimum location of the UPFC at the relating generator fault conditions once the above process is over [27]. The influenced location parameters were analyzed using the N R load flow analysis. Using the CSA algorithm depending on the optimum location parameters, the UPFC capacity is selected, which is shown in the accompanying section quickly. Fig 4 (a) shows the flowchart of IFA.

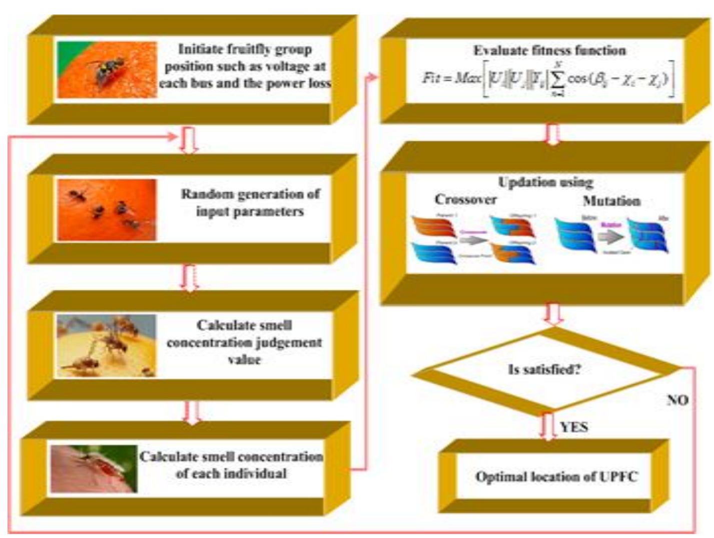

***Fig. 4** (a). Flowchart of IFA*

3.5 UPFC Capacity Optimization Using CSA Technique

The crow search algorithm (CSA) is a meta-heuristic nature awakened optimization algorithm, which relies upon the looking technique for crows in nature [28]. Crows are one of the most knowledgeable birds in terms of their size of the body containing the largest brain. Their brain is marginally lower than a human brain in view of a brain-to-body ratio. By utilizing the CSA algorithm with the assistance of an objective function the UPFC capacities at different generator faults conditions with diminished cost are optimized. The minimum voltage deviation and UPFC cost is estimated as the optimal function for best ability issue. At various fault conditions, the CSA algorithm optimization process is apportioned on the best position load flow parameters. The CSA algorithm creates the distinctive UPFC capacities and those capacities actualized into the best position. The promising capacity for satisfying the motivation behind the function is chosen as the best capacity. By utilizing the optimized UPFC capacity is utilized to reestablish the dynamic stability constraints at a secure limit. The steps for optimization of UPFC capacity is described in the following:

Step 1: Initialize the adjustable parameters of CSA such as power flow equation of the UPFC and bus system voltage.

Step 2: Initialize the position and the memory of each crow which can be expressed as follows,

$$Crows = \begin{bmatrix} c_1^1 & c_2^1 & \cdots & c_d^1 \\ c_1^2 & c_2^2 & \cdots & c_d^2 \\ \cdots & \cdots & \vdots & \cdots \\ c_1^M & c_2^M & \cdots & c_d^M \end{bmatrix} \quad (30)$$

$$Memory_{Crow} = \begin{bmatrix} m_1^1 & m_2^1 & \cdots & m_d^1 \\ m_1^2 & m_2^2 & \cdots & m_d^2 \\ \cdots & \cdots & \vdots & \cdots \\ m_1^M & m_2^M & \cdots & m_d^M \end{bmatrix} \quad (31)$$

Step 3: Generate the random population for each input parameters.

Step 4: Evaluate the fitness function to determine the optimal capacity of UPFC which is expressed as follows,

$$OF = \{of_1, of_2\} \quad (32)$$

$$of_1 = \sum_{i=1}^{N_B} (U_{normal} - U_i) \quad (33)$$

$$of_2 = Cost_{UPFC} \quad (34)$$

Here, the normal voltage is expressed as U_{normal}; the voltage of the bus is specified as U_i.

Step 5: In the following the crows update their memory is expressed as follows,

$$m^{l,iter+1} = \begin{cases} c^{l,iter+1} & of\,(c^{l,iter+1})\; is\; better\; than\; of\,(m^{l,iter}) \\ m^{l,iter} & Otherwise \end{cases} \quad (35)$$

Here, $of\,(.)$ depicts the fitness function value. Determine the maximum and minimum fitness of the initial population. From the minimum values of the solutions are selected as the best solutions. As it is observed from the process, the crow updates its memory by the new position if the fitness function value of the new crow position is better than the fitness function value of the memorized position.

Step 6: Until the maximum iteration is reached the steps 4 to 5 are repeated. In terms of the objective function value the best position of the memory is reported as the solution of the optimization problem when the termination criterion is met. The flowchart for CSA is depicted in Fig 4 (b).

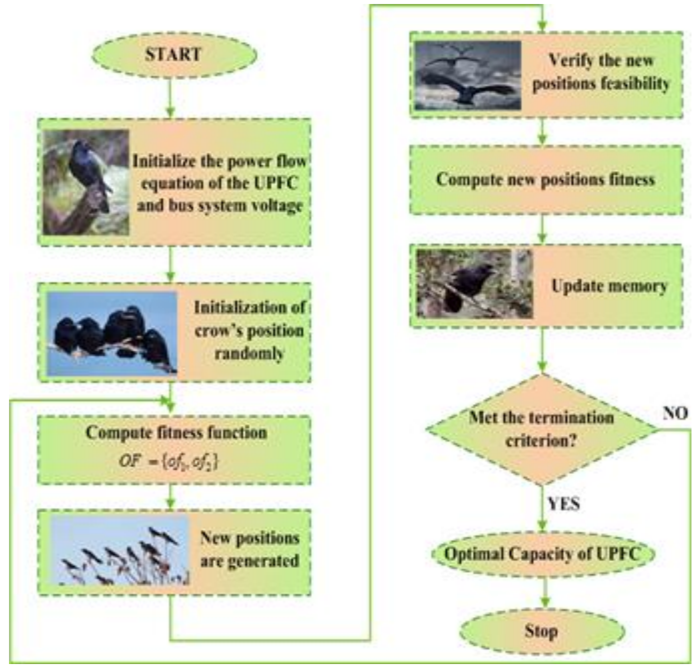

***Fig. 4** (b). Flowchart for CSA*

4 RESULTS AND DISCUSSION

In this paper, the proposed hybrid technique is realized in the MATLAB/Simulink Stage. In the proposed hybrid method is associated with the IEEE 30 bus system and IEEE 14 bus system. The gained outcomes are compared with different solution procedures, for example, ABC-GSA, FOAPSO. The IEEE benchmark system of two bus systems of IEEE 30 bus and IEEE 14 bus system is given as pursues. The data of IEEE 30 bus system and IEEE 14 bus system was taken from [10].

4.1 Testing of IEEE 30 Bus System

This section quickly depicts the implementation of the proposed method when connected to the bus system IEEE 30. There are 6 generator buses, 21 load buses and 42 transmission lines in the IEEE 30 bus system. At first, the normal load flow of the IEEE 30 bus system is analyzed using the Newton - Raphson (N - R) load flow method. Single and double generator problems occur randomly in the generator buses, such as 1, 2, 6, 13, 22 and 27. Because the IEEE 30 bus system, loses the dynamic stability measured by the bus system's load flow research work after the generator failure.

4.1.1 Single Generator Outage Condition

In this section, the performance evaluation of single generator outage condition of proposed with various existing techniques is analyzed. Fig 5 depicts the voltage profile fault in the generator at 2nd bus. When the DG-off condition, the voltage profile of the system is literally gives the maximum solution of

1.079 p.u. In normal condition, the voltage profile of the system gives the maximum value of 1.08. By applying the proposed technique in the system it gives a voltage range of 1.09. Fig 6 depicts the comparison graph of voltage profile fault in generator at 2nd bus. As seen from the figure, the proposed technique gives a maximum voltage value even in the fault occurred in the bus number 2. The maximum value acquired by the proposed technique is 1.09. The performance analysis of losses in generator at 2nd bus is illustrated in Fig 7
.

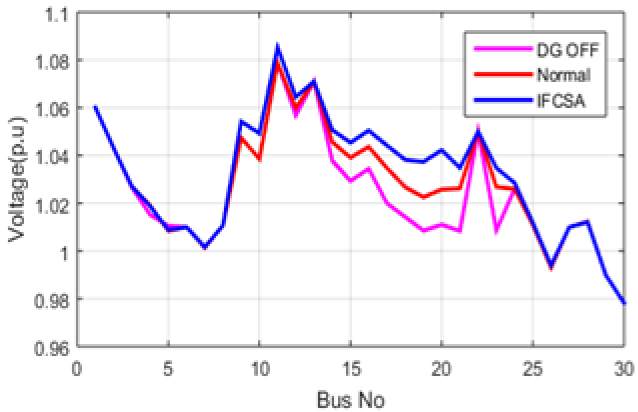

***Fig. 5**. Voltage profile fault in generator at 2nd bus*

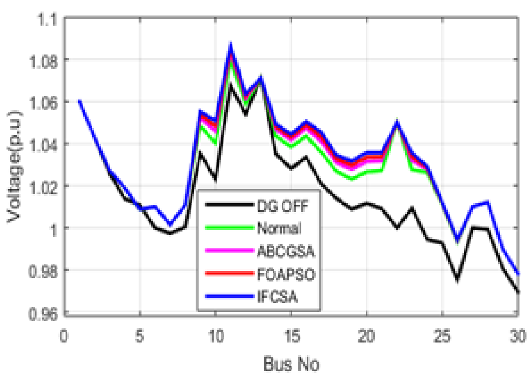

***Fig. 6**. Comparison of voltage profile fault in generator at 2nd bus*

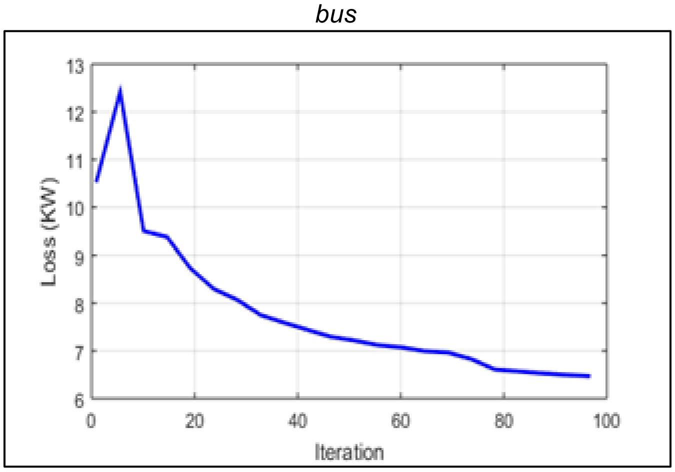

***Fig 7:** Performance analysis of losses in generator at 2nd bus*

The proposed technique reduces the losses from the initial condition to the final condition in the range of 12.5 to 6.5 KW. Fig 8 depicts the voltage profile fault in the generator at 6th bus. When the DG-off condition, the voltage profile of the system is literally gives the maximum solution of 1.07. In normal condition, the voltage profile of the system gives the maximum value of 1.08. By applying the proposed technique in the system it gives a voltage range of 1.085. The performance analysis of losses in generator at 6th bus is illustrated in Fig 9. The proposed technique reduces the losses from the maximum to the minimum range. At the initial stage, the loss is considerably higher which is in the range of 10.5 KW and goes increasing with the peak value of 12 KW and by applying the proposed technique, the system goes to optimal state i.e. the system losses gets reduced with the range of 6.5 KW. Fig 10 shows the voltage profile fault in generator at 13th bus. When the DG-off condition, the voltage profile of the system is literally gives the maximum solution of 1.069. In normal condition, the voltage profile of the system gives the maximum value of 1.07. By applying the proposed technique in the system it gives a voltage range of 1.08.

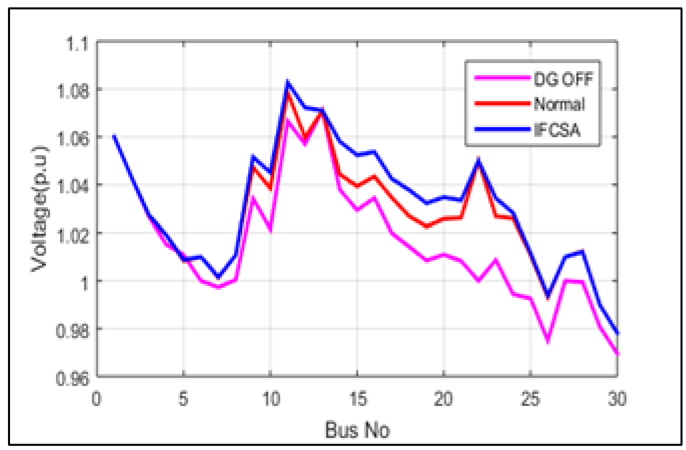

***Fig. 8.** Voltage profile fault in generator at 6th bus*

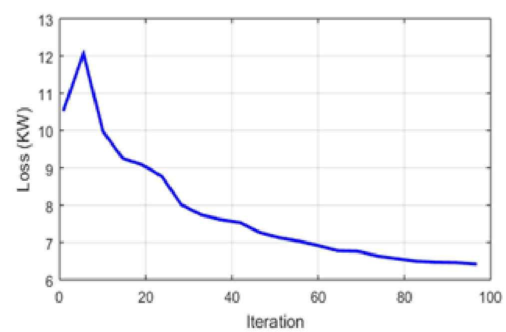

***Fig. 9**. Performance analysis of losses in generator at 6th bus*

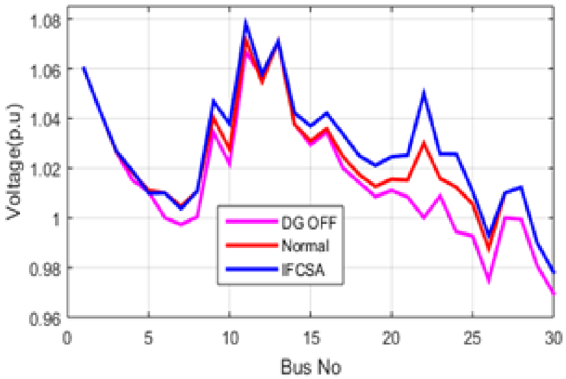

Fig. 10. *Voltage profile fault in generator at 13th bus*

The performance analysis of losses in generator at 13th bus is illustrated in Fig 11. The proposed technique reduces the losses from the maximum to the minimum range. At the initial stage, the loss is considerably higher which is in the range of 10.5 KW and goes increasing with the peak value of 12.2 KW and by applying the proposed technique, the system goes to optimal state i.e. the system losses gets reduced with the range of 6.5 KW. Fig 12 shows the voltage profile fault in generator at 22nd bus. When the DG-off condition, the voltage profile of the system is literally gives the maximum solution of 1.066. In normal condition, the voltage profile of the system gives the maximum value of 1.068. By applying the proposed technique in the system it gives a voltage range of 1.081. The performance analysis of losses in generator at 22nd bus is illustrated in Fig 13. The proposed technique reduces the losses from the maximum to the minimum range. At the initial stage, the loss is considerably higher which is in the range of 10.5 KW and goes increasing with the peak value of 11.5 KW and by applying the proposed technique, the system goes to optimal state i.e. the system losses gets reduced with the range of 6.5 KW.

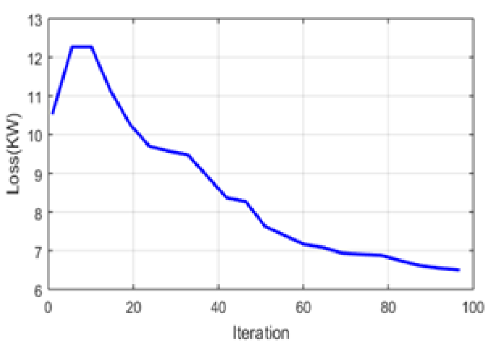

Fig. 11. *Performance analysis of losses in generator at 13th bus*

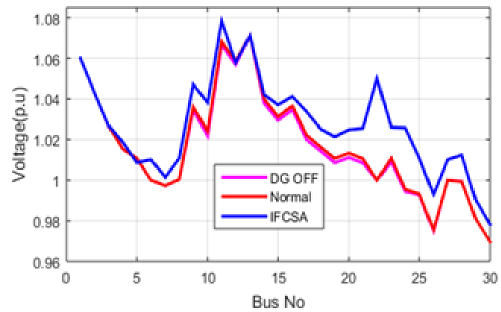

Fig. 12. *Voltage profile fault in generator at 22nd bus*

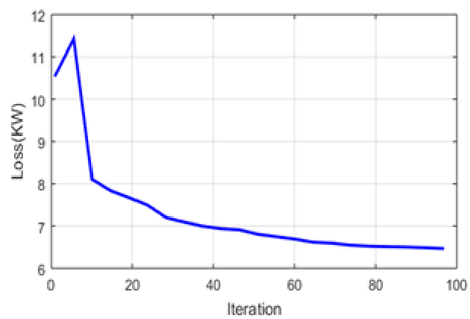

Fig. 13. *Performance analysis of losses in generator at 22nd bus*

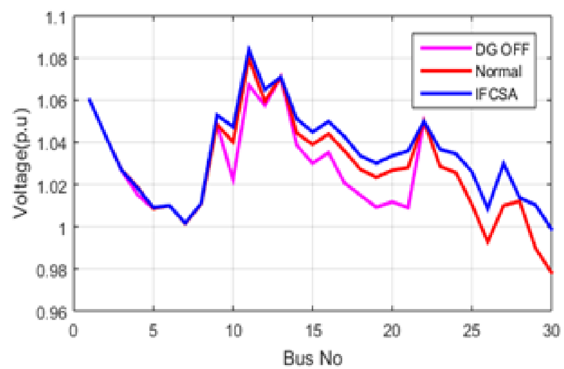

Fig. 14*. Voltage profile fault in generator at 27th bus*

Fig 14 shows the voltage profile fault in generator at 27th bus. When the DG-off condition, the voltage profile of the system is literally gives the maximum solution of 1.064. In normal condition, the voltage profile of the system gives the maximum value of 1.08. By applying the proposed technique in the system it gives a voltage range of 1.084. The performance analysis of losses in generator at 27th bus is illustrated in Fig 15. The proposed technique reduces the losses from the maximum to the minimum range. At the initial stage, the loss is considerably higher which is in the range of 10.5 KW and goes increasing with the peak value of 11.5 KW and by applying the proposed technique, the system goes to optimal state i.e. the system losses gets reduced with the range of 6.5 KW. Table 1 depicts the comparison of power flow in various generator bus numbers with different techniques. The Table 1 comprised of generator number, best location, and the power flow such as active and reactive power flow in the normal, generator outage and the proposed technique is studied.

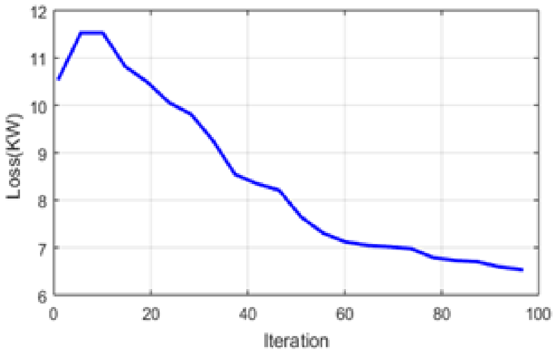

***Fig. 15**. Performance analysis of losses in generator at 27th bus*

TABLE 1
COMPARISON OF POWER FLOW IN VARIOUS GENERATOR BUS NUMBERS WITH DIFFERENT TECHNIQUES

Generator bus no.	Best location		Power flow					
			Normal		Generator outage		Proposed method	
	From bus	To bus	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
2	12	14	24.596	-6.905	22.842	-6.228	25.294	-7.232
6	12	15	26.027	4.089	25.737	2.707	29.664	4.608
13	6	7	87.390	-24.352	86.882	-25.825	87.521	-23.417
22	12	16	17.740	-7.838	16.768	-6.949	18.629	-8.380
27	23	24	0.807	1.519	0.309	-0.851	2.998	-0.259

TABLE 2
COMPARISON OF POWER LOSSES AND UPFC COST IN VARIOUS GENERATOR BUS NUMBERS WITH DIFFERENT TECHNIQUES

Generator bus no.	Best location		Power loss in MW			UPFC cost ($/KVAR)
	From bus	To bus	Normal	Generator outage	Proposed method	
2	12	14		12.4192	6.4727	184.6148
6	12	15		12.0615	6.4205	183.9075
13	6	7	10.5653	12.2683	6.5022	198.4884
22	12	16		11.4231	6.4649	188.5708
27	23	24		11.5255	6.536	186.7653

TABLE 3
COMPARISON OF POWER LOSS AND UPFC COST AT GENERATOR 2 WITH PROPOSED AND EXISTING TECHNIQUES

Methods	Power loss in MW	UPFC cost
IFCSA	6.4727	184.6148
FOAPSO	6.551	186.8586
ABCGSA	6.5095	189.2299

TABLE 4
PLA EVALUATION OF THE PROPOSED METHOD AND EXISTING TECHNIQUES

Solution Techniques	PLA (%)
ABC-GSA	38.3745
FOAPSO	37.9816
Proposed Technique	38.7229

Table 2 depicts the comparison of power losses and UPFC cost in various generator bus numbers with different techniques. The Table 2 comprised of generator number, best location, and the power losses obtained by the normal, generator outage and the proposed technique, UPFC cost of every generator bus number is studied. Table 3 depicts the comparison of power loss and UPFC cost at generator 2 of proposed and existing techniques. The existing techniques such as ABC-GSA and FOAPSO and from the figure, the power loss as well as the UPFC cost is very optimal than the existing techniques. The maximum power loss line can be achieved through the proposed technique in the single generator outage condition. Table 4 shows the PLA evaluation of proposed and the existing techniques. As seen from the Table 4, the proposed method gives accurate results than the existing techniques. The PLA % can be calculated using the following equation.

$$PLA(\%) = \frac{(N_P - B_P)}{N_P} \times 100 \qquad (36)$$

Where, the power loss accuracy is specified as PLA, the normal power loss defined as N_P, the best minimum power loss can be defined as B_P.

4.1.2 Double Generator Outage Condition

In this section, the performance evaluation of double generator outage condition of proposed with various existing techniques is analyzed. Fig 16 shows the voltage profile fault in generator at 2nd and 6th bus. When the DG-off condition, the voltage profile of the system is literally gives the maximum solution of 1.062. In normal condition, the voltage profile of the system gives the maximum value of 1.08. By applying the proposed technique in the system it gives a voltage range of 1.082. Thus, the proposed techniques achieve a maximum voltage even in the double generator outage condition. The performance analysis of losses in generator at 2nd and 6th bus is illustrated in Fig 17. The proposed technique reduces the losses from the maximum to the minimum range. At the initial stage, the loss is considerably higher which is in the range of 10.5 KW and goes increasing with the peak value of 14.2 KW and by applying the proposed technique, the system goes to optimal state i.e. the system losses gets reduced with the range of 6.2 KW.

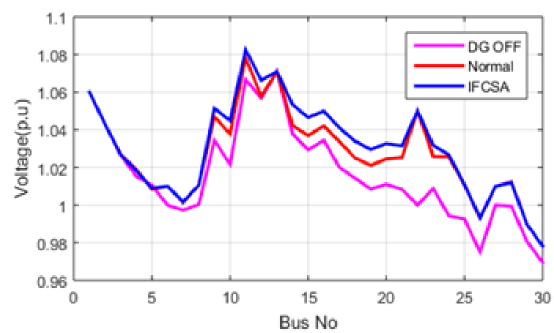

***Fig. 16**. Voltage profile fault in generator at 2nd and 6th bus*

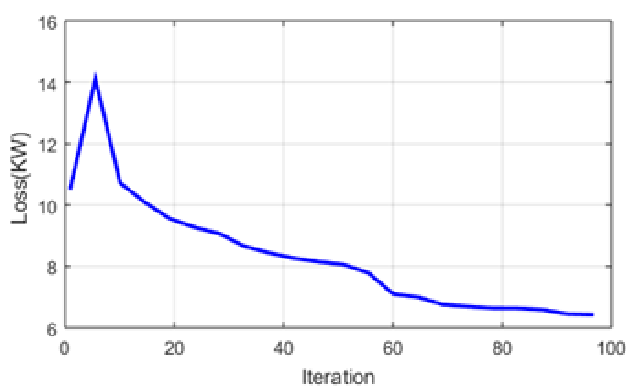

***Fig. 17.** Performance analysis of losses in generator at 2nd and 6th bus*

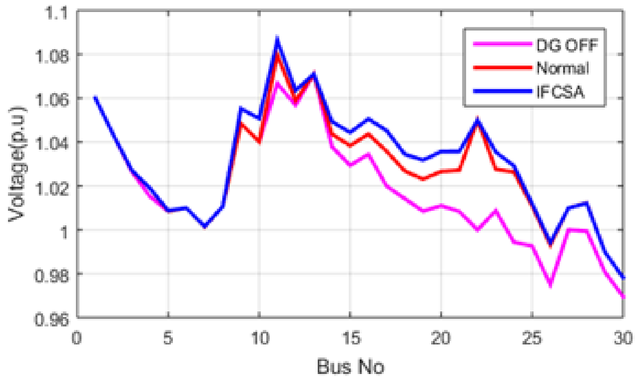

***Fig. 18**. Voltage profile fault in generator at 2nd and 13th bus*

Fig 18 shows the voltage profile fault in generator at 2nd and 13th bus. When the DG-off condition, the voltage profile of the system is literally gives the maximum solution of 1.064. In normal condition, the voltage profile of the system gives the maximum value of 1.081. By applying the proposed technique in the system it gives a voltage range of 1.085. Thus, the proposed techniques achieve a maximum voltage even in the double generator outage condition. The performance analysis of losses in generator at 2nd and 13th bus is illustrated in Fig 19. The proposed technique reduces the losses from the maximum to the minimum range. At the initial stage, the loss is considerably higher which is in the range of 10.4 KW and goes increasing with the peak value of 14.4 KW and by applying the proposed technique, the system goes to optimal state i.e. the system losses gets reduced with the range of 6.2 KW. Fig 20 depicts the comparison of voltage profile fault in generator at 2nd and 13th bus of proposed and existing techniques. When the DG-off condition, the voltage profile of the system is literally gives the maximum solution of 1.064. In normal condition, the voltage profile of the system gives the maximum value of 1.071. For ABCGSA has the voltage range of 1.075. The FOAPSO attains the maximum value of 1.081. By applying the proposed technique in the system it gives a voltage range of 1.085. Thus, the proposed techniques achieve a maximum voltage even in the double generator outage condition. Fig 21 shows the voltage profile fault in generator at 6th and 13th bus. When the DG-off condition, the voltage profile of the system is literally gives the maximum solution of 1.064. In normal condition, the voltage profile of the system gives the maximum value of 1.081. By applying the proposed technique in the system it gives a voltage range of 1.085. Thus, the proposed techniques achieve a maximum voltage even in the double generator outage condition.

***Fig. 19**. Performance analysis of losses in generator at 2nd and 13th bus*

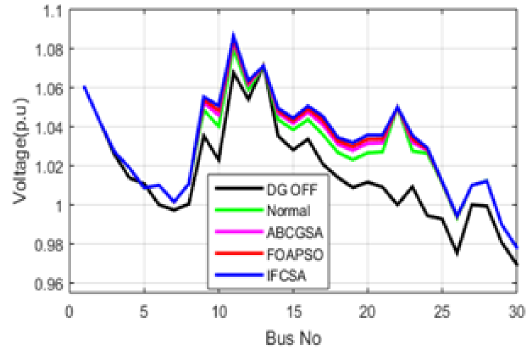

***Fig. 20**. Comparison of voltage profile fault in generator at 2nd and 13th bus of proposed with existing techniques*

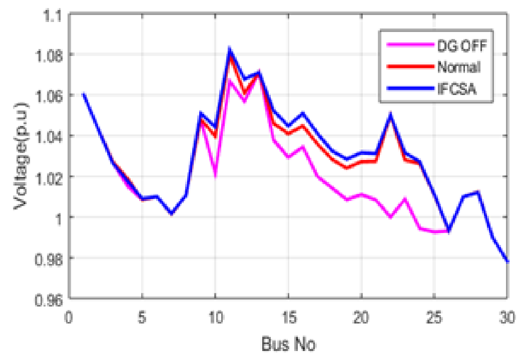

***Fig. 21.** Voltage profile fault in generator at 6th and 13th bus*

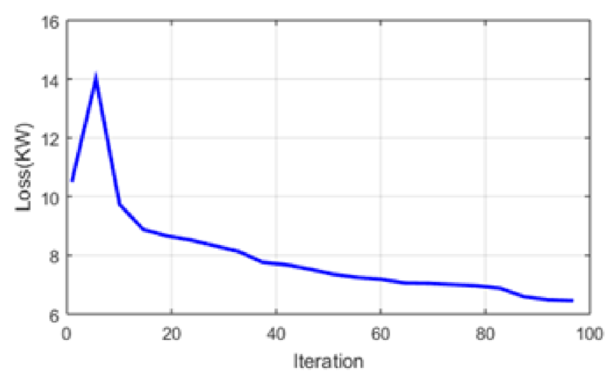

***Fig. 22.** Performance analysis of losses in generator at 6th and 13th bus*

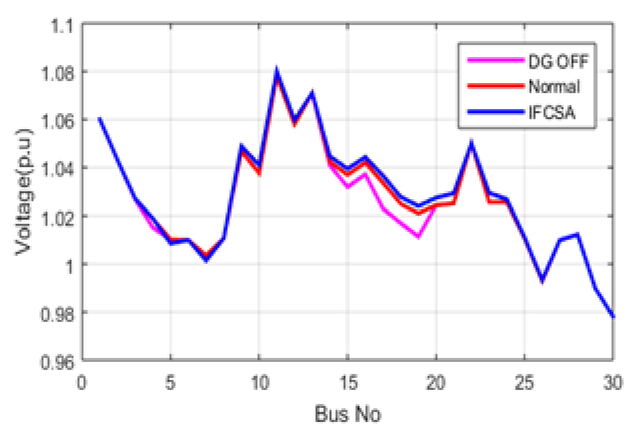

***Fig. 23**. Voltage profile fault in generator at 13th and 27th bus*

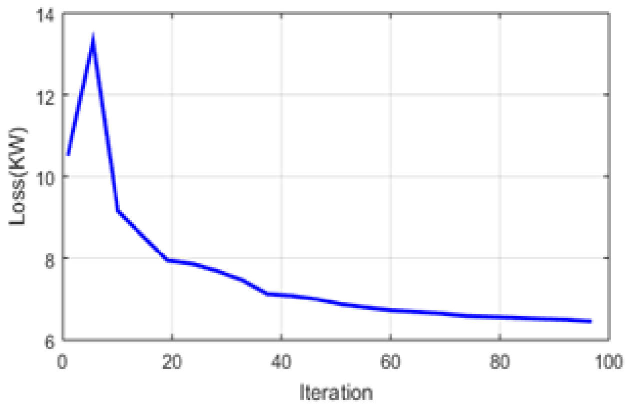

***Fig. 24**. Performance analysis of losses in generator at 13th and 27th bus*

The performance analysis of losses in generator at 6th and 13th bus is illustrated in Fig 22. The proposed technique reduces the losses from the maximum to the minimum range. At the initial stage, the loss is considerably higher which is in the range of 10.4 KW and goes increasing with the peak value of 14.2 KW and by applying the proposed technique, the system goes to optimal state i.e. the system losses gets reduced with the range of 6.2 KW. Fig 23 shows the voltage profile fault in generator at 13th and 27th bus. When the DG-off condition, the voltage profile of the system is literally gives the maximum solution of 1.078. In normal condition, the voltage profile of the system gives the maximum value of 1.08. By applying the proposed technique in the system it gives a voltage range of 1.082. Thus, the proposed techniques achieve a maximum voltage even in the double generator outage condition. The performance analysis of losses in generator at 13th and 27th bus is illustrated in Fig 24.

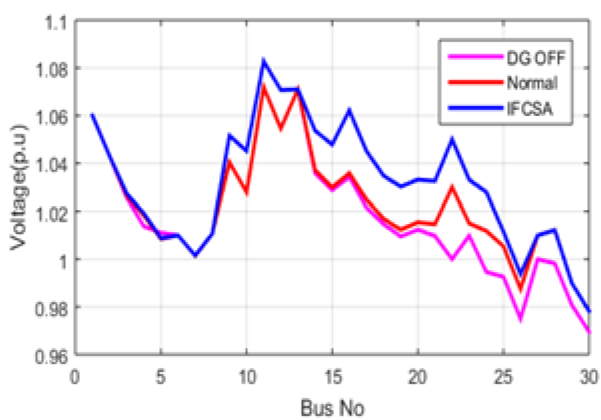

***Fig. 25.** Comparison of voltage profile fault in generator at 22nd and 27th bus*

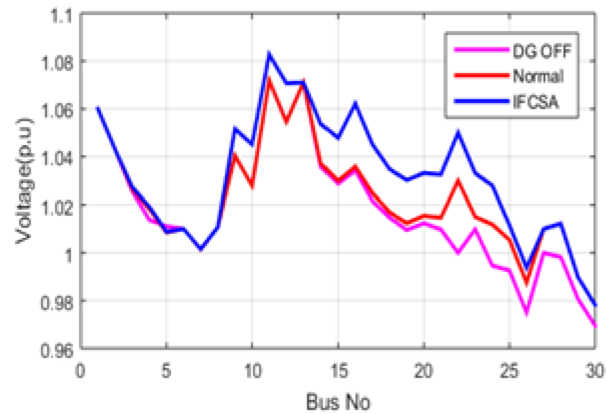

***Fig. 26**. Performance analysis of losses in generator at 22nd and 27th bus*

The proposed technique reduces the losses from the maximum to the minimum range. At the initial stage, the loss is considerably higher which is in the range of 10.4 KW and goes increasing with the peak value of 13.6 KW and by applying the proposed technique, the system goes to optimal state i.e. the system losses gets reduced with the range of 6.3 KW. Fig 25 shows the voltage profile fault in generator at 22nd and 27th bus. When the DG-off condition, the voltage profile of the system is literally gives the maximum solution of 1.07. In normal condition, the voltage profile of the system gives the maximum value of 1.07. By applying the proposed technique in the system it gives a voltage range of 1.082. Thus, the proposed techniques achieve a maximum voltage even in the double generator outage condition. Fig 26 illustrates the performance analysis of losses in generator at 22nd and 27th bus. The proposed technique reduces the losses from the maximum to the minimum range. At the initial stage, the loss is considerably higher which is in the range of 10.5 KW and goes increasing with the peak value of 12.5 KW and by applying the proposed technique, the system goes to optimal state i.e. the system losses gets reduced with the range of 6.5 KW. Table 5 depicts the comparison of power flow in various generator bus numbers with different techniques.

TABLE 5

COMPARISON OF POWER FLOW IN VARIOUS GENERATOR BUS NUMBERS WITH DIFFERENT CONDITIONS

Generator bus no.	Best location		Power flow					
			Normal		Generator outage		Proposed method	
	From bus	To bus	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
2 and 6	15	23	1.050	6.950	0.934	7.374	2.370	6.724
2 and 13	10	22	3.548	14.257	2.875	13.867	4.148	14.416
6 and 13	12	15	32.657	0.790	30.489	4.948	34.700	-0.925
22 and 27	6	7	75.279	-19.282	71.752	-18.969	75.010	-22.013
13 and 27	12	16	22.229	-6.144	19.274	-6.883	22.858	-7.518

TABLE 6

COMPARISON OF POWER LOSSES AND UPFC COST IN VARIOUS GENERATOR BUS NUMBERS WITH DIFFERENT CONDITIONS

Generator bus no.	Best location		Power loss in MW			UPFC cost ($/KVAR)
	From bus	To bus	Normal	Generator outage	Proposed method	
2 and 6	15	23		14.1067	6.4267	184.3199
2 and 13	10	22		14.3518	6.3751	180.0378
6 and 13	12	15	10.5653	14.0103	6.4592	185.1217
22 and 27	6	7		12.4465	6.435	197.3829
13 and 27	12	16		13.3187	6.4567	188.3386

TABLE 7

COMPARISON OF POWER LOSS AND UPFC COST AT GENERATOR 22 AND 27 WITH PROPOSED AND EXISTING TECHNIQUES

Methods	Power loss in MW	UPFC cost
IFCSA	6.3751	180.0378
FOAPSO	6.4035	181.1406
ABCGSA	6.4207	184.0374

TABLE 8

PLA EVALUATION OF THE PROPOSED METHOD AND EXISTING TECHNIQUES

Solution Techniques	PLA (%)
ABCGSA	39.2284
FOAPSO	39.3912
Proposed Technique	39.6600

The Table 5 comprised of generator number, best location, and the power flow such as active and reactive power flow in the normal, generator outage and the proposed technique is studied. Table 6 depicts the comparison of power losses and UPFC cost in various generator bus numbers with different techniques. The Table 6 comprised of generator number, best location, and the power losses obtained by the normal, generator outage and the proposed technique, UPFC cost of every generator bus number is studied. Table 7 depicts the comparison of power loss and UPFC cost at generator 2 of proposed and existing techniques. The existing techniques such as ABC-GSA and FOAPSO and from the figure, the power loss as well as the UPFC cost is very optimal than the existing techniques. The maximum power loss line can be achieved through the proposed technique in the single generator outage condition. Table 8 shows the PLA evaluation of proposed and the existing techniques. As seen from the Table 8, the proposed method gives accurate results than the existing techniques. The PLA of the ABCGSA is 39.2284%, the FOAPSO is 39.3912% and the proposed technique achieves the PLA of 39.6600%.

4.2 Testing of IEEE 14 Bus System

This section shows the information in a proposed technique about the IEEE 14 bus system, consisting of two generator buses, one is a slack bus and the other is a second bus. The load flow analysis is estimated in normal conditions by N - R load flow, which recognizes the total arrangement of load flow parameters such as bus voltage and power loss and dynamic stability constraint. The problem of an IEEE 14 bus system with a single generator is presented in the second bus. The power flow analysis then faces a couple of problems such as maximum power loss and voltage stability. To overcome this problem, by identifying the location of the fault and establishing UPFC with appropriate capacity. Fig 27 shows the voltage profile fault in generator at 2nd bus. When the DG-off condition, the voltage profile of the system is literally gives the maximum solution of 1.082. In normal condition, the voltage profile of the system gives the maximum value of 1.083. By applying the proposed technique in the system it gives a voltage range of 1.085. Thus, the proposed techniques achieve a maximum voltage even in the single generator outage condition. Fig 28 depicts the comparison of voltage profile fault in generator at bus of proposed and existing techniques. When the DG-off condition, the voltage profile of the system is literally gives the maximum solution of 1.082. In normal condition, the voltage profile of the system gives the maximum value of 1.083. For ABCGSA has the voltage range of 1.075. The FOAPSO attains the maximum value of 1.081. By applying the proposed technique in the system it gives a voltage range of 1.085. Thus, the proposed techniques achieve a maximum voltage even in the single generator outage condition. The performance analysis of losses is illustrated in Fig 29. The proposed technique reduces the losses from the maximum to the minimum range. At the initial stage, the loss is considerably higher which is in the range of 12.8 KW and goes increasing with the peak value of 15 KW and by applying the proposed technique, the system goes to optimal state i.e. the system losses gets reduced with the range of 11.5 KW.

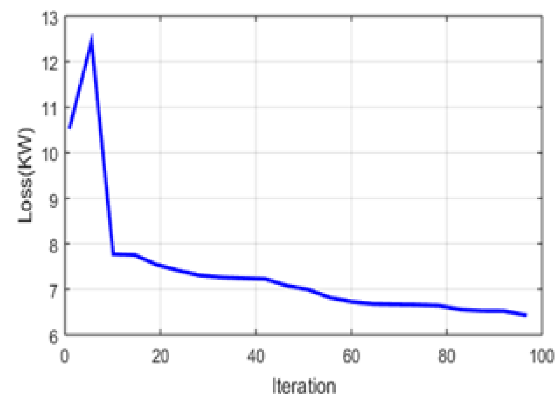

***Fig. 27**. Voltage profile fault in generator at 2nd bus*

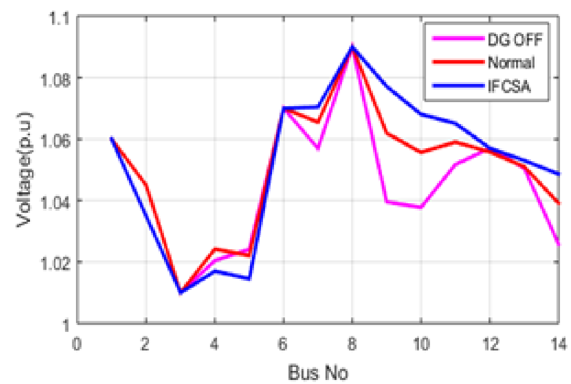

***Fig. 28**. Comparison of voltage profile fault in generator at 2nd bus*

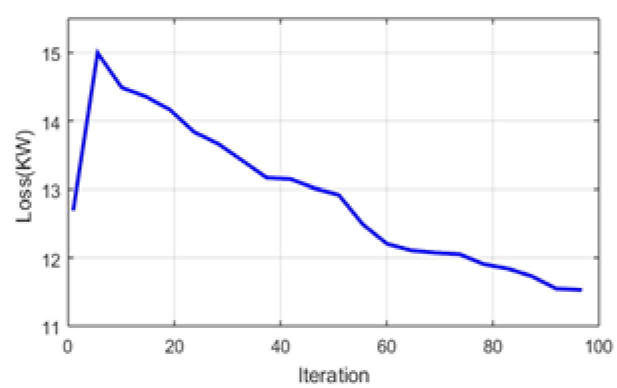

***Fig. 29**. Performance analysis of losses vs. iteration*

TABLE 9
COMPARISON OF POWER FLOW IN GENERATOR BUS NUMBER 2 WITH DIFFERENT TECHNIQUES

Generator bus no.	Best location		Power flow					
			Normal		Generator outage		Proposed method	
	From bus	To bus	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
2	2	4	57.374	-2.564	56.482	-2.023	59.120	-3.271

TABLE 10
COMPARISON OF POWER LOSSES AND UPFC COST IN GENERATOR BUS NUMBER 2 WITH DIFFERENT TECHNIQUES

Generator bus no.	Best location		Power loss in MW			UPFC cost ($/KVAR)
	From bus	To bus	Normal	Generator outage	Proposed method	
2	2	4	12.718	14.9957	11.3782	180.4529

TABLE 11
COMPARISON OF POWER LOSS AND UPFC COST OF PROPOSED WITH EXISTING TECHNIQUES

Methods	Power loss in MW	UPFC cost
IFCSA	11.3782	180.4529
FOAPSO	11.5304	181.4552
ABCGSA	12.3584	192.9496

TABLE 12
PLA EVALUATION OF THE PROPOSED METHOD AND EXISTING TECHNIQUES

Solution Techniques	PLA (%)
ABC-GSA	2.8274
FOAPSO	9.3379
Proposed Technique	10.5346

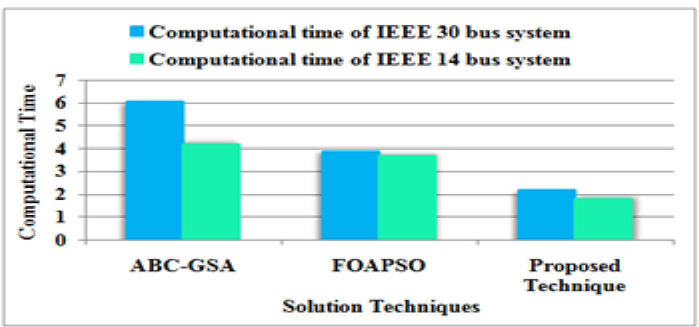

***Fig. 30.** Computational time of proposed with existing techniques for IEEE 30 and 14 bus system*

Table 9 depicts the comparison of power flow in generator bus number 2 with different techniques. The Table 9 comprised of generator number, best location, and the power flow such as active and reactive power flow in the normal, generator outage and the proposed technique is studied. Table 10 depicts the comparison of power losses and UPFC cost in various generator bus number 2 with different techniques. The Table 10 comprised of generator number, best location, and the power losses obtained by the normal, generator outage and the proposed technique, UPFC cost of every generator bus number is studied. Table 11 depicts the comparison of power loss and UPFC cost at generator 2 of proposed and existing techniques. The existing techniques such as ABC-GSA and FOAPSO and from the figure, the power loss as well as the UPFC cost is very optimal than the existing techniques. The maximum power loss line can be achieved through the proposed technique in the single generator outage condition. Table 12 shows the PLA evaluation of proposed and the existing techniques. As seen from the Table 12, the proposed method gives accurate results than the existing techniques. The PLA of the ABCGSA is 2.8274%, the FOAPSO is 9.3379% and the proposed technique achieves the PLA of 10.5346%. Fig 30 illustrates the computational time of proposed with existing technique for IEEE 30 and 14 bus system. From the fig 30, the proposed technique has fast convergence characteristics than the other solution techniques. In these things, we can undoubtedly analyze that at the time of fault circumstance the proposed hybrid technique incorporates least power misfortune. It was plainly clarifying that the proposed hybrid technique minimizes the changes effectively from the normal condition. The solutions gained from the comparative analysis affirm the controlling process of the proposed hybrid technique over the existing strategies as far as protect the strong help of power system.

5 CONCLUSION

The paper proposes the hybrid technique based enhancement of dynamic stability of the power system using UPFC. The performance of the proposed hybrid technique is tested on the IEEE 30 bus and IEEE 14 bus systems. By using the IFA technique in the bus system different types of generator faults are created and the most affected location is determined. The affected constraints are restored into secure limits and is optimized by CSA by locating the optimum capacity of the UPFC. The specifications of dynamic stability are determined for normal condition, fault condition and proposed hybrid technique. The arithmetical solutions of the proposed hybrid technique are corrected by the comparison analysis with existing techniques like ABCGSA and FOAPSO. The comparison analysis confirms that the proposed hybrid technique is a useful technique to elaborate the dynamic stability of the power system and is capable over the existing techniques.

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