ENHANCEMENT OF VOLTAGE STABILITY WITH UPFC USING A NOVEL HYBRID ALGORITHM(GA-GSA)

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ABSTRACT

The voltage collapse problem can avoid by providing proper reactive power resources to maintain specified voltage profile in the power system network. The traditional approaches are not sufficient to mitigate reactive power imbalance in the modern power system. Hence one of the emerging technologies like integration of Flexible AC Transmission System (FACTS) devices has been adopted in this paper. A hybrid algorithm is proposed to improve voltage stability of power system and to optimize the FACTS controllers. This Hybrid algorithm intended by the combination of genetic algorithm (GA) and gravitational search algorithm (GSA). For the implementation of this technique, one of the FACTS devices namely Unified power flow controller (UPFC) is selected. The GA is applied to identify best locations of UPFC and later GSA is implemented to optimize UPFC ratings in a sequential manner. The proposed method is implemented on IEEE-30 bus system using MATLAB working platform. The results have shown the effectiveness of proposed algorithm for practical applications.

Index Terms: Voltage Stability, FACTS controllers, UPFC, GSA, GA

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1. INTRODUCTION

The present day power system is a complex network comprising of transmission Lines interconnecting all the generator stations, transformers and all the loading points in the power system. The important requirement of a reliable power system is to maintain the voltage within the permissible ranges to ensure a high quality of customer service. The problem of voltage collapse may simply be explained as the inability of the power system to supply the reactive power or by an excessive absorption of reactive power. Therefore, it is difficult to provide voltage stability, even in normal conditions. Stability depends upon both the initial operating conditions of the system and the severity of the disturbance . The voltage stability is increasingly becoming a limiting factor in the planning and operation of power system. There are two types of voltage stability based on the time frame of simulation: static voltage stability and dynamic voltage stability. The determination of voltage stability limit at various operating condition is essential to operate the system with sufficient safety margin.

Voltage instability is mainly associated with a reactive power imbalance. Voltage instability problem is being addressed in two different ways. The first approach is to mitigate the problem and the second approach is to enhance the Voltage Stability Margin (VSM) of the system for the selected operating condition. This has been imposed the threat of maintaining the required bus voltage and the systems have been facing voltage instability problem. The only way to save the system from voltage collapse is to reduce the reactive power load or add additional reactive power prior to reaching the point of voltage collapse. Several analytical techniques have been used to assess the risk of voltage instability and analyze the voltage stability margin. To achieve secure and economic operation, Flexible AC Transmission System (FACTS) devices are properly installed in the system.

The FACTS devices have been used during the last three decades and provide better utilization of existing systems. The primary function of the FACTS is to control the transmission line power flow; the secondary functions of the FACTS can be voltage control, transient stability improvement and oscillation damping. There are various forms of FACTS devices are used. Such as Static Synchronous Series Compensator (SSSC), Static Synchronous Compensator (STATCOM), Static Var Compensator (SVC) and unified power flow controller UPFC.

Of all the FACTS devices, the combined compensators such as the UPFC and the interline power flow controller(IPFC) are regarded as the most powerful and versatile ones . Therefore, the voltage stability, and steady state and transient stabilities of a complex power system can be effectively improved by the use of FACTS devices.

The principal function of the UPFC is to control the flow of real and reactive power by injecting a voltage in series with the transmission line. The major advantages of embedding UPFC in power system is not only improves the power handling capability or installing new generations plant but also reduces the generations cost through utilizations of excess power available.

2. POWER INJECTION MODELING OF UPFC

The real and reactive power flow model of UPFC is depends on voltage magnitude, angle, and series branch admittance values. In steady state condition, the two voltage source converters represent the fundamental components of output voltage waveform and the two coupling transformers leakage reactance's. The injected real and reactive power flow model of UPFC is described as follow,

$$P_{i,inj,upfc} = 0.02 r b_{in} V_i^2 V_j \sin\gamma - 1.02 r b_{in} V_i V_j \sin\left(\theta_i - \theta_j + \gamma\right) \tag{1}$$

$$P_{j,inj,upfc} = r b_{in} V_i V_j \sin\left(\theta_i - \theta_j + \gamma\right) \tag{2}$$

$$Q_{i,inj,upfc} = -r b_{in} V_i^2 \cos\gamma \tag{3}$$

$$Q_{j,inj,upfc} = r b_{in} V_i V_j \cos(\theta_i - \theta_j + \gamma) \tag{4}$$

where, n =j,k....,$V_i and V_j$ are the magnitude busvoltages at buses i, j respectively, is the magnitude of controllable series injected voltage source, $b_{in}$is the series branch admittance are the voltage angle between bus i, j respectively.

3. PROBLEM FORMULATION

The main parameters that influence the voltage stability of the system are the real power, voltage magnitude, and angle. So, the voltage stability of the system is maintained by control the above mentioned parameters. In this paper, a hybrid approach is proposed for improving the voltage stability of power system by FACT controller. Here, UPFC is used to inject real and reactive power for enhancing the stability. GA is used to determine the optimal location of UPFC as per the changes of stability margin. Then applying GSA, the capacity of UPFC is determined. The problem for locating and sizing of UPFC can be formulated as a multi objective problem with the following objectives and constraints.

Min F(x,u) (5)

Subject to h(x,u)=0 (6)

P(x,u)≤0 (7)

where, F is the objective function, h is the equality constraints and p is the inequality constraints which depends on the control variables x and u .

3.1 Equality Constraints:

The power balance condition of the system is depends on the principle of equilibrium between total generation and total load of the system. The power balance condition is represented in terms of nonlinear power flow equations which described as follow,

$$P_{Gi} - P_{Di} = \sum_{j=1}^{N} |V_i|\,|V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) \tag{8}$$

$$Q_{Gi} - Q_{Di} = \sum_{j=1}^{N} |V_i|\,|V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) \tag{9}$$

Where, $P_{Gi}, P_{Di}, Q_{Gi}\ and\ Q_{Di}$ are the real and reactive power injected at i^{th} bus and the corresponding load demands respectively. $Y_{ij}\ and\ \theta_{ij}$ are the admittance matrix and voltage angle between $i^{th} and j^{th}$ buses. $V_i, V_j, \delta_i\ and\ \delta_j$ are the magnitude and angle of bus $i^{th}\ and\ j^{th}$ respectively.

3.2 Inequality Constraints:

The generation limits of the generating units are divided in to upper and lower bound which lies in between the actual limits. The real, and reactive power are described as following them, This voltage magnitude is having its own lower and upper bound and mathematically represented by follow,

$$P_n^{min} \leq P_n \leq P_n^{max} \tag{10}$$

$$Q_n^{min} \leq Q_n \leq Q_n^{max} \tag{11}$$

$$V_n^{min} \leq V_n \leq V_n^{max} \tag{12}$$

$$\delta_n^{min} \leq \delta_n \leq \delta_n^{max} \tag{13}$$

Where, $P_n^{min}\ and\ P_n^{max}$ are the real power flow limits of nth bus, $Q_n^{min}\ and\ Q_n^{max}$ are the reactive power of flow limits of nth bus, $V_n^{min}\ and\ V_n^{max}$ are the voltage magnitude limits of nth bus, $\delta_n^{min}\ and\ \delta_n^{max}$ are the voltage magnitude limits nth bus of respectively.

4. PROPOSED HYBRID ALGORITHM APPROACH

4.1 LOCATION OF UPFC USING GA

The GA is one of the evolutionary algorithms which play an important role for optimization process. It is a global search technique, based on the mechanisms of natural selection and genetics; that can search several possible solutions simultaneously. It can start with random generation of initial population and then selection, crossover and

mutation are produced until the best population is found . Here, the GA is used to optimize the location of UPFC. The GA steps are described as follows:

4.1.1 Initialization

The starting process of GA is randomly generated the N number of chromosomes. Here, the input genes are voltage V , real power P and the reactive power Q of the bus. The location of FACTS device is denoted as the F_L. These genes are specified as string values. The voltage values are denoted as the first string, the real power values are represented as second string, The reactive power values are denoted as third string and the location of FACTS device is denoted as fourth string. The input genes are specified as a certain limit function, such as minimum and maximum.

i.e,$[V_{min}, V_{max}]$,$[P_{min}, P_{max}]$ and $[Q_{min}, Q_{max}]$.

$$X=\{x_i^1, x_i^2 \dots \dots x_i^d\} \tag{14}$$

where, i =1,....n , and d is specified as the dimensions of the population space. After that, the fitness function is evaluated.

4.1.2 Fitness Function

The objective function is specified as the fitness function. Here, the fitness function is used to specify the maximization of the power loss of the system. The fitness values of each chromosome are calculated. The fitness function can be expressed as follows,

$$fitness\ function = \max\begin{pmatrix} \sum_{i=1}^{NP} v_i \\ \sum_{i=1}^{NP} p_i \\ \sum_{i=1}^{NP} q_i \end{pmatrix} \tag{15}$$

Where, the voltage, real and reactive power represented as:

$V_i = \{v_i^1, v_i^2 \dots \dots v_i^d\}$,

$P_i = \{p_i^1, p_i^2 \dots \dots p_i^d\}\ and$

$Q_i = \{q_i^1, q_i^2 \dots \dots q_i^d\}$.

4.1.3 Crossover Operation

The crossover operation is achieved between the two chromosomes, which is generated a new set of chromosomes. The crossover function is based on the crossover rate (*CR*). Then, the new child chromosomes are generated based on their CR. After generating new chromosome, a fitness function is applied to the new child. Crossover operator is applied to the mating pool with the hope that it creates a better offspring. There are various crossover techniques used. After that, the mutation operation is performed.

4.1.4 Mutation

The mutation operation is based on the mutation rate (*MR*). The MR is defined as ratio of the mutation point of the chromosome to the chromosome length. The mutation operation is applied to the chromosomes. Based on their MR, the best chromosomes are selected.

4.1.5 Termination

In this section, if the maximum number of iterations is reached then the process is exit; otherwise it will do the process of mutation and crossover operation. Here, the best chromosomes of the voltage, real and reactive power are calculated, based on the fitness values. Based on the fitness function, the UPFC location is optimally identified.

4.2 SIZING OF UPFC USING GSA

A GSA algorithm is the stochastic search algorithm, which is based on Newtonian laws and mass interaction. In the GSA technique, agents are taken as the consideration of the objects and the performances are measured by their masses. Here, the bus voltage and the corresponding angles are the inputs. From the inputs the minimized power loss, real and reactive power injection can be evaluated; depending on the evaluation the optimal capacity of the UPFC device is determined. The steps to find the optimal sizing of the UPFC device are briefly explained in the following.

Algorithm

Step 1: To determine the search space of the proposed method and initialize the voltage limits and the angle, which are assumed as the agents. We consider the proposed system consists of N agents and the position of the ith agent is given by:

$$X = \left(x_i^1, \dots, x_i^d, \dots x_i^n\right) \ for\ i = 1,2, \dots n$$

where, n is the search space dimension of the problem, x_i^d is the position of the ith agent in the dth dimension.

Step 2: Random generation of the input values such as the voltage and the corresponding angles. From the input values evaluate the fitness, which is given in the following equation (16).

$$Fitness\ function = Min\left(\sum_{j=1}^{N} |V_i|\,|V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j)\right) \quad for\ i = 1,2, \dots n \qquad (16)$$

Step 3: Evaluate the fitness of the agents and determine the solution.

Step 4: Update the gravitational constant G(t), best fitness F(B), worst fitness F(W) and mass of the agents $M_i(t)$. The gravitational search constant G(t) is initialized at the beginning and it will reduce the time to control the search precision.

The gravitational constant is given by the following: $G(t) = G(G_0, t)$, the best fitness F(B), worst fitness F(B) and mass of the agents $M_i(t)$ can be described as the following equations (17) - (19).

$$F(B) = Min_{j\epsilon\{1\dots N\}} FITNESS_j(t) \qquad (17)$$

$$F(W) = Max_{j\epsilon\{1\dots N\}} FITNESS_j(t) \qquad (18)$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)} \qquad (19)$$

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

Step 5: To evaluate the total force of the agents at different directions, it can be described by the following equation (20).

$$TF_i^d(t) = \sum_{j=1, j\neq i}^{N} random_j(force_{ij}^d(t)) \qquad (20)$$

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

Step 6: Find the acceleration of the agent, which can be i^{th} determined by using the following equation (21).

$$a_i^d(t) = \frac{TF_i^d(t)}{M_i(t)} \tag{21}$$

Step 7: Updating the agent's velocity and position using the following equation (22) and (23).

$$V_i^d(t+1) = random_i \times V_i^d(t) + a_i^d(t) \tag{22}$$

$$X_i^d(t+1) = x_i^d(t) + V_i^d(t+1) \tag{23}$$

Where $V_i^d(t)$ and $X_i^d(t)$ are the velocity and position of an agent at the t time and d dimension, $random_i$ is the random number at the interval at [0, 1].
Step 8. Repeat the procedure from step 3 to 7 until it reaches the stop criteria.
Step 9. Terminate the process.

The complete algorithm is in the form of flow chart has been given Figure. 1.

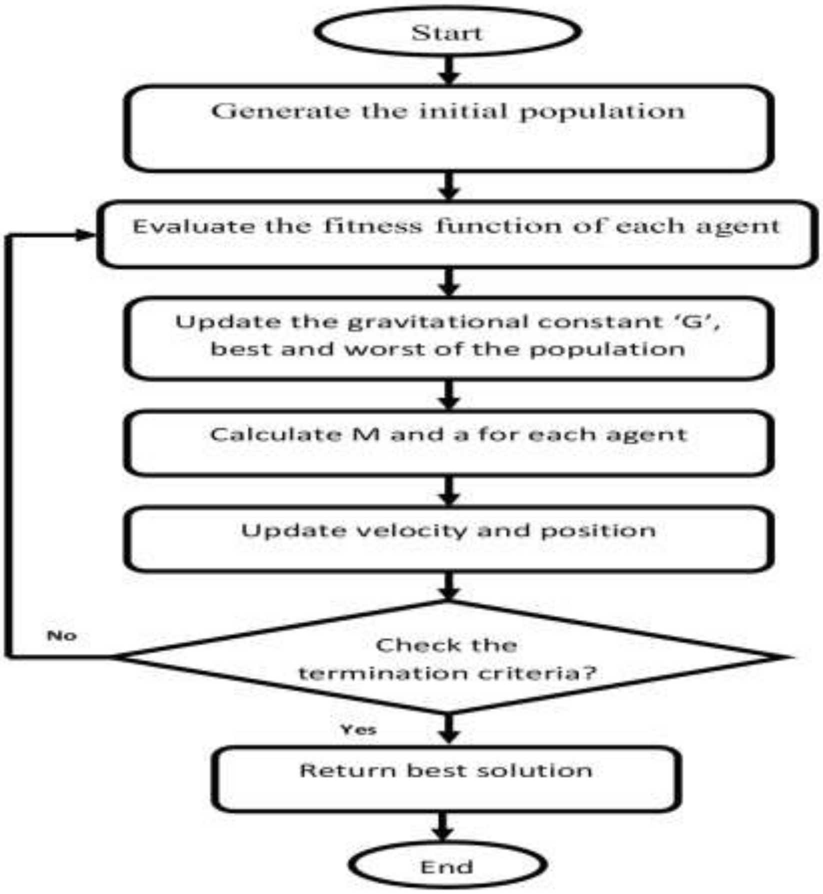

Fig. 1. Flow Chart of GA-GSA Algorithm

5. RESULTS AND DISCUSSION

Here hybrid algorithm depends on GA-GSA is applied for finding the optimal placement and sizing of statcom in IEEE 30-bus system. The line and bus data is given [12]. In IEEE 30- bus system bus no. 1 is slack bus, bus nos. 2, 5, 8, 11 and 13 are generator buses, and remaining buses are load buses. The IEEE 30 bus system comprising of two synchronous compensators connected at bus 11, 13, including four generators which are connected at bus no. 1, 2, 5 and 8. Synchronous compensators are used to provide support of reactive power. There are 41 branches with transformer tap setting between buses 6-10, 9-11, 4-13 and 4-12. Under the base case condition, the connected load is 283.4 MW and 126.20 MVAR and voltage magnitude at all buses are within their voltage security limit (0.94 p.u.to l.06 p.u.). Therefore power system is secured. However during severe stressed condition as well as critical contingencies under stressed condition, voltages at some buses violating from their voltage security limit.

In this paper, two cases are considered. Case A is stressed condition and Case B is critical contingencies under stressed condition with and without UPFC. For optimally placement of UPFC using GA, the 5 load buses (bus nos. 23, 24, 25, 26 and 27) have been selected using modal analysis, as possible locations, to improve voltage profile and voltage stability. As a first step, load flow analysis and modal analysis have been performed for the base case condition. This has been observed that this test system has a satisfactory voltage profile with TVD (Total Voltage Deviation) is 0.3520 and thus needs no UPFC. From modal analysis, the minimum Eigen value for this system is found to be 2.777l. Load flow analysis and modal analysis have also been performed during Case A and Case B for calculating minimum Eigen values. Contingency selection and ranking is carried out to find out the most severe condition which is given in table l. On this basis three most critical single line outage contingencies, outage of line (LO) nos. 14 and 16 are found critical line outages during Case B

Table1. Result analysis of IEEE 30 bus system without UPFC.

Bus no	Normal case	Stressed case	Line outage 14	Line outage 16
1	1.0600	1.0600	1.0600	1.0600
2	1.0450	1.0450	1.0451	1.0450
3	1.0212	1.0171	1.0170	1.0155
4	1.0123	1.0082	1.0081	1.0061
5	1.0100	1.0101	1.0102	1.0101
6	1.0106	1.0063	1.0060	1.0043
7	1.0026	1.0001	1.0010	0.9993
8	1.0100	1.0104	1.0104	1.0101
9	1.0511	1.0481	1.0480	1.0440
10	1.0454	1.0412	1.0418	1.0350
11	1.0820	1.0822	1.0801	1.0822
12	1.0573	1.0551	1.0550	1.0522
13	1.0710	1.0711	1.0710	1.0710
14	1.0425	1.0390	1.0392	1.0352
15	1.0379	1.0330	1.0321	1.0272
16	1.0446	1.0410	1.0410	1.0374
17	1.0402	1.0361	1.0365	1.0306
18	1.0284	1.0243	1.0230	1.0174
19	1.0259	1.0212	1.0212	1.0153
20	1.0300	1.0250	1.0260	1.0190
21	1.0330	1.0270	1.0261	1.0193
22	1.0335	1.0270	1.0250	1.0189

Table2. Result analysis of IEEE 30 bus system With UPFC.

Bus no	Stressed case with UPFC	Line outage 14 with UPFC	Line outage 16 with UPFC
1	1.0600	1.0600	1.0600
2	1.0450	1.0450	1.0450
3	1.0244	1.0260	1.0259
4	1.0159	1.0177	1.0174
5	1.0100	1.0100	1.0100
6	1.0136	1.0146	1.0137
7	1.0044	1.0067	1.0060
8	1.0100	1.0100	1.0100
9	1.0575	1.0570	1.0540
10	1.0565	1.0548	1.0491
11	1.0820	1.0820	1.0820
12	1.0631	1.0635	1.0606
13	1.0710	1.0710	1.0710
14	1.0508	1.0505	1.0463
15	1.0495	1.0485	1.0434
16	1.0546	1.0536	1.0496
17	1.0534	1.0520	1.0468
18	1.0452	1.0440	1.0386
19	1.0452	1.0437	1.0382
20	1.0472	1.0456	1.0401
21	1.0456	1.0435	1.0360
22	1.0466	1.0444	1.0363

23	1.0274	1.0181	1.0160	1.0061
24	1.0218	1.0080	1.0040	0.9881
25	1.0176	0.9790	0.9810	0.9452
26	0.9999	0.9442	0.9342	0.8763
27	1.0235	0.9800	0.9901	0.9541
28	1.0071	0.9964	0.9982	0.9913
29	1.0037	0.9250	0.9490	0.8930
30	0.9922	0.8921	0.9240	0.8870

23	1.0445	1.0424	1.0330
24	1.0411	1.0375	1.0224
25	1.0331	1.0249	1.0078
26	1.0208	1.0023	0.9848
27	1.0343	1.0286	1.0106
28	1.0109	1.0110	1.0086
29	1.0161	1.0103	0.9809
30	1.0085	1.0027	0.9754

Table 3: Real and Reactive Power Losses

Type of losses		**P loss (MW)**	**Q loss (Mvar)**
Normal case		17.55	67.69
Without UPFC Placement	Stressed condition	18.38	70.56
	Line Outage 16(LO 16)	22.91	87.56
	Line Outage 14 (LO 14)	20.65	79.30
With UPFC Placement	Stressed condition	11.38	43.32
	Line Outage 16(LO 16)	6.77	26.08
	Line Outage 14 (LO 14)	9.02	36.78

Table 4: Percentage Power Loss with respect to Normal Case

Types of losses		**(+) for increment and (-) for decrement**		**(+) for increment and (-) for decrement**	
		P loss(MW)	**Q loss(MVAr)**	**%P loss(MW)**	**%Q loss(MVAr)**
Without UPFC placement	Stressed condition	-0.83	-2.29	-4.7	-3.38
	Line outage 16	-5.36	-19.87	-25.34	-29.35
	Line outage 14	-3.10	-11.61	-17.66	-17.15
With UPFC placement	Stressed condition	+6.17	+24.37	+35.15	+36.00
	Line outage 16	+10.78	+26.55	+61.42	+39.22
	Line outage 14	+8.53	+30.91	+48.60	+45.66

From modal analysis, the minimum Eigen value for this system is found to be 2.777l. Load flow analysis and modal analysis have also been performed during Case A and Case B for calculating minimum Eigen values. Contingency selection and ranking is carried out to find out the most severe condition which is given in table l. On this basis three most critical single line outage contingencies, outage of line (LO) nos. 14 and 16 are found critical line outages during Case B. Using GA-GSA the placement of UPFC and size of UPFC is determined respectively, based on fitness function showing large voltage deviation with respect to base value and maximum power loss by GA and using fitness function of the GSA the size of the UPFC is determined

Table 5: Placement and Size of UPFC

Case	LO(line outages)	OPTIMAL LOCATION	Capacity (MVAR)
Case A	……	30	11.5001
Case B	14	30	10.0583
	16	26	18.4253

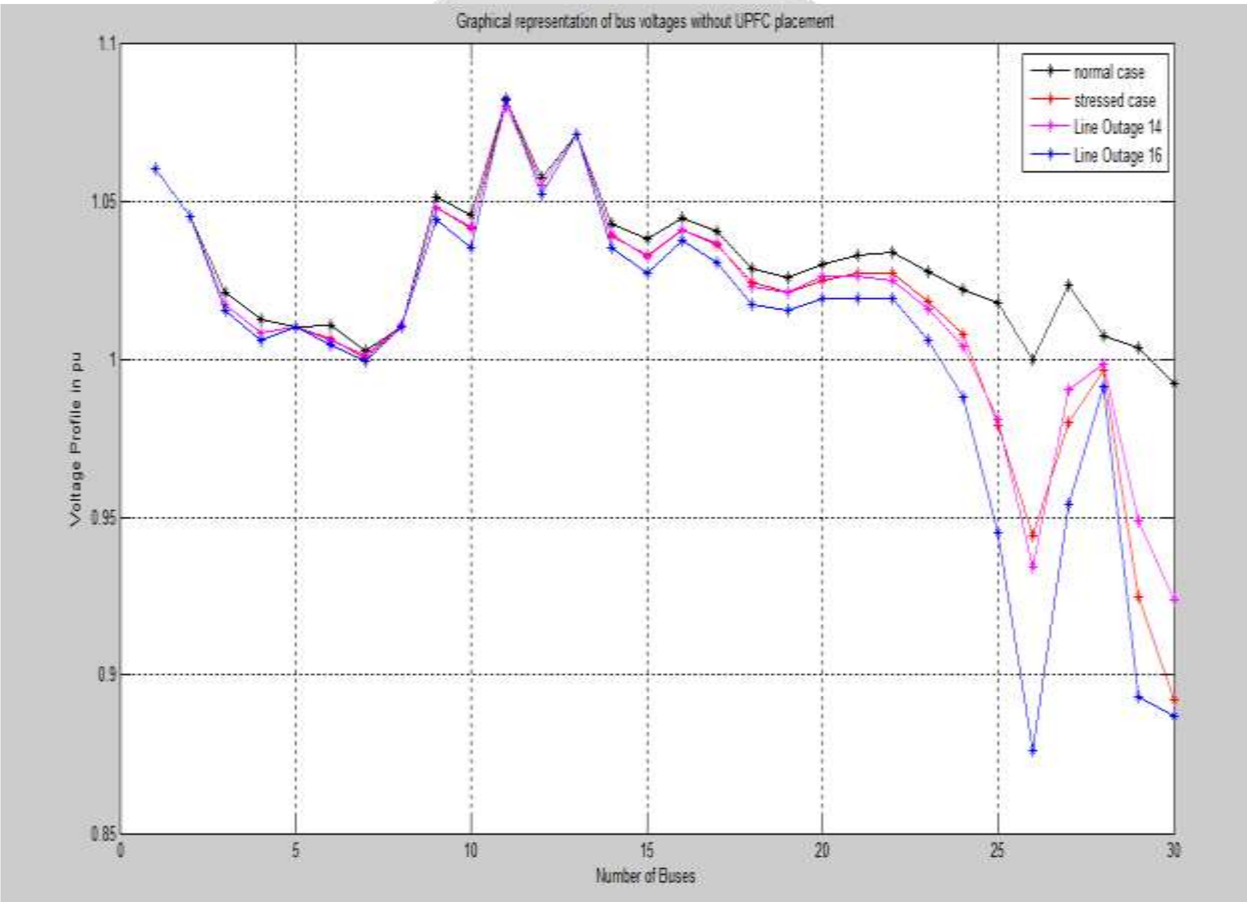

Fig. 2.comparison of voltages(p.u) without UPFC

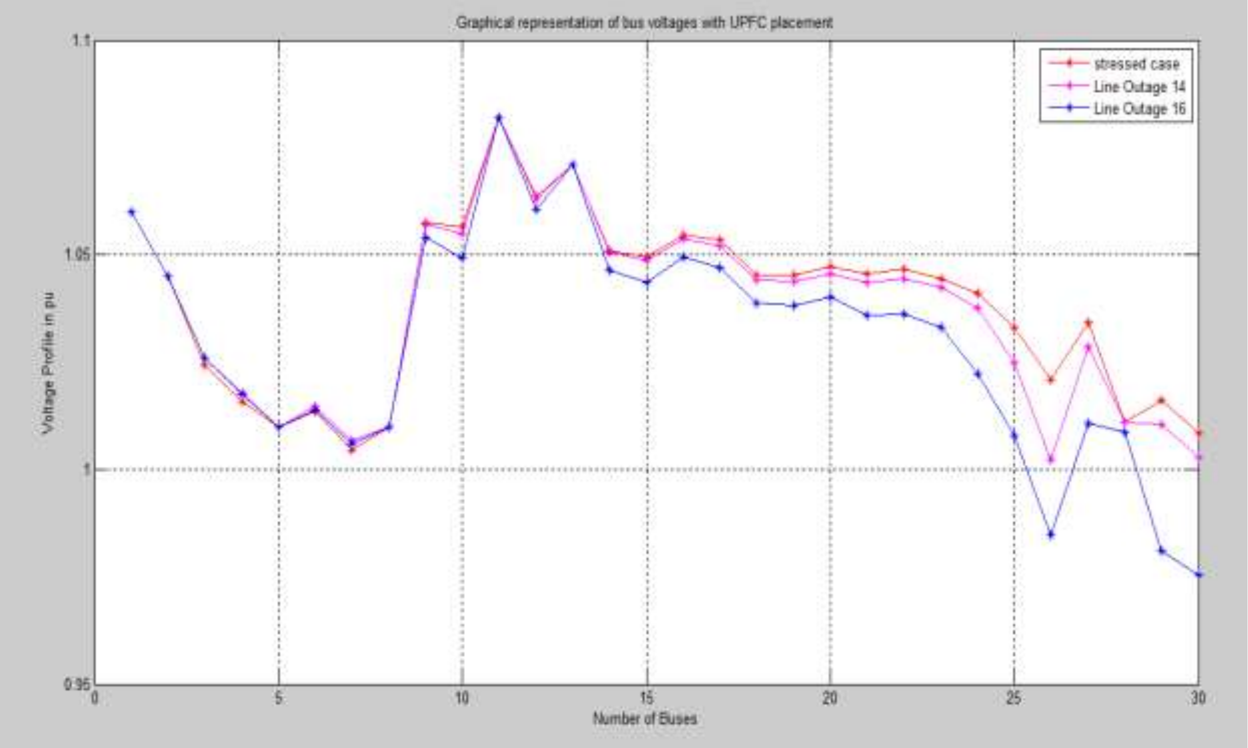

Fig. 3.comparison of voltages(p.u) with UPFC

6. CONCLUSION

In this paper, GA and GSA algorithm based hybrid technique was investigated to improve the stability oftransmission system. The proposed approach was implemented and the performance is evaluated with IEEE 30 bus benchmark system. Initially, the voltage collapse rating of the system is analyzed and the optimal location of UPFC is determined. From the location, injected power rating of UPFC is determined by GA and GSA algorithm depends on the voltage magnitude and angle. Then, UPFC is placed on that location and the stability of the system is analyzed. The stability analysis of proposed method is depends on the magnitude and power loss performance. The result shows that this proposed hybrid algorithm quickly finds the optimal solution in finding the location and size of UPFC than individual GA algorithm.

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