# VOLTAGE STABILITY MARGIN ENHANCEMENT BY OPTIMAL CONTROL OF UPFC USING HYBRID ALGORITHM

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***Abstract*— In the present scenario of the power system the main issue is the voltage stability enhancement which plays an important role in the complex network. This paper introduces the forthcoming technology employing the integration of Flexible AC transmission System (FACTS) device in to the system. Betwixt of all the FACTS devices this paper mainly rivet on Unified Power Flow Controller (UPFC). This is because UPFC has the aid to manage voltage, phase, and reactive power. A hybrid algorithm is developed for the improvement of voltage stability of the power system and to optimize the FACTS controller. The hybrid algorithm abide combination of Particle Swarm Optimization (PSO) and Gravitational Search Algorithm (GSA). PSO is performed to pinpoint the location of the UPFC device in the power system network. Whereas GSA is implemented to optimize UPFC device rating in a sequence. This method proposed was done for IEEE-14 bus system and IEEE-30 bus system using MATLAB platform. The results were impressive by the prospective method for practical applications.**

***Keywords—Voltage Stability, UPFC, FACTS, PSO, GSA***

## I. INTRODUCTION

Nowadays secure operation of power system has always been a challenge to system operators. With increasing interconnection and growing load demand, a power system, sometimes, may go into the insecure operation especially after severe contingencies. A complex network was obtained as a result of interconnection of transmission lines this strategy was done to reduce the fuel and generation plant costs[1].

Voltage stability is defined as the ability of a power system to maintain steady voltages at all the buses in the system after being subjected to a disturbances from a given initial operating condition it depends on the ability to maintain or restore equillibrium between the load demand and load supply from the power system[2]. The two types of voltage instability based on the time frame simulation are: static voltage stability and dynamic voltage stability. A system is said to be voltage stable if at a given operating condition for every bus in the system the bus voltage magnitude increases as the reactive power injection at the same bus is increased[3]. Thus voltage instability is mainly due to imbalance in reactive power flow. The main factors considered for votage analysis are real power, voltage magnitude and angle. Voltage instability problem can be addrressed enhance voltage stability margin of the selected operating system[5]. Therefore for the secure and economic operation Flexible AC Transmission Sytem (FACTS) devices are installed into the system[6].

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 function of FACTS can be voltage control, transient stability improvement and oscillation damping[7]. Depending on the power electronic devices used in the control, the FACTS controllers are classified as: variable impedance type and voltage source-based[8]. Among all the devices UPFC is the most versatile FACTS controller with three control variables. The FACTS controllers provide voltage support at critical buses in the system (shunt connected controllers) and regulate power flow in critical lines(series connected controllers). Whereas UPFC can control both voltage and power flow as its combination of series and shunt controllers[9]. The major advantage of integrating UPFC in power system is not only improves the power handling capability or installing new generations plant but also reduces the generations cost through utiizations of excess power available[10]

## II. VOLTAGE STABILITY ANALYSIS

Voltage stability in a system is defined as the ability of a system to maintain the steady voltages at all buses even after the disturbances in the system. Voltage instability is mainly due to imbalance in reactive power flow in the network. The main factors to be considered for voltage stability analysis are real power, voltage

Where $P_{Gi}, Q_{Gi}, P_{Di}$ *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 voltageangle between $i^{th}$ *and* $j^{th}$ buses. $V_i, V_j,$

in two different ways [4]. The first approach is to mitigate the problem and the second to

magnitude and voltage angle. In order to maintain the voltage stability of the system these are the parameters that are to be controlled. This paper is emphasised on FACTS controllers which plays a vital role in the maintainance voltage to a secure level[11]. Among these FACTS devices this paper concentrates on UPFC as it injects real and reactive power to maintain the voltage stability of the system. Contingency analysis is done in order to determine the best outage condition using Newton-Raphson method[12][13].PSO is used to determine the location of UPFC in power system[14][15]. GSA is used to to determine the capacity of UPFC[16]. The problem can be formulated as multi-objective problem with objectives and constraints as follows:

$$Min\, F(x,u) \qquad (1)$$

$$\text{Subject to} \quad h(x,u) = 0 \qquad (2)$$

$$p(x,u) \le 0 \qquad (3)$$

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 $u$.

### A. *Equality Constraints*

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

$$P_{Gi} - P_{Di} = \sum_{j=1}^{N} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \qquad (4)$$

$$Q_{Gi} - Q_{Di} = \sum_{j=1}^{N} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \qquad (5)$$

$\delta_i$ *and* $\delta_j$.are the magnitude and angle of bus $i^{th}$ *and* $j^{th}$ respectively.

### B. *Inequality Constraints*

The generation limits of the generating units are divided in to upper and lower limits in which actual value lies. The limits of the real and reactive power and the upper and lower limits for voltage magnitude and angles can be mathematically described as follows:

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

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

$$V_n^{min} \le V_n \le V_n^{max} \quad (8)$$

$$\delta_n^{min} \le \delta_n \le \delta_n^{max} \quad (9)$$

$P_n^{min}$ *and* $P_n^{max}$ are the real power limits of the $n^{th}$ bus,

$Q_n^{min}$ and $Q_n^{max}$ are the reactive power limits of the $n^{th}$ bus,

$V_n^{min}$ *and* $V_n^{max}$ are the voltage limits of the $n^{th}$ bus,

$\delta_n^{min}$ *and* $\delta_n^{max}$ are the angle limits of the $n^{th}$ bus

respectively.

## III. CONTINUATION POWER FLOW

The continuation power flow is used to run in various loading conditions. Initially load parameter is one then plot P-V curve for all buses and the weakest bus can be found , then gradually increment the load parameter[18]. When the maximum loading point reaches power flow would stop. Slack bus is also used so all transmission losses distributed among all the buses. The main principle in this technique is simple it uses predictor-corrector scheme to locate a solution path. Mainly two modes are used in this method are local parameterized and perpendicular iteration. Continuation power flow searches for successive load flow solutions according to the load patterns. A Tangent predictor is used to estimate next solution for a specified load scenario, from the base solution. The corrector step uses Newton-Raphson technique to determine exact solution by conventional power flow. For a new load, a new prediction is made based which is depended upon a new tangent vector. At critical point, the tangent vector is zero indicating the critical loadability of the system[19].

The major application of continuation power flow in this paper is for IEEE-14 and IEEE-30 bus systems. In IEEE-14 bus system there are 4 generator buses, 10 load buses, 20 transmission lines and in IEEE-30 bus system there are 5 generator buses, 25 load buses, 41 transmission lines.

## IV. PRINCPLE OPERATION AND INJECTION MODELING OF UPFC

UPFC is one of the most versatile devices in the FACTS family. Depending on the mode of operation it can be used as series/parallel compensator, phase shifter and voltage regulator. UPFC is a generalized as synchronous voltage source (SVS), the UPFC consists of two voltage sourced converters, as these back-to-back converters, labeled "Converter 1" and "Converter 2" are operated from a common dc link provided by a dc storage capacitor. The basic function of Converter 1 is to supply or absorb the real power demanded by Converter 2 at the common dc link to support the real power exchange resulting from the series voltage injection. This dc link power demand of Converter 2 is converted back to ac by Converter 1 and coupled to the transmission line bus via a shunt connected transformer. In addition to the real power need of Converter 2, Converter 1 can also generate or absorb controllable reactive power, if it is desired, and thereby provide independent shunt reactive compensation for the line.

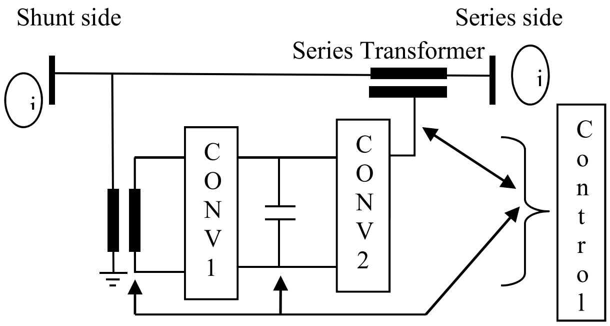

Fig. 1 UPFC device circuit arrangement

The real and reactive power flow model of UPFC is depended on the 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 follows:

$$P_{i,inj,upfc} = -rb_{s\,V_iV_j\sin(\theta_{ij}+\gamma)} \quad (10)$$

$$Q_{i,inj,upfc} = -rb_{s\,V_i^2\cos\gamma + Q_{conv1}} \quad (11)$$

$$P_{j,inj,upfc} = rb_{s\,V_iV_j\sin(\theta_{ij}+\gamma)} \qquad (12)$$

$$Q_{j,inj,upfc} = rb_{s\,V_iV_j\cos(\theta_{ij}+\gamma)} \qquad (13)$$

Having the bus power injections of the UPFC obtained there is the UPFC injection model.

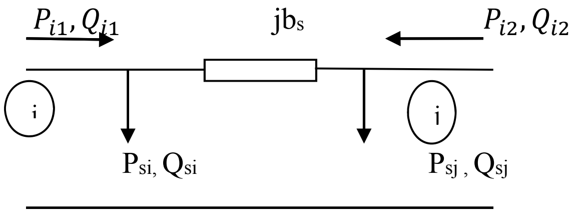

Fig. 2 The UPFC injection model

Besides the bus power injections it is very useful to have expressions for power flows from both sides of the UPFC injection model defined. At the UPFC shunt side, the active and reactive power flows are given as:

$$P_{i1} = -rb_sV_iV_j\sin(\theta_{ij}+\gamma) - b_sV_iV_j\sin\theta_{ij} \qquad (14)$$

$$Q_{i1} = -rb_sV_i^2\cos(\theta_{ij}+\gamma) - b_sV_j^2 + b_sV_iV_j\cos\theta_{ij} \qquad (15)$$

Whereas at the series side they are

$$P_{i2} = +rb_sV_iV_j\sin(\theta_{ij}+\gamma) + b_sV_iV_j\sin\theta_{ij} \qquad (16)$$

$$Q_{i1} = +rb_sV_iV_j\cos(\theta_{ij}+\gamma) - b_sV_j^2 + b_sV_iV_j\cos\theta_{ij} \qquad (17)$$

The UPFC injection model is thereby defined by the constant series branch susceptance, b$_s$ which is included in the system bus admittance matrix [B], and the bus power injections $P_{si}\,, Q_{si}\,, P_{sj}\ and\ Q_{sj}$ .

## V. LOCATION OF UPFC USING PSO

### A. *Overview of Particle Swarm Optimization*

PSO plays an important role as it is a population based stochastic optimization technique. PSO shares similarities with evolutionary computation techniques such as Genetic Algorithms. In , PSO the potential solutions, called particles fly through the problem space by following the current optimum particles.

Each particles keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. This value is called pbest. Another best value that is tracked by the particle swarm optimizer is the best value obtained so far by any particle in the neighbors of the particle. This location is called lbest when a particle takes all the population as its topological neighbors, the best value is a global best and is called gbest. The particle Swarm optimization concept consists of, at each time step, changing the velocity of each particle toward its pbest and lbest locations[20].

Here PSO is used to optimize the location of UPFC. The PSO steps are described below:

Step 1: Initialize a population array.

Step 2: for each particle, evaluate desired optimization

fitness function.

Step 3: Compare particle's fitness evaluation with its

pbest$_i$. If current value is better than pbest$_i$, then

pbest$_i$ = current value

p$_i$= current location x$_i$ in D-dimensional space.

Step 4: Identify the particle with the best success so far,

and assign its index to variable g.

Step 5: Change the velocity and position of the particle.

Step 6: if the criteria is met then exit.

Step 7: If the criteria are not met then go to step 2.

## VI. SIZING OF UPFC USING GSA

A GSA algorithm is based on the Newtonian laws and mass interaction. In the GSA technique, agents are considered to be objects and performances are their masses. Here the continuation power flow outcomes are used for the simulation of GSA algorithm. The bus voltages and the corresponding angles are the input. The input of GSA gives the minimized power loss for each outage condition in the network has been evaluated and the plots have been obtained; depending the evaluation the optimal capacity of UPFC device is determined. The steps to determine the optimal capacity of UPFC can be described as follows:

*Algorithm*

Step 1: To determine the search space of proposed method and initialize the voltage limits and the angle they are considered as agents. Assume that the proposed system consist of $N$ agents and the position of the ith agent is given by:

$$X = \left(x_i^1, \dots . x_i^d, \dots \dots . x_i^n\right)$$

for i=1,2,…….,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 input such as voltages and corresponding angles. From the input the fitness value is evaluated.

$$fitness\ function = Min\left(\sum_{j=1}^{N} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j)\right)$$

For i=1,2,……n

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 M1(t).the gravitational search constant G(t) is initialized at beginning and will reduce the time to control the search precision.

$$G(t) = G(G_0 + t) \qquad (18)$$

$$F(B) = \underset{j \in \{1 \dots N\}}{\text{Min}} FITNESS_j(t) \qquad (19)$$

$$F(W) = \underset{j \in \{1 \dots N\}}{\text{Max}} FITNESS_j(t) \qquad (20)$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)} \qquad (21)$$

$where\ m_i(t) = \frac{F_i(t) - F(B)_t}{F(B)_t - F(W)_t}$,

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:

$$TF_i^d(t) = \sum_{j \neq i} random_j \left(force_{ij}^d(t)\right) \qquad (22)$$

Where,

$$force_{ij}^d(t) = G(t) \frac{M_{pi}(t) * M_{aj}(t)}{R_{ij} + \varepsilon} * \left(y_i^d(t) - y_j^d(t)\right)$$

$R_{ij} = \left\| X_i(t), X_j(t) \right\|_2$ is the Euclidian distance between two agents i and j, $random_j$ is the random values, [0,1]. $\varepsilon$ is a small constant $M_{pi}\ and\ M_{aj}$ are the active and passive gravitational masses of the agents.

Step 6: the acceleration of the ith agent,

$$a_i^d(t) = \frac{TF_i^d(t)}{M_i(t)} \qquad (23)$$

Step 7: Updating agent's velocity and position using,

$$V_i^d(t+1) = random_i V_i^d(t) + a_i^d(t) \qquad (24)$$

$$X_i^d(t+1) = x_i^d(t) + V_i^d(t+1) \qquad (25)$$

Step 8: Repeat the procedure from step 3 to 7 until it reaches the stop criteria.

Step 9: Terminate the process.

The GSA algorithm flowchart for the algorithm is:

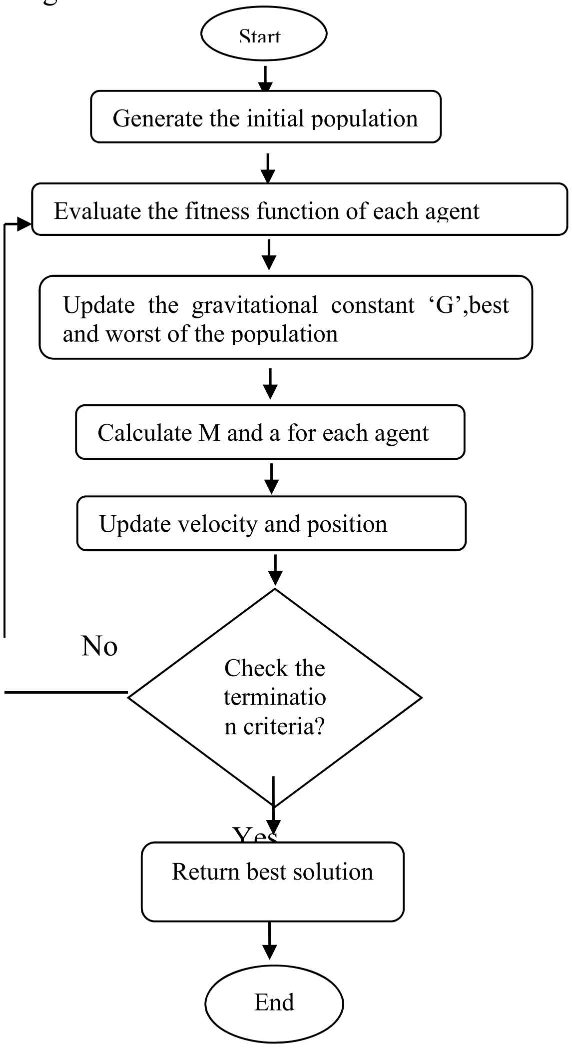

Fig. 3 Flow Chart for GSA Algorithm

## VII. RESULTS AND DISCUSSIONS

In this paper PSO and GSA based hybrid algorithm is proposed for the voltage stability enhancement of the system. This was performed on MATLAB platform and output performance was evaluated for IEEE-14 bus system and IEEE-30 bus system. Firstly Newton-Raphson load flow analysis was used to analyze the system. Contingency analysis for the systems were performed and based on that performance indices were calculated at normal load and were ranked accordingly. Thus the optimal location for UPFC is decided determined based on the contingency analysis. The location of UPFC is optimized by PSO which depends on the fitness value. Nextly the sizing of UPFC is optimized using GSA algorithm. After placing the UPFC in the system the results at the time of voltage collapse was analyzed. 1,2,3,6 and 8 are the generator buses excepted whereas UPFC is connected at all other buses.

TABLE I

BUS VOLTAGES PROFILES WTHOUT AND WITH UPFC

| Bus No: | During Collapse | With UPFC |
|---|---|---|
| 1 | 1.060 | 1.0600 |
| 2 | 1.0450 | 1.0380 |
| 3 | 1.0100 | 1.0100 |
| 4 | 1.0182 | 1.0100 |
| 5 | 1.0207 | 1.0100 |
| 6 | 1.0700 | 1.0700 |
| 7 | 1.0594 | 1.0590 |
| 8 | 1.0900 | 1.0900 |
| 9 | 1.0510 | 1.0500 |
| 10 | 1.0451 | 1.0450 |
| 11 | 1.0600 | 1.0580 |
| 12 | 1.0549 | 1.0549 |
| 13 | 1.0495 | 1.0490 |
| 14 | 1.0323 | 1.0320 |

The iteration performance of GSA is analysed for achieving an optimal voltage and minimum power loss when connecting UPFC. The performances are represented by in figures:2(a) and 2(b). Nextly the magnitudes of voltage of 14 buses are evaluated when connected to UPFC, when the load changes and without connecting UPFC when N-R method is applied. This performances are compared and is depicted in figure 3.

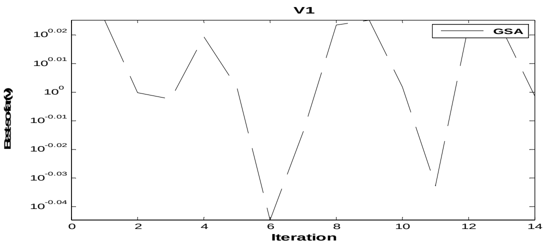

Fig.4(a) Iteration of GSA

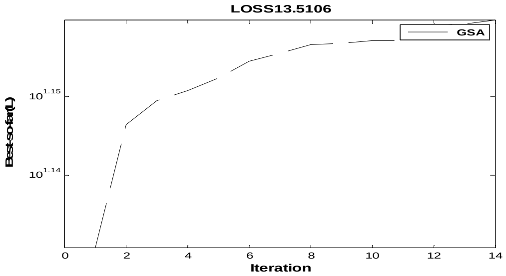

Fig. 4(b) Loss of GSA while connecting UPFC

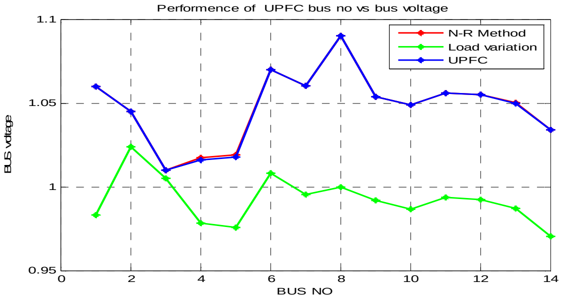

Fig. 5 Comparison performance of bus voltage after connecting UPFC

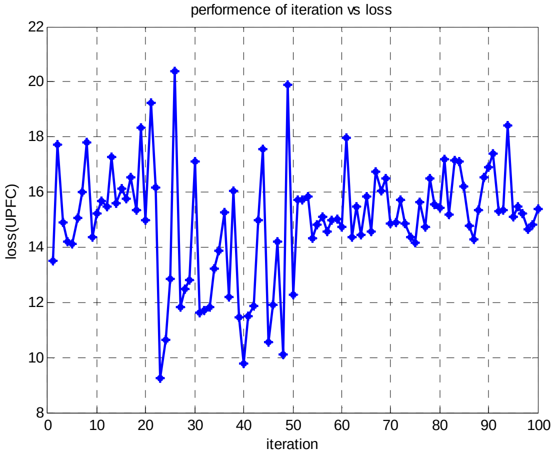

Fig. 6 Loss after connecting UPFC

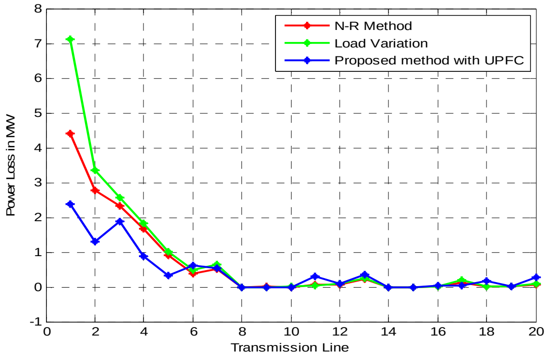

Fig. 7 Transmission line power loss comparison after connecting UPFC

Then the power loss of the system is determined after the connection of UPFC this is being illustrated in figure 4.

In figure 2(a) and (b), the GSA based voltage stability method shows that after the 8th iteration the voltage level has reached to the stable level and the power loss is less. Thus the time of convergence is reduced to achieve the solution. The computational complexity is being reduced in this case. Figure 3 depicts the improvement in voltage stability in the presence of UPFC when compared to the absence of UPFC. Nextly figure 4 shows that the power loss of the system has been reduced at the initial iterations after connecting the UPFC. Finally figure 5 shows that the transmission loss have been reduced when UPFC is connected in the system.

## VIII. CONCLUSION

In this paper a novel approach is done to determine the location and capacity of UPFC in IEEE 14 bus system using an hybrid algorithm. The hybrid algorithm performed in a sequential manner consisting of PSO and GSA respectively. The proposed method was done for IEEE 14 and IEEE 30 bus systems. Firstly load flow analysis was conducted using N-R method for the system. Nextly Contingency analysis was performed based on which the location for UPFC was decided by the application of PSO algorithm. Thereafter continuation power flow analysis was done for the system and using GSA the parameters of UPFC were determined in order to maintain the voltage level in the system. This proposed method for voltage stability margin enhancement quickly finds the optimal solution in determing the location and size of UPFC to be placed in the system.

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