



# Voltage Stability Improvement with finest position of UPFC using GA & PSO

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## ABSTRACT

Power system is a largely inter connected network, due to this interconnection some of the lines may get over loaded and voltage collapse will occur, hence these lines are called weak lines, this causes serious voltage instability at the particular lines of the power system. The improvement of stability will achieve by controlling the reactive power flow. The Flexible Alternating Current Transmission Systems (FACTS) devices have been proposed to effectively controlling the power flow in the lines and to regulate the bus voltages in electrical power systems, resulting in an increased power transfer capability, low system losses and improved stability.

In FACTS devices the Unified Power Flow Controller (UPFC) is one of the most promising device for power flow control. It can either simultaneously or selectively control both real and reactive flow and bus voltage. UPFC is a combination of shunt and series compensating devices. Optimal location of UPFC is determined based on Voltage Stability Index (VSI). GA and PSO techniques are used to set the parameters of UPFC [6]. The objective function formulated here is fitness function, which has to be maximized for net saving. The results obtained using PSO on IEEE 14 Bus is compared with that of results obtained using GA, to show the validity of the proposed techniques and for comparison purposes

**KEYWORDS:** Unified Power Flow Controller (UPFC), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Voltage Stability Index (VSI).

## I. INTRODUCTION

As the load increases, power utilities are looking for ways to maximize the utilization of their existing transmission systems, therefore controlling the power flow in the transmission lines is an important issue in planning and operating of power system. By using FACTS devices [1], it is also possible to control the phase angle, the voltage magnitude at chosen buses and/or line impedances of transmission system. Unified Power Flow Controller (UPFC) [3] is a versatile FACTS device which can independently or simultaneously control the active power, the reactive power, at the bus voltage to which it is connected. Following

factors can be considered in the optimal installation and the optimal parameter of UPFC, the active power loss reduction, the stability margin improvement [2], the power transmission capacity increasing and power blackout prevention. Therefore conventional power flow algorithm should incorporate with UPFC considering one or all of the above mentioned factors. An algorithm is based on the steady state injection model of UPFC, a continuation power flow, and an optimal power flow was proposed in References and implemented an evolutionary programming approach to determine the optimal allocation of multi-type of FACTS devices [5]. This

paper deals with the application of Particle Swarm Optimization (PSO) for finding the optimal location and the optimal parameters setting of the UPFC [6] with the consideration of total power loss reduction in the power system.

## II. SYSTEM MODEL

To study the new control strategy for UPFC [7], a single-machine infinite-bus system is shown in the Fig. 1. The series converter injects a variable voltage source and the shunt converter injects a variable current. This modeling is helpful for understanding the effect of the UPFC on the power system in the steady state. The UPFC model can easily be incorporated in the steady state power flow model [8-9].

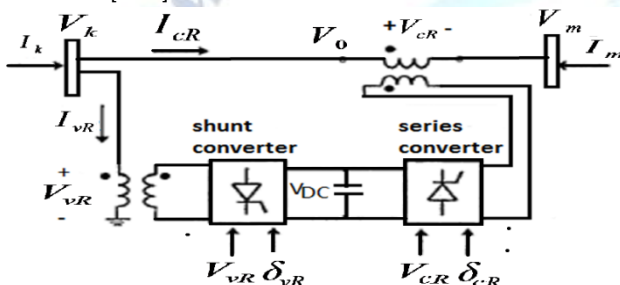


Figure.1. schematic diagram of UPFC

### MODELING OF UPFC

The UPFC voltages are

$$E_{vR} = V_{vR} (\cos \delta_{vR} + J \sin \delta_{vR})$$

Eq.1

$$E_{cR} = V_{cR} (\cos \delta_{cR} + J \sin \delta_{cR})$$

Eq.2

Where  $V_{vR}$  and  $\delta_{vR}$  are the controllable magnitude ( $V_{vRmin} \leq V_{vR} \leq V_{vRmax}$ ) and phase angle ( $0 \leq \delta_{vR} \leq 2\pi$ ) of the voltage source representing the shunt converter. The magnitude  $V_{cR}$  and phase angle  $\delta_{cR}$  of the voltage source representing the series converter are controlled between limits ( $V_{cRmin} \leq V_{cR} \leq V_{cRmax}$ ) and ( $0 \leq \delta_{cR} \leq 2\pi$ ) respectively. The phase angle of the series- injected voltage determines the mode of power flow control. If  $\delta_{cR}$  is in phase with the nodal voltage angle  $\theta_k$ , the UPFC regulates the terminal voltage. If  $\delta_{cR}$  is in quadrature with respect to  $\theta_k$ , it controls active power flow, acting as a phase shifter. If  $\delta_{cR}$  is in quadrature with the line current angle then it controls active power flow, acting as a variable series compensator. At any other value of  $\delta_{cR}$ , the UPFC operates as a combination of voltage regulator, variable series

compensator, and phase shifter. The magnitude of the series-injected voltage determines the amount of power flow to be controlled.

## III. POWER FLOW MODEL

The equivalent circuit consists of two ideal voltage sources representing the fundamental Fourier series component of the switched voltage waveforms at the AC converter terminals. As shown in the Fig.2 Based on the equivalent circuit, the active and reactive power equations [10-11] are

### A. At bus K

$$P_k = V_k^2 G_{kk} + V_k V_m [G_{km} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_k - \theta_m)] + V_k V_{cR} [G_{km} \cos(\theta_k - \delta_{cR}) + B_{km} \sin(\theta_k - \delta_{cR})] + V_k V_{vR} [G_{vR} \cos(\theta_k - \delta_{vR}) + B_{vR} \sin(\theta_k - \delta_{vR})]$$

Eq.3

$$Q_k = -V_k^2 B_{kk} + V_k V_m [G_{km} \sin(\theta_k - \theta_m) - B_{km} \cos(\theta_k - \theta_m)] + V_k V_{cR} [G_{km} \sin(\theta_k - \delta_{cR}) - B_{km} \cos(\theta_k - \delta_{cR})] + V_k V_{vR} [G_{vR} \sin(\theta_k - \delta_{vR}) - B_{vR} \cos(\theta_k - \delta_{vR})]$$

Eq.4

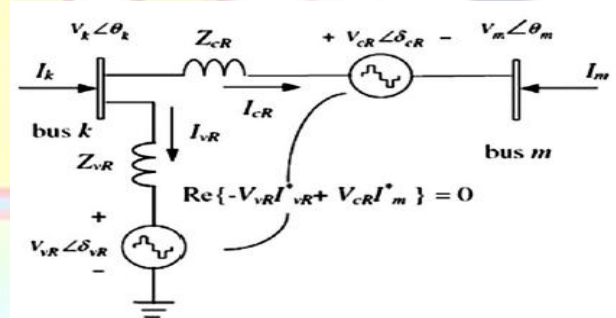


Fig.2. Unified Power Flow Controller equivalent circuit

At bus m

$$P_m = V_m^2 G_{mm} + V_m V_k [G_{mk} \cos(\theta_m - \theta_k) + B_{mk} \sin(\theta_m - \theta_k)] + V_m V_{cR} [G_{mm} \cos(\theta_m - \delta_{cR}) + B_{mm} \sin(\theta_m - \delta_{cR})]$$

Eq.5

$$Q_m = -V_m^2 B_{mm} + V_m V_k [G_{mk} \sin(\theta_m - \theta_k) - B_{mk} \cos(\theta_m - \theta_k)] + V_m V_{cR} [G_{mm} \sin(\theta_m - \delta_{cR}) + B_{mm} \sin(\delta_{cR} - \theta_m)]$$

Eq.6

Assuming loss-free converter valves, the active power supplied to the shunt converter,  $P_{vR}$ , equals the active power demanded by the series converter,  $P_{cR}$ , that is,

$$P_{vR} + P_{cR} = 0$$

Eq.11

Furthermore, if the coupling transformers are assumed to contain no resistance then the active power at bus k matches the active power at bus m,

accordingly.

### UPFC Jacobian Equation

The linearized power equations of UPFC are combined with the linearized system of equations corresponding to the rest of the network

$$[J] = \begin{bmatrix} H_{kk} & H_{km} & H_{kvR} & N_{km} & H_{kcR} & N_{kcR} & H_{cvR} \\ H_{mk} & H_{mm} & 0 & N_{mm} & H_{mvR} & N_{mvR} & 0 \\ J_{kk} & J_{km} & L_{kvR} & L_{km} & J_{kcR} & L_{kcR} & J_{kvR} \\ J_{mk} & J_{mm} & 0 & J_{mm} & J_{mcR} & L_{mcR} & 0 \\ H_{mk} & H_{mm} & 0 & N_{mm} & H_{mcR} & N_{mcR} & 0 \\ J_{mk} & J_{mm} & 0 & L_{mm} & J_{mcR} & L_{mcR} & 0 \\ H_{cRk} + H_{vRk} & H_{cRm} & N_{cRk} + N_{vRk} & N_{cRm} & H_{cRcR} & N_{cRcR} & H_{vRcR} \end{bmatrix}$$

Eq.12

$$[f(x)] = [J][\Delta X]$$

Eq.13

$$[\Delta X] = \left[ \Delta\theta_k \Delta\theta_m \frac{\Delta v_{vR}}{v_{vR}} \frac{\Delta v_m}{v_m} \Delta\theta_{cR} \frac{\Delta v_{cR}}{v_{cR}} \Delta\theta_{vR} \right]^T$$

Eq.14

$\Delta P_{bb}$  = is the power mismatch

$[\Delta X]$  = is the solution vector

$[J]$  = is the Jacobian matrix, T= represents transposition

### IV. VOLTAGE STABILITY INDEX COMPUTATION

Voltage stability index is the one which will give the information about the of voltage collapse in weak bus or also called overload buses, this technique is very much helpful to predict the operating condition of a power system. Voltage stability index (L-Index) developed by Kassel et al based on the power flow solution equation [12]. The L-index illustrates the stability of the entire system. The L-index is a measure for the estimation of system stability limit. A load flow result is obtained for a given system operating condition which is otherwise available from the output of an on line estimator.

Consider the power network consisting n number of buses with 1, 2, g generator buses, and g+1, n remaining (n-g) buses. In this paper we have tested on the IEEE 14 bus system for a given operating condition, using the load flow results, the Voltage stability index 'L' can be calculated as

$$L_j = \left| 1 - \sum_{i=1}^g F_{ji} \frac{V_i}{V_j} \right|$$

Eq.15

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix}$$

Eq.16

### V. EVOLUTIONARY OPTIMIZATION TECHNIQUES

#### Overview of GA

One of the most famous meta-heuristic optimization algorithms is Genetic Algorithm (GA) [13] which is based on natural evolution and population. To reach the near global optimum solution Genetics are used. In each iteration of GA (generation), a new set of string (i.e. chromosomes) with improved fitness is produced using genetic operators (i.e. selection, crossover and mutation).

**Selection Operator:** it will give importance to better individuals, and pass them on their genes to the next generation. The best of each individual depends on its fitness.

By using objective function the Fitness may be determined or by a subjective judgment.

**Crossover Operator:** It is the Prime distinguished factor of Genetic algorithm from other optimization techniques. Using the selection operator two individuals are chosen from the population. A crossover site along the bit strings is randomly chosen. The values of the two strings are exchanged up to this point. If S1=000000 and s2=111111 and the crossover point is 2 then S1'=110000 and s2'=001111. The two new offspring created from this mating are put into the next generation of the population. This process is likely to create even better individuals by recombining portions of good individuals,

**Mutation Operator:** a portion of the new individuals will have some of their bits flipped with some low probability. The purpose of Mutation is to maintain diversity within the population and prevent premature convergence. Mutation alone induces a random walk through the search space; Mutation and selection (without crossover) create a parallel, hill-climbing algorithm.

#### Overview of PSO

First proposed by Kennedy and Eberhart in 1995, inspired by social behavior of bird flocking or fish schooling .Particle Swarm Optimization (PSO) is a population-based optimization method [14] it is

also related, however, to evolutionary computation, and has ties to both genetic algorithms and evolutionary programming. The PSO as an optimization tool provides a population-based search procedure in which individuals called particles change their position (state) with time. In a PSO system, particles fly around in a multidimensional search space. During flight, each particle adjusts its position according to its own experience (This value is called Pbest), and according to the experience of a neighboring particle (This value is called Gbest), made use of the best position encountered by itself and its neighbor. After finding the best values the particles updated its velocity and position with the following equation:

$$V_1^{k+1} = W V_1^k + C_1 * rand1 * (P_{best1} - S_1^k) + C_2 * rand2 * (G_{best1} - S_1^k)$$

Eq.18

$$S_i^{k+1} = S_i^k + V_i^{k+1}$$

Eq.19

$$W = W_{max} - \left( \frac{W_{max} - W_{min}}{iter_{max}} \right) * iter$$

Eq.20

### VI. UPFC COST FUNCTION

Using Siemens AG Database, cost function for UPFC is developed [15-16] as follows:

$$C_{UPFC} = 0.0003S^2 - 0.2691S + 188.9US\$/KVAR$$

Eq.21

$$S = |Q_2 - Q_1|$$

Eq.22

Where, Operating range of UPFC is in MVAR  
 Q1= MVAR flow through the branch before placing FACTS device

Q2= MVAR flow through the branch after placing FACTS device

The goal of optimization algorithm is to place FACTS devices in order to enhance voltage stability margin of power system considering cost function FACTS devices. So these devices should be place to prevent congestion in transmission lines and transformer and maintain bus voltages close to their reference.

### VII. FITNESS FUNCTION

The fitness function [16] can be expressed as bellow

$$Max, f = \{k_e * T * [T_L - UPFC T_L] - \alpha [C_{UPFC} * UPFC_{rating}]\}$$

Eq.23

Where, Ke =Energy Cost,

T = Time Period (8760),

T<sub>L</sub>= Total power loss before UPFC placement,

α = Depreciation factor is 0.1

C<sub>UPFC</sub> = UPFC Cost in Rs/KVAR, UPFC<sub>rating</sub> = Rating of the UPFC,

### VII. SUMMARY OF PROPOSED TECHNIQUES FOR IEEE-14 BUS TEST SYSTEM:

Aspec t	Without UPFC	UPFC+GA	UPFC+PS O	
PQ Los ses	P <sub>Lo ss</sub>	14.02138 MW	13.960192 MW	13.913635 MW
	Q <sub>L oss</sub>	54.425583 MVAR	51.935853 MVAR	51.702028 MVAR
Total Losses		54.2682M VA	53.7794M VA	53.5424M VA
proposed location		Between bus10 & 11	Between bus 9 and 14	
Investment Cost of UPFC		7087.245 Rs/MW	7037.36 Rs/MW	
Fitness Value		70.803	68.90	
Elapsed Time		1.434176 min	1.197035 min	

TABLE-I: Voltage Profile

Bus number	Voltage(with out UPFC)	Voltage(G A)	Voltage(PS O)
1	1.00000	1.00000	1.00000
2	1.00000	1.00000	1.00000
3	1.00000	1.00000	1.00000
4	0.95205	1.00000	1.00000
5	1.00000	1.00000	1.00000
6	1.01514	1.02334	1.02333
7	1.01814	1.03280	1.03284
8	1.01814	1.02859	1.2871
9	0.11419	1.00609	1.00624
10	0.98815	1.00000	1.00000
11	0.99194	1.05000	1.05000
12	0.98516	1.03489	1.03594
13	0.98482	1.03184	1.03182
14	0.92566	0.95483	0.95494

TABLE.2. Percentage Power Flows:

Line number	PQ Flows (With out)	PQ Flows	PQ Flows (PSO)
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	UPFC)	(GA)	
1	0.4999	0.9420	0.9423
2	0.5491	0.5543	0.5536
3	0.5700	0.5639	0.5643
4	0.8824	0.8780	0.8747
5	0.7294	0.7419	0.7401
6	0.7312	0.7316	0.7301
7	0.7224	0.5503	0.5639
8	0.4680	0.5927	0.5424
9	0.3865	0.4209	0.4210
10	0.7967	0.9022	0.9069
11	0.9462	0.9098	0.9096
12	1.0594	0.9796	0.9891
13	0.5314	0.3571	0.4052
14	1.0435	0.9962	0.9793
15	0.2957	0.0619	0.0619
16	0.0595	0.0484	0.0519
17	0.5879	0.6952	0.7025
18	0.1922	0.1383	0.1479
19	0.5281	0.4570	0.4690
20	0.7856	0.9001	0.8832

TABLE.3. Power Loss information:

Line number	PQ Loss (without UPFC)	PQ Loss(GA)	PQ Loss(PSO)
1	5.7265	5.5896	5.5947
2	7.8874	8.0325	8.0071
3	8.0235	7.8041	7.8181
4	3.9227	3.7793	3.8000
5	2.1020	2.1932	2,1744
6	0.4510	0.4442	0.4407
7	0.1837	0.6260	0.4407
8	0.4764	0.6926	0.5801
9	0.4184	0.4497	0.4499
10	0.9152	1.0636	1.0748
11	6.3416	5.7750	5.7723
12	4.9648	4.1817	4.2626
13	0.2642	0.1165	0.1499
14	3.3703	2.9996	2.8978
15	0.1915	0.0037	0.0126
16	0.0211	0.0067	0.0077
17	1.4351	1.8025	1.8403
18	0.3167	0.1614	0.1845
19	1.5413	1.1360	1.1963
20	6.3398	8.1540	7.8474
Total Losses	54.2682	53.7794	53.5424

## VIII. RESULTS

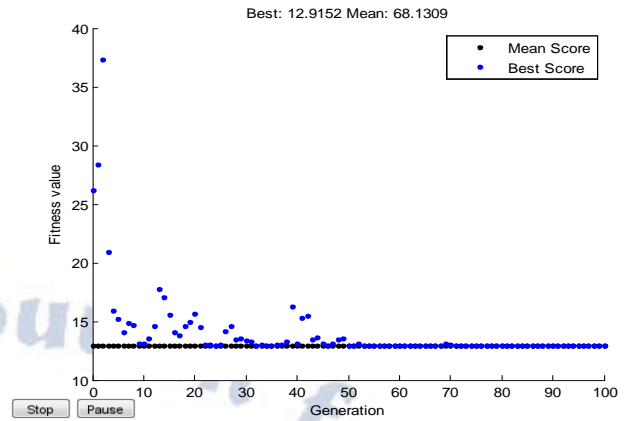


Fig.3. Plot between Objective Function of GA Vs Generations

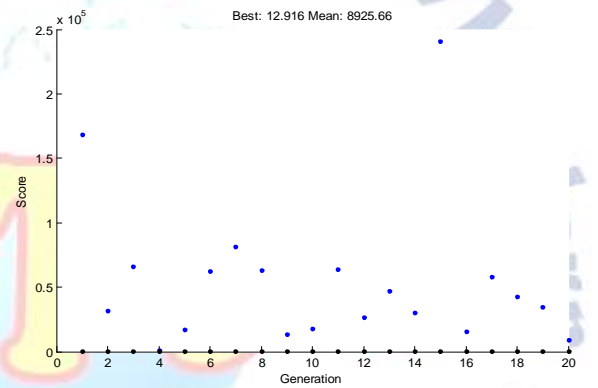


Fig.4. Plot between objective function of PSO Vs Generations

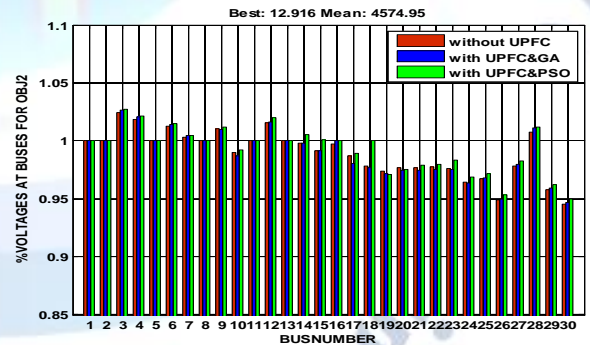


Fig.5. Voltage profile

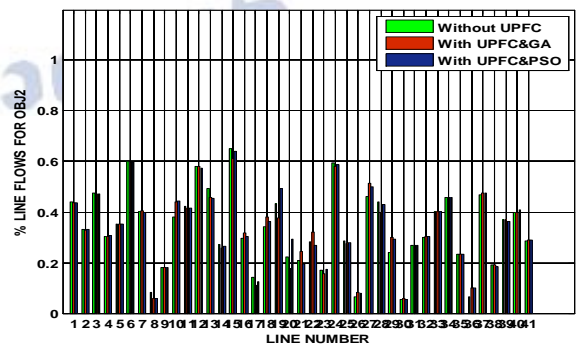


Fig.6. line flows

## IX. CONCLUSION

In this paper, voltage stability index has been identified, which will enhance the power system stability. GA and PSO techniques are implemented for finding the optimal location for UPFC in the IEEE 14 Bus System. The obtained results show that PSO technique has superior features than GA, including high quality solution, stable convergence characteristics and good computation efficiency. Finally our results show that using UPFC in the optimal location with the optimal parameter settings can significantly improve the security of power system.

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