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WIPSO, PSO and GA Techniques to Locate UPFC Effectively in Power System to Improve Voltage Stability and Reduce Losses

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***Abstract:** The domestic and industrial demand for electricity has been increasing extensively making the power system more expensive. With this increases in demand for electricity, the losses also increase in demand for electricity the losses also increase from power generation to distribution Flexible alternating currents transmission system (FACTS) is used to maintain flexible operation of the power system from power generation level to the distribution level. The reliability of the network system can be enhanced by using FACTs devices in the power system more reliably, the inventions in the advanced power electronics devices can be implemented in the design of FACTs, serices, shunt, serices-shunt and shunt-shunt are some of the FACTs devices. One way to operate the power system with less power losses and improved system voltage profile is to use FACTs. Unified power flow controller (UPFC) is one of the serices-shunt FACTs systems. This paper throws light on how UPFC can be used to improve the voltage profile and reduce the installation cost of UPFC, the system loss, in the electrical power system. Analyst and soft computing methods such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Weight Enhanced Particle Swarm Optimization (WIPSO) are used to determine ideal FACTs device settings and FACTs device place.*

***Keywords:** Flexible alternating currents transmission system (FACTS), Unified power flow controller (UPFC), Genetic algorithm (GA), particle swarm optimization (PSO), weight improved particle swarm optimization (WIPSO).*

I. INTRODUCTION

The contemporary energy system networks are operated under extremely strained circumstances due to the ever-increasing demand for electrical energy. As a result of this stressed operations the bus voltage has become a challenge. The system's power to maintain adequate voltage under ordinary operating circumstances is voltage stability, absence of voltage fluctuations. The use of FACT instruments can efficiently enhance voltage stability and stable state and transient stability of the strained energy system. FACT devices positioned in the energy system network at suitable places help mitigate voltage instability.
Improving power transmission capacity, enhancing static and dynamic stability, increasing accessibility and decreasing transmission losses are key factors for using FACT equipment, including the capacity to regulate transmission line parameters and variables.

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UPFC is used for voltage control applications such as Static Var Compansator, Static Synchronous Compensaator, Thyristor Controlled Series Capacitor, Thyristor Controlled Phase Shifter, Static Synchronous Series Compensator, and Unified Power Flow Controller. Helps keep a bus voltage during load changes at the required value. UPFC can be used for generating or absorbing reactive power by changing the firing angle. The place of the voltage to be fixed and the angle to be poured are the main issues in the FACT controllers. Using stochastic algorithms can solve this issue. Some of the stochastic algorithms are Genetic Algorithms, Differential Evolution, Tabu Search, Simulated Annealing, Ant Colony Optimization, Particular Swarm Optimization and Bees Algorithm. These algorithms are unique in nature and have widespread use of their own benefits including GA, PSO and WIPSO.

II. UNIFIED POWER FLOW CONTROLLER

UPFC's corresponding circuit displayed in Fig.1 is used to device the steady state model.

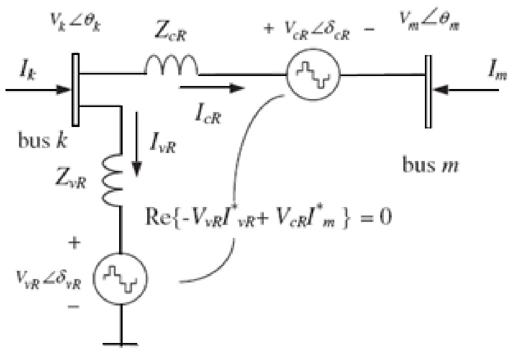

Fig. 1 Unified Power Flow Controller equivalent circuit

The equivalent circuit comprises of two optimal voltage sources at the AC converter terminals representing the fundamental component of the Fourier series of the switched voltage waveforms. The perfect source of voltage is:

$$V_{vR} = V_{vR}\ (cos\theta_{vR} + sin\theta_{vR})$$
$$V_{cR} = V_{cR}\ (cos\theta_{cR} + sin\theta_{cR})$$

Where V_{vR} and θ_{vR} are the controllable magnitude ($V_{vRmin} \leq V_{vR} \leq V_{vRmax}$) and angle ($0 \leq \theta_{vR} \leq 2\pi$) of the voltage source representing the shunt converter. The magnitude V_{cR} and angle θ_{cR} of the voltage sources of the series converter are controlled between limits ($V_{cRmin} \leq V_{cR} \leq V_{cRmax}$) and ($0 \leq \theta_{cR} \leq 2\pi$), respectively Based on the equivalent circuit shown in Fig.1, the active and reactive power equations are At $node\ k$:

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

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

At *node m*:

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

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

Series converter:

$$P_{cR} = V_{cR}^2 G_{mm} + V_{cR} V_k (G_{km}\cos(\theta_{cR} - \theta_k) + B_{km}\sin(\theta_{cR} - \theta_k)) + V_{cR} V_m (G_{mm}\cos(\theta_{cR} - \theta_m) + B_{mm}\sin(\theta_{cR} - \theta_{vR}))$$

$$Q_{cR} = -V_{cR}^2 B_{mm} + V_k V_{cR}(G_{km}\sin(\theta_{cR} - \theta_k) - B_{km}\cos(\theta_{cR} - \theta_k)) + V_m V_{cR}(G_{mm}\sin(\theta_{cR} - \theta_m) - B_{mm}\cos(\theta_{cR} - \theta_m))$$

Shunt converter:

$$P_{vR} = -V_{vR}^2 G_{vR} + V_{vR} V_k (G_{vR}\cos(\theta_{vR} - \theta_k) + B_{vR}\sin(\theta_{vR} - \theta_k))$$

$$Q_{vR} = V_{vR}^2 B_{vR} + V_{vR} V_k (G_{vR}\sin(\theta_{vR} - \theta_k) - B_{vR}\cos(\theta_{vR} - \theta_k))$$

The UPFC does not absorb or inject active power with regard to the AC system, assuming a loss-free converter operation. The shunt converter provides the active power required by the series converter from the AC power scheme via the prevalent DC connection. The voltage of the Dc connection stays continuous. The active power provided to the shunt converter must therefore meet the active power the series converter requires.

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

III. VOLTAGE STABILITY INDEX

The voltage stability indexes are introduced in order to evaluate the stability limit. Stability of voltage is an essential issue for the safe operation of today's energy systems. The difficulty of voltage instability is regarded primarily as the network's failure to satisfy the load demand imposed by insufficient reactive power assistance or active power transmission capacity or both. It focuses primarily on analyzing and enhancing FVSI-based stable state voltage stability.

Consider a n-bus scheme with 1, 2, 3, ... n, the load buses and g+1,g+2, ... n. By using a hybrid representation, the transmission system can be entitled to the following set of equations,

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

Where,

$Z_{LL}, F_{LG}, K_{GL}, Y_{GG}$ are the sub-matrices of the hybrid matrix H.

The H matrix can be assessed by partial inversion from the Y bus matrix, where the voltages at the load stations are exchanged against their currents. This representation can then be used to describe an indicator of voltage stabilization at the load bus, namely L_j. by,

$$L_j = \left| 1 + \frac{V_{0j}}{V_j} \right| \quad and \quad V_{0j} = \sum_{i \epsilon G} F_{ji} V_i$$

The word V_{oj} represents an equivalent generator that includes all generators ' contribution. It is also possible to derive the index L_j and express it in terms of the following energy terms.

$$L_j = \left| \frac{S_j^*}{Y_{jj} + V_j^2} \right|$$

Where, $S_j^* = S_{jcorr} + S_j$, * indicates the complex conjugate of the vector.

$$S_{jcorr} = \left(\sum_{\substack{i \epsilon Loads \\ i \neq j}} \frac{Z_{ji}^* S_i}{Z_{jj}^* V_i} \right) \times V_j$$

$$Y_{jj} = \frac{1}{Z_{jj}}$$

The complex power term element Sjcorr reflects the contributions to the index assessed at node j from the other loads in the scheme. When a load bus approaches a condition of collapse of a steady state voltage, the L_j voltage index reaches the number 1.0. The index assessed at any of the buses must therefore be less than unit for a general system stability situation. The index value L_j thus provides an indication of how far the device has come from the crash of voltage. For all load buses, the L_j indices for a given load condition are calculated. The L-index equation for the j[th] node can be written as,

$$L_j = \left| 1 - \sum_{i=1}^{i=g} |F_{ji}| \frac{|V_i|}{|V_j|} (F_{ji}^r + jF_{ji}^m) 1 - \sum_{i=1}^{i=g} |F_{ji}| \frac{|V_i|}{|V_j|} \angle\theta_{ji} + \delta_i - \delta_j \right|$$

$$L_j = \left| 1 - \sum_{i=1}^{i=g} |F_{ji}| \frac{|V_i|}{|V_j|} (F_{ji}^r + jF_{ji}^m) \right|$$

$$F_{ji}^r = |F_{ji}| \cos(\theta_{ji} + \delta_i - \delta_j) \text{ and } F_{ji}^m = |F_{ji}| \sin(\theta_{ji} + \delta_i - \delta_j)$$

It noted that if the load bus approaches a condition of crash of a steady state voltage, the L_j index approaches the number value 1.0. Therefore, the index assessed at any of the buses must be less than unit for a complete system voltage stability condition. Thus the voltage index value L gives an indication of how far the system is from voltage collapse.

IV. UPFC COST AND FITNESS FUNCTION

Since the cost of the UPFC devices is high, the devices must be installed at the optimal locations in order to achieve the maximum benefit. The objective function has three conditions; the first word reflects the highest value of L_j, the second and third terms representing UPFC device costs and line losses respectively. Minimizing the suggested objective function is expressed as follows:

$$Multi\ Objective\ Optimization\ \ function(K) = K_1 * (max\ L_j) + K_2 * C_{UPFC} + K_3 * (Losses)$$

Where constants are K1, K2 and K3,
The cost function for UPFC is:

$$C_{UPFC} = 0.0003S^2 - 0.2691S + 188.22\ \ US\$/kVAR$$

$S = |Q_{withupfc} - Q_{withoutupfc}|$, S is operating range of UPFC in MVAR

V. SOFT COMPUTING TECHNIQUES

A. Particle Swarm Optimization (PSO) Technique*:*

Eberhart and Kennedy have created a heuristic search technique, a PSO based on the swarm intelligence idea. SI was displayed by a fish flock of Birds College, etc. It is conduct on self-experience and swarm experience in this method. PSO is comparable to the GA method of evolutionary computation. By pursuing the present optimum particles, particles also called prospective solutions fly through the problem space. The best fitness value is called Pbest. The Pbest values are evaluated and compared against the previous iteration values obtained. The best values of fitness function of the particles. In the next generation Pbest are refined. The best value, when a particle takes all population as neighbours is called global best (Gbest). Comparing the present and previous iteration Gbest and retaining the least Gbest value.

This modification can be represented by the concept of velocity. Velocity of each agent can be modified by the following equation:

$$V_i^{k+1} = WV_i^k + C_1 \times r1 \times (P_{besti} - S_i^k) + C_2 \times r2 \times (G_{besti} - S_i^k)$$

Where V_i^k = Velocity of agent i at k^{th} iteration
V_i^{k+1} = The Velocity of agent i at $(k+1)^{th}$ Iteration
W = Weight of inertia
C_1, C_2 = cognitive & social factors
S_i^k = Current location of the Agent's at k^{th} iteration
S_i^{k+1} = Current position of agent at $(k+1)^{th}$ Iteration
$iter_{max}$ = Maximum iteration number
$r1, r2$ = The chosen random numbers from 0 to 1.
P_{besti} = P_{best} of agent i
G_{besti} = G_{best} of the group

$$W = W_{max} - \frac{W_{max} - W_{min}}{iter_{max}} \times iter$$

The above Equation is called "inertia weights approach (IWA)". Using the above equation, the diversification trait is gradually reduced and a certain velocity can be calculated, which gradually passes the present search point near Pbest and Gbest.. The current position (search point the solution space) can be modified by the following equation:

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

Where S_i^k = Agent's current location at k^{th} iteration
S_i^{k+1} = Current position of agent at $(k+1)^{th}$ iteration

B. Weight Improved Particle Swarm Optimization (WIPSO)

The base for the WIPSO method is improved weight parameter function. In order to achieve a better worldwide solution, the traditional PSO algorithm is enhanced by changing the inertia weight, cognitive and social factor. The velocity of an individual of WIPSO is determined by

$$V_i^{k+1} = W_{new}V_i^k + C_1 \times r1 \times (P_{besti} - S_i^k) + C_2 \times r2 \times (G_{besti} - S_i^k)$$

$$W_{new} = W_{min} + W * r_3$$

$$W = W_{max} - \frac{W_{max} - W_{min}}{iter_{max}} * iter$$

$$C_1 = c_{1max} - \frac{C_{1max} - C_{1min}}{iter_{max}} * iter$$

$$C_2 = c_{2max} - \frac{C_{2max} - C_{2min}}{iter_{max}} * iter$$

r_1, r_2 and r_3: The random numbers selected between 0 and 1.
W_{max}, W_{min}: Initial & Final Weights
c_{1min}, c_{1max} : Initial and final cognitive factor
c_{2min}, c_{2max}: =Initial and final social factor.
*Iter*max=Maximum iteration number.

VI. SIMULATED RESULTS

GA, PSO and WIPSO algorithms were tested on the following IEEE 5, 9, 30 -Bus test systems to validate the suggested methods.

A. IEEE 5 Bus System:

IEEE BUS-5 system problem has been solved with the presence of UPFC in the 5-BUS test system .By taking the highly mobile voltage solidity indication, bus-5 is more vulnerable interims of system protection, with the help of node bus-6,UPFC have been joitled , the affected real network is inclusive of a UPFC, placed between nodel points bus-5 and bus-6. The addition of UPFC voltage solidity index has enhanced alot than previous. The set of rules were applied to trace the variable settings and consecration charges of the UPFC in IEEE-5 bus test system. Simulation results of voltage and phase angles of UPFC as shown in Table 1, with GA, PSO, and WIPSO have been compared and displayed in below Table 2.

Table 1 Comparison of UPFC voltage and phase angles with GA, PSO and WIPSO

Bus No	UPFC with GA		UPFC with PSO		UPFC with WIPSO	
	Voltage Mag (p. u)	Phase Angle (deg)	Voltage Mag (p. u)	Phase Angle (deg)	Voltage Mag (p. u)	Phase Angle (deg)
1	1.060	0.000	1.060	0.000	1.060	0.000

2	1.000	-2.181	1.000	-2.181	1.000	-2.181
3	0.997	-4.361	0.997	-4.363	0.997	-4.363
4	0.996	-4.581	0.997	-4.584	0.997	-4.584
5	1.000	-7.376	1.000	-7.379	1.000	-7.379
6	1.020	-4.003	1.021	-4.014	1.021	-4.014

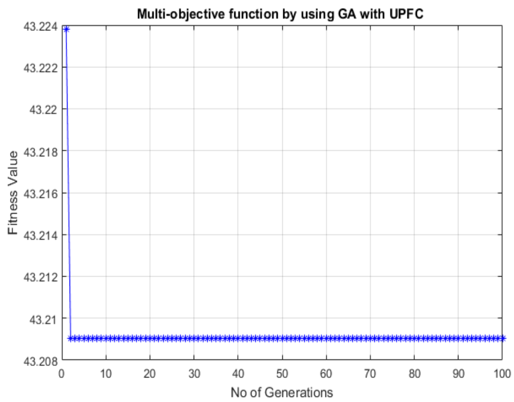

Fig .2 Minimization Multi-objective function by using GA with UPFC

Multi objective fitness function (K) is comprised with variables like loss quantity and cost, to minimise losses per MVA. By using this function we can effectively minimise losses and cost per MVA. With the effective utilization UPFC, with various control methods with it. Below Figs. 2, 3 and 4, indicating improvements in the system. Furthermore Cost/MVA has been improvements in the system. Furthermore cost/MVA has been minimised step by step with, UPFC, GA with UPFC, PSO with UPFC and WIPSO with UPFC. At the same time losses also considerably reduced those valves are shown in Table 2. Finally UPFC with WIPSO has shown best results in terms of Cost and losses per MVA.

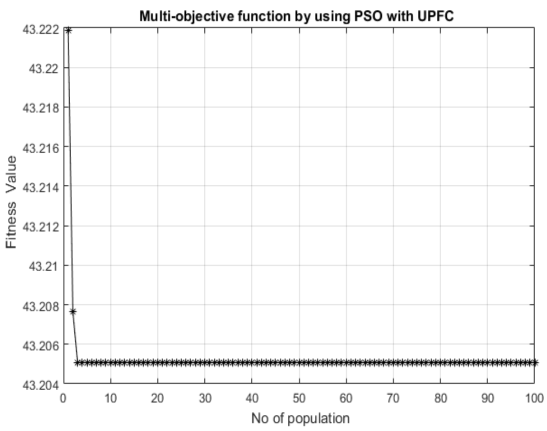

Fig .3 Minimization Multi-objective function by using PSO with UPFC

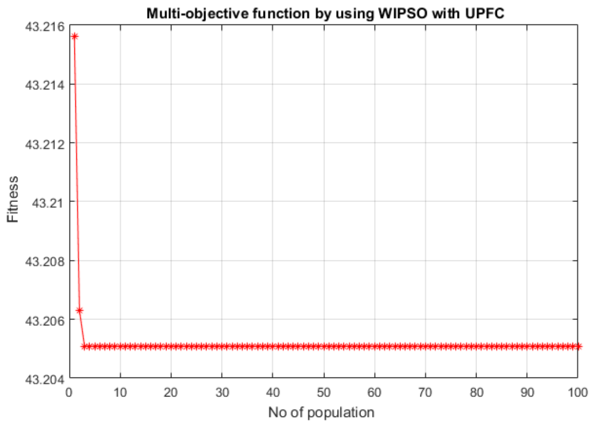

Fig .4 Minimization Multi-objective function by using WIPSO with UPFC

Table 2 GA, PSO and WIPSO comparison for 5-Bus testing system

Aspect	Existing Method with UPFC	Genetic Algorithm (GA)	Particle Swarm Optimization (PSO)	Weight Improved PSO (WIPSO)
Power loss without UPFC (MVA)	12.395	12.395	12.395	12.395
Power loss without UPFC (MVA)	12.100	12.073	12.073	12.070
Cost of UPFC Rs/kVAR)	174.703	183.767	183.70	183.701
Fitness Value (K)	42.358	43.209	43.205	43.205
Elapsed Time (Sec)		6.820	2.814	2.73

B. IEEE 9 Bus System:

IEEE BUS-9 system problem has been solved with the presence of UPFC in the 9-BUS test system .By taking the highly mobile voltage solidity indication, bus-4 is more vulnerable interims of system protection, with the help of node bus-10,UPFC have been joitled , the affected real network is inclusive of a UPFC, placed between nodel points bus-4 and bus-10. The addition of UPFC voltage solidity index has enhanced alot than previous. The set of rules were applied to trace the variable settings and consecration charges of the UPFC in IEEE-9 bus test system. Simulation results of voltage and phase angles of UPFC as shown in Table 3, with GA, PSO, and WIPSO have been compared and displayed in below Fig. 5 and Table 4.

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Table 3 Comparison of UPFC voltage and phase angles with GA, PSO and WIPSO

Bus No	UPFC with GA		UPFC with PSO		UPFC with WIPSO	
	Voltage Mag (p. u)	Phase Angle (deg)	Voltage Mag (p. u)	Phase Angle (deg)	Voltage Mag (p. u)	Phase Angle (deg)
1	1.030	0.000	1.030	0.000	1.030	0.000
2	1.040	2.326	1.040	2.500	1.040	2.463
3	0.997	2.361	1.005	2.872	1.003	2.768
4	1.000	1.982	1.000	2.488	1.000	2.987
5	1.027	4.159	1.006	3.103	1.006	3.426
6	1.019	4.426	1.012	3.751	1.012	3.887
7	1.010	5.043	1.010	4.706	1.010	4.778
8	1.022	1.579	1.022	1.473	1.022	1.495
9	1.027	3.398	1.026	3.305	1.026	3.334
10	1.035	4.070	1.018	3.033	1.012	2.818

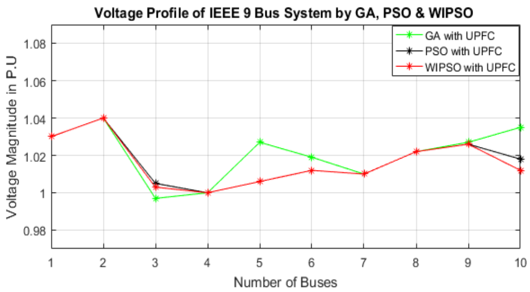

Fig. 5 Comparison with suggested WIPSO, PSO & GA techniques for voltage magnitudes and phase angles UPFC

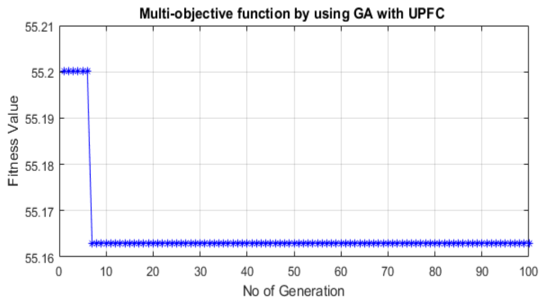

Fig .6 Minimization Multi-objective function by using GA with UPFC

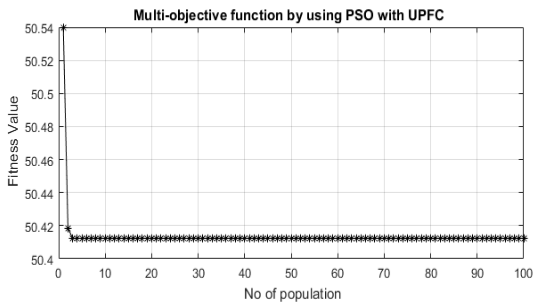

Fig .7 Minimization Multi-objective function by using PSO with UPFC

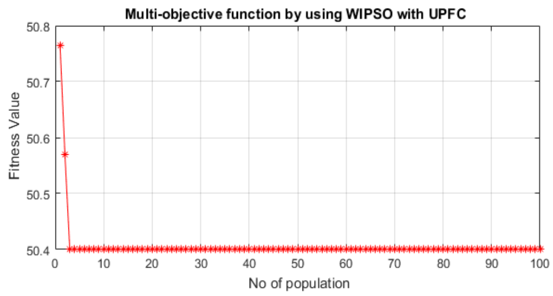

Fig .8 Minimization Multi-objective function by using WIPSO with UPFC

Table 4 GA, PSO and WIPSO comparison for the 9-Bus test system

Aspect	Existing Method with UPFC	Genetic Algorithm (GA)	Particle Swarm Optimization (PSO)	Weight Improved PSO (WIPSO)
Power loss without UPFC (MVA)	26.836	26.836	26.836	26.836
Power loss without UPFC (MVA)	20137	18.081	15.873	15.847
Cost of UPFC (Rs/kVAR)	179.351	184.267	178.102	178.102
Fitness Value (K)	58.163	55.163	50.412	50.400
Elapsed Time in Sec		4.763	4.321	3.783

Multi objective fitness function (K) is comprised with variables like loss quantity and cost, to minimise losses per MVA. By using this function we can effectively minimise losses and cost per MVA. With the effective utilization UPFC, with various control methods with it. Below Figs. 6, 7 and 8, indicating improvements in the system. Furthermore Cost/MVA has been improvements in the system. Furthermore cost/MVA has been minimised step by step with, UPFC, GA with UPFC, PSO with UPFC and WIPSO with UPFC. At the same time losses also considerably reduced those valves are shown in Table 4. Finally UPFC with WIPSO has shown best results in terms of Cost and losses per MVA

C. IEEE 30 Bus System:

IEEE BUS-30 system problem has been solved with the presence of UPFC in the 30-BUS test system .By taking the highly mobile voltage solidity indication, bus-30 is more vulnerable interims of system protection, with the help of node bus-31,UPFC have been joitled , the affected real network is inclusive of a UPFC, placed between nodel points bus-24 and bus-31. The addition of UPFC voltage solidity index has enhanced alot than previous. The set of rules were applied to trace the variable settings and consecration charges of the UPFC in IEEE-30 bus test system. Simulation results of voltage and phase angles of UPFC as shown in Fig.3, with GA, PSO, and WIPSO have been compared and displayed in below Table 6.

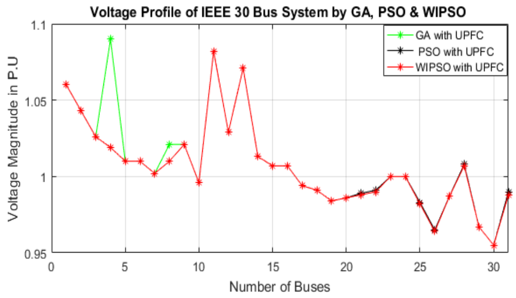

Fig. 9 Comparison for Voltage magnitudes and phase angles UPFC with proposed WIPSO, PSO & GA Techniques

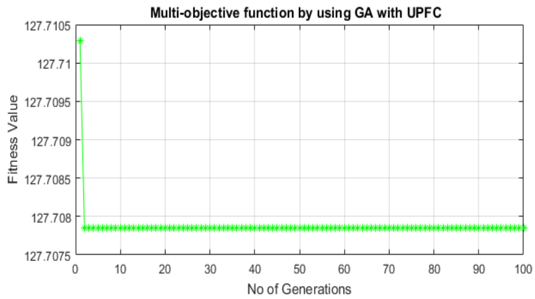

Fig .10 Minimization Multi-objective function by using GA with UPFC

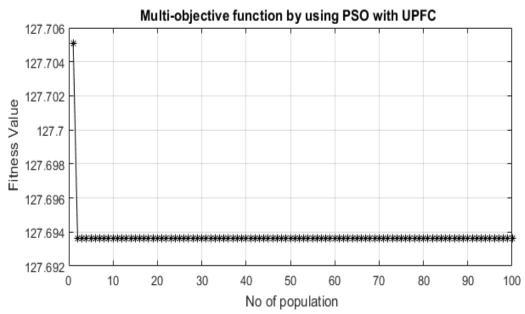

Fig .11 Minimization Multi-objective function by using PSO with UPFC

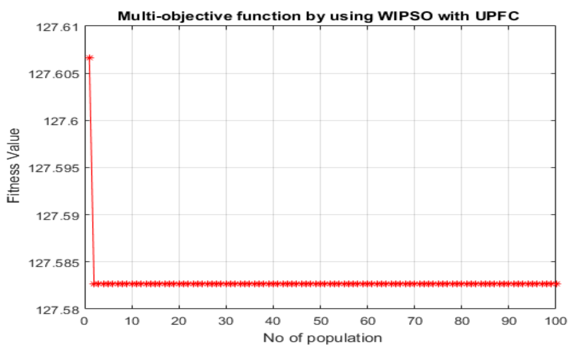

Fig .12 Minimization Multi-objective function by using WIPSO with UPFC

Multi objective fitness function (K) is comprised with variables like loss quantity and cost, to minimise losses per MVA. By using this function we can effectively minimise losses and cost per MVA. With the effective utilization UPFC, with various control methods with it. Below Figs. 10, 11 and 12, indicating improvements in the system. Furthermore Cost/MVA has been improvements in the system. Furthermore cost/MVA has been minimised step by step with, UPFC, GA with UPFC, PSO with UPFC and WIPSO with UPFC. At the same time losses also considerably reduced those valves are shown in Table 6. Finally UPFC with WIPSO has shown best results in terms of Cost and losses per MVA

Table 6 Comparison of GA, PSO and WIPSO for 9-Bus test System

Aspect	Existing Method with UPFC	Genetic Algorithm	Particle Swarm Optimization	Weight Improved PSO
Power loss without UPFC (MVA)	55.933	55.933	55.933	55.933
Power loss without UPFC (MVA)	53.088	53.081	52.074	51.988
Cost of UPFC Rs/kVAR	188.05	187.112	187.106	187.241
Fitness Value (K)	127.81	127.708	127.694	127.583
Elapsed Time (Sec	691.73	22.190	21.664	20.150

VII. CONCLUSION

Installation of FACTS devices helps in the maximum capacity of power system which makes the study of FACTS devices more relevant. The advantages of FACTs Devices installation is that it can be placed at any feasible location in the power system network. However in order to get maximum benefit the location and rating of FACT devices have to be fixed optimally. Placement of FACTS devices is a problem, fast voltage stability indices and power losses are analysed and the results obtained are compared GA, PSO and WIPSO algorithms.Case studies are carried out on conventional IEEE test systems using the algorithms created to optimize UPFC device positioning. The result of these study indicates that the device installation cost and power lose are minimized after the optimal UPFC device placement leading to enhancement of the power security. The analysis further reveals that when compared to PSO and GA, WIPSO techniques give best performance. The proposed WIPSO techniques, therefore yields an efficient solution by reducing power losses and device cost under various conditions.

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