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UTILITY OF PSO FOR LOSS MINIMIZATION AND ENHANCEMENT OF VOLTAGE PROFILE USING UPFC

A.S Kannan, R. Kayalvizhi

Abstract - The loss minimization is a major role in Power System (PS) research. Transmission line losses in a PS can be reduced by Var compensation. After the establishment of power markets with transmission open access, the significance and use of Flexible AC Transmission Systems (FACTS) devices for manipulating line power flows to relieve congestion and maximize the overall grid operation have been increased. This paper presents a method to provide simultaneous or individual controls of basic system parameters like transmission voltage, impedance and phase angle, which are controlling by using Unified Power Flow Controller (UPFC). The Particle Swarm Optimization (PSO) method is used to compute the power flow in optimum value. The performance of this technique is tested using IEEE - 14 bus system through the MatLab/Simulink simulation software package. The simulation results of test power system show that the location of the UPFC has been able to enhance the voltage level of the test power system and also minimize the transmission line losses.

Keywords - Flexible AC Transmission Systems (FACTS), Particle Swarm Optimization (PSO), Real and Reactive Power, Unified Power Flow Controller (UPFC).

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1. INTRODUCTION

Most of the large power system blackouts, which occurred worldwide over the last twenty years, which are caused by heavily stressed system with large amount of real and reactive power demand and low voltage condition. When the voltages at power system buses are low, the losses will also to be increased. This study is devoted to develop a technique for improving the voltage and minimizing the losses and hence eliminate voltage instability in a power system [4]. State estimation is the process of estimating the values to an unknown system variable based on the measurement system according to some criterion. The basic idea was to "fine-tune" state variables by minimizing the sum of the residual squares. This is the well-known least squares (LS) method; State estimation is a widely used tool in power system energy management systems. The essence of state estimation is that the measurements are taken of active and reactive power, and system voltage magnitudes and phase angles (i.e, the 'states') are estimated [1]-[2]. Application of FACTS devices are currently pursued very intensively to achieve better control over the transmission lines for manipulating power flows.

State estimation in power system can be formulated as a nonlinear weighted least squared errors (WLSE) problem representing the zero injections of buses and the zero active power exchange between the power system and FACTS devices. There are several kinds of FACTS devices. Thyristor-Controlled Series Capacitors (TCSC), Thyristor Controlled Phase Shifting Transformer (TCPST) and Static Var Compensator (SVC) can exert a voltage in series with the line and, therefore, can control the active power through a transmission line[3][15]. On the other hand UPFC has a series voltage source and a shunt voltage source, allowing independent control of the voltage magnitude, and the real and reactive power flows along a given transmission line. The UPFC was proposed for real-time control and dynamic compensation of ac transmission systems, providing the necessary functional flexibility required to solve many of the problems facing the utility industry. The UPFC consists of two switching converters, which in the implementations considered are voltage sourced inverters using Gate Turn-Off (GTO) thyristor switch [5]. Particle swarm optimization (PSO) is a population based stochastic optimization technique inspired by social behavior of bird flocking or fish schooling. PSO is related to evolution-inspired problem solving techniques such as genetic algorithms [9].

In this paper Particle Swarm Optimization (PSO) technique is introduced to optimize the measurement error vector. The proposed technique was tested on the IEEE 14 bus system and UPFC can be installed at any of the weakest voltage at load buses. For practical and economic considerations, the number of UPFC units is limited to one. Here UPFC is connected in between 9 in IEEE 14 bus system to perform the test.

2. BASIC CIRCUIT OF UPFC

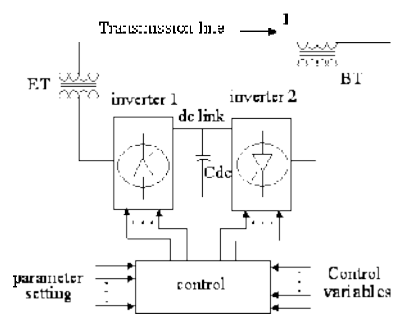


Fig. 1.Power Circuit of the Unified Power Flow Controller.

Fig.1 shows the power circuit of a UPFC which is composed of an Excitation Transformer (ET), a Boosting transformer (BT), two three phase GTO based voltage source converters (VSCs), and a dc link capacitor. This arrangement functions as an ideal ac to ac power converter in which the real power can freely flow in either direction between the ac terminals of the two inverters and each inverter can independently generate (or absorb) reactive power at its own ac output terminal . Inverter 1 can also generate or absorb controllable reactive power, if it is desired, and thereby it can provide independent shunt reactive compensation for the line. Inverter 2 provides the main function of the UPFC by injecting an ac voltage V_w with controllable magnitude V_m and phase angle (ɵ) at the power frequency, in search with line via an insertion transformer. This injected voltage *can* be considered essentially as a synchronous ac voltage source [6]. The transmission line current flows through this voltage source resulting in real and reactive power exchange between it and the ac system. The real power exchanged at the ac terminal (i.e., at the terminal of the insertion transformer) is converted by the inverter into dc power which appears at the dc link as positive or negative real power demand. The reactive power exchanged at the ac terminal is generated internally by the inverter [7].

3. STEADY STATE MODEL OF UPFC

A UPFC can be represented in the steady-state by two voltage sources representing fundamental components of output voltage waveforms of the two converters and impedances being leakage reactances of the two coupling transformers. Figure 2 depicts a two voltage-source model of UPFC [5].

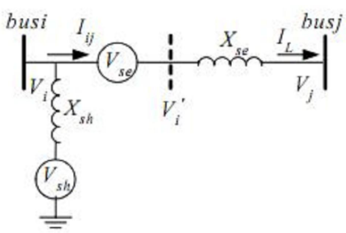


Figure 2. Two voltage-source model of UPFC

Voltage of bus i is taken as reference vector, $V_i = V_i <0'$ and $V_i' = Vse + V_i$. The voltage sources, V_{se} and $V_{sh,}$ are controllable in both their magnitudes and phase angles. The values of r and γ are defined within specified limits given by Equation (1).

$$0 \le r \le r_{max} \text{ and } 0 \le \gamma \le 2\pi. \quad (1)$$

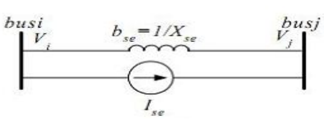
V_{se} should be defined as:

$$V_{se} = rV_i e^{j\gamma} \quad (2)$$

The steady-state UPFC mathematical model is developed by replacing voltage source V_{se} by a current source I_{se} parallel with the transmission line, where $b_{se} = 1/X_{se}$.

$$I_{se} = -jb_{se}V_{se} \quad (3)$$

The current source I_{se} can be modeled by injection powers at the two auxiliary buses i and j as shown in Figure 3.



$$S_{is} = V_i\,(-I_{se})^* \quad (4)$$
$$S_{js} = V_j\,(-I_{se})^* \quad (5)$$

Figure 3. Replacement of series voltage source by a current source

The injected powers Sis and Sjs can be simplified according to the following operations, by substituting Equation (2) and (3) into Equation (4).

$$S_{is} = V_i\,(jb_{se}\, rV_i e^{j}\gamma)^* \quad (6)$$

By using the Euler Identity, ($ej\gamma = \cos\gamma + j \sin\gamma$), Equation (6) takes the form:

$$S_{is} = V_i\,(e^{-j(\gamma+90)} b_{se} r V_i^*) \quad (7)$$
$$S_{is} = V_i^2 b_{se} r\,[\cos(-\gamma-90)+ j \sin(-\gamma-90)]. \quad (8)$$

By using trigonometric identities, Equation (8) reduces to:

$$S_{is} = -rb_{se}V_i^2 \sin\gamma - jrb_{se}V_i^2 \cos\gamma \quad (9)$$

Equation (9) can be decomposed into its real and imaginary components,

$S_{is} = P_{is} + jQ_{is}$, where

$$P_{is} = -rb_{se}V_i^2 \sin\gamma \quad (10)$$
$$Q_{is} = -rb_{se}V_i^2 \cos\gamma \quad (11)$$

Similar modifications can be applied to Equation (5); the final equation takes the form:

$$S_{js} = V_iV_jb_{se}\, r \sin(\theta_i - \theta_j + \gamma) + jV_iV_jb_{se}\, r \cos(\theta_i - \theta_j + \gamma) \quad (12)$$

Equation (12) can also be decomposed into its real and imaginary parts,

$S_{js} = P_{js} + jQ_{js}$, where

$$P_{js} = V_iV_jb_{se}r \sin(\theta_i - \theta_j + \gamma) \quad (13)$$
$$Q_{js} = V_iV_jb_{se}r \cos(\theta_i - \theta_j + \gamma) \quad (14)$$

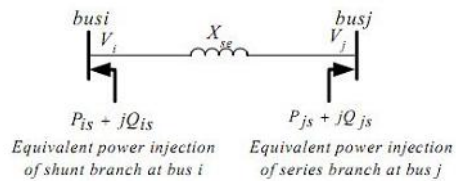


Figure 4. Equivalent power injections of series branch

In UPFC, the shunt branch is used mainly to provide both the real power, P_{series}, which is injected to the system through the series branch, and the total losses within the UPFC. The total switching losses of the two converters is estimated to be about 2% of the power transferred, for thyristor based PWM convertors [12]. If the losses are to be included in the real power injection of the shunt connected voltage source at bus i, P_{shunt} is equal to 1.02 times the injected series real power P_{series} through the series connected voltage source to the system [9 - 10].

$$P_{shunt} = -1.02P_{series} \quad (15)$$

The apparent power supplied by the series converter is calculated as

$$S_{series} = V_{se}I_{ij}^* = re^{j\gamma}V_i \left(\frac{V_i - V_j}{jX_{se}}\right) \quad (16)$$

Active and reactive power supplied by the series converter can be calculated from Equation (16):

$$S_{series} = re^{j\gamma}V_i\,((re^{j\gamma}V_i - V_j)\, jX_{se})^* \quad (17)$$

$$S_{series} = rV_ie^{j}\,(\theta_i+\gamma)\,((rV_ie^{-j(\theta i+\gamma)}+V_ie^{-j\,\theta i} - V_je^{-j\,\theta j})l\text{-}jX_{se}) \quad (18)$$

$$S_{series} = jb_{se}r^2V_i^2 + jb_{se}rV_i^2e^{j\gamma} - jb_{se}V_iV_je^{j(\theta i-\theta j+\gamma)} \quad (19)$$

The steady state model of UPFC consists of two ideal voltage sources, one in series and one in parallel with the associated line. Neglecting UPFC losses, during steady-state operation it neither absorbs nor injects real power into the system. No real-power is exchanged between the UPFC and the system. The two sources are mutually dependent. The real and reactive power going through line can be formulated by the equation (3).

4. PARTICLE SWARM OPTIMIZATION TECHNIQUE

PSO is basically developed through simulation of bird flocking in two dimension space. The position of each agent is represented by XY-axis position and the velocity is expressed by v_x (the velocity of

X-axis) and v_y (the velocity of Y-axis). Modification of the agent position is realized by the position and velocity information. PSO procedures based on the above concept can be described as follows. Namely, bird flocking optimizes a certain objective function. Each agent knows its best value so far (p_{best}) and its XY position. Moreover, each agent knows the best value in the group (g_{best}) among p_{bests}. Each agent tries to modify its position using the current velocity and the distance from p_{best} and g_{best}. The modification can be represented by the concept of velocity. Velocity of each agent can be modified by the following equation.[9]-[10] Vi=Vi + rand x (p_{best} i – Si) + rand x (g_{best} – Si)

where, Vi : velocity of agent i,
rand : uniformly distributed random number between 0 and 1,
Si : current position of agent i,
p_{best} i : p_{best} of agent i,
g_{best} : g_{best} of the group.

Using the above equation, a certain velocity that gradually gets close to p_{best} and g_{best} can be calculated. The current position (searching point in the solution space) can be modified by the following equation.

$$s_i^- = s_i + v_i \quad (20)$$

The particle swarm optimization concept consists of, at each time step, regulating the velocity and location of each particle towards its p_{best} and g_{best} locations according to the following two equations respectively.

$$V_{id}^{n}+1 = wv_{id}^{n} + c_1r_1^{n} (p_{id}^{n}-X_{id}^{n}) + c_2r_2^{n} (p_{id}^{n}-X_{id}^{n}) \quad (21)$$

$$X_{id}^{n+1} = X_{id}^{n} + V_{id}^{n}+1 \quad (22)$$

where w is inertia weight; c_1, c_2 are two positive constants, called cognitive and social parameter respectively ;d=1, 2, …, D; i=1, 2, …, m, and m is the size of the swarm; r_1, r_2 are random numbers, uniformly distributed in [0,1]; and n=1, 2, …, N, denotes the iteration number, N is the maximum allowable iteration number.

4.1.Particle Swarm Optimization Technique for Reactive Power and Voltage Control

Reactive Power and Voltage Control (Volt/Var Control: VVC) determines an on-line control strategy for keeping voltages of target power systems considering varying loads in each load point and reactive power balance in target power systems. VVC can be formulated as a mixed-integer nonlinear optimization problem with continuous state equipment. The objective function can be varied according to the power system condition. For example, the function can be loss minimization of the target power system for the normal operating condition [9]-[10].

Active and reactive power losses occur in transmission lines depending upon the power to be transmitted. The active power loss equation of the k^{th} line, between buses i and j (fig 2). can be written as (14),

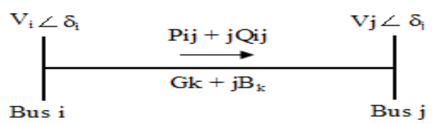


Fig 5.Transmission line

$$P_{L-k}=G_k(V_i^2+V_j^2-2V_iV_j\cos(\delta_i-\delta_j)) \quad (23)$$

The series reactive power loss equation of the k^{th} line, between buses i and j can be written as,

$$Q_{L-k}=B_k(V_i^2+V_j^2-2V_iV_j\cos(\delta_i-\delta_j)) \quad (24)$$

Where,
G_k; is k^{th} line conductance
B_k; is k^{th} line susceptance
V_i;voltage magnitude of i^{th} bus
δ_i;phase angle of i^{th} bus

In power system, the total active power loss of all the lines of the system is

$$P_L=\sum P_{L-k} \qquad k=1\ldots\ldots\ldots nl \quad (25)$$

and the total series reactive power loss of all the lines is

$$Q_L=\sum Q_{L-k} \qquad k=1\ldots\ldots\ldots nl \quad (26)$$

Where, nl is the total number of lines.

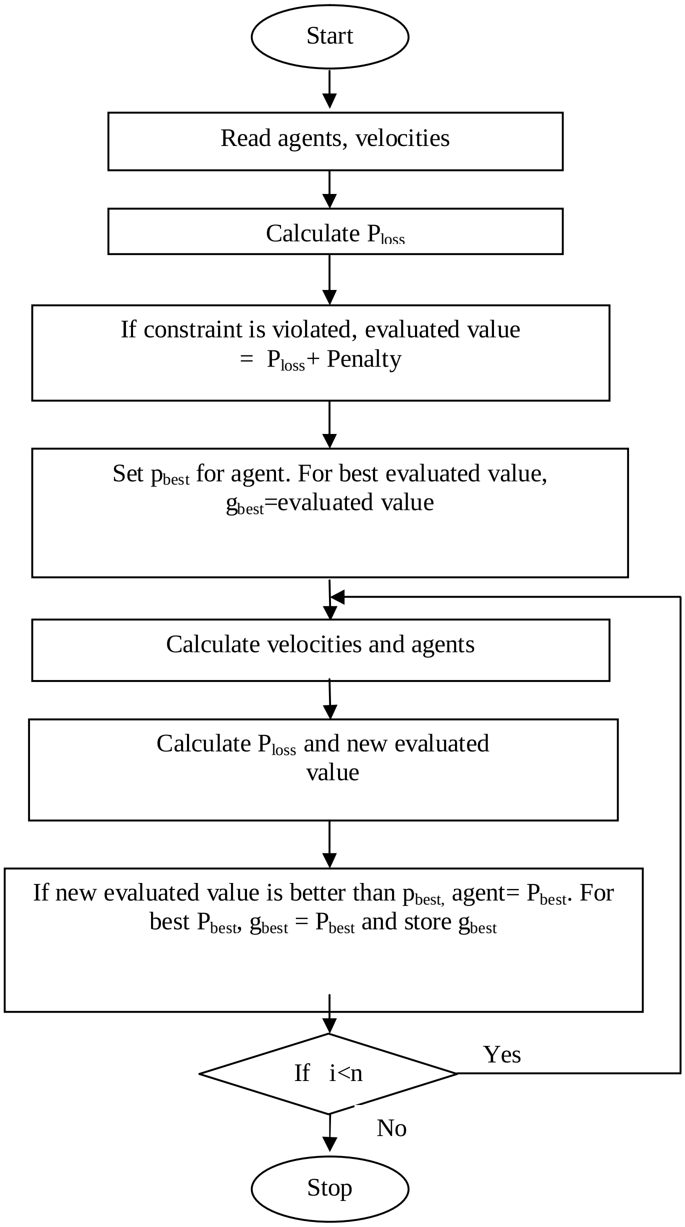
4.2. VVC Algorithm using PSO

The proposed VVC algorithm using PSO is expressed as follows:

Step 1. Initial Searching points (agents) and velocities are generated using the above-mentioned state variables randomly.
Step 2. Pl_{oss} to the searching point for each agent is calculated using load flow. If the constraints are violated, penalty is added to the loss (evaluation value of agent).
Step 3. p_{best} is set to each initial searching point. The initial best evaluated value (loss with penalty) among p_{bests} is set to g_{best}.
Step 4. Velocities are calculated using (2).
Step 5. New searching points are calculated using (3).

Step 6. P_{loss} to the new searching point and the evaluation value is calculated.
Step 7. If the evaluation value of each agent is better than the previous p_{best}, the value is set to p_{best}. If the best p_{best} is better than g_{best}, the value is set to g_{best}. All of g_{bests} are stored as candidates for the final control strategy.
Step 8. If the iteration number reaches to the maximum iteration number, then exit otherwise, go to Step 4.

4.3 VVC Flowchart using PSO



4.4 PSO Parameter Control

The following parameters are subjected to vary and their values are given in Table I.

Table -1 Various parameters and their values

Sl. No	Parameter	Value
1.	Number of particles	50-110
2.	Dimension of particles	6
3.	Range of particles	0.1-0.7
4.	Maximum velocity	25
5.	Learning factors C_1 & C_2	1.6
6.	Inertia weight W_{min} & W_{max}	0.5 & 0.95

5. RESULTS AND DISCUSSION

Fig. 7 show the IEEE 14-bus system. UPFC has been included between the buses 4 and 9 in IEEE 14 bus system. Table 2 show the state variables without and with UPFC. Table 3and 4 show power flow results of IEEE 14 bus system without and with UPFC. Table 5 shows the comparative results of proposed system. From the tables it is concluded that the system voltages have been improved and the losses are reduced when UPFC is installed.

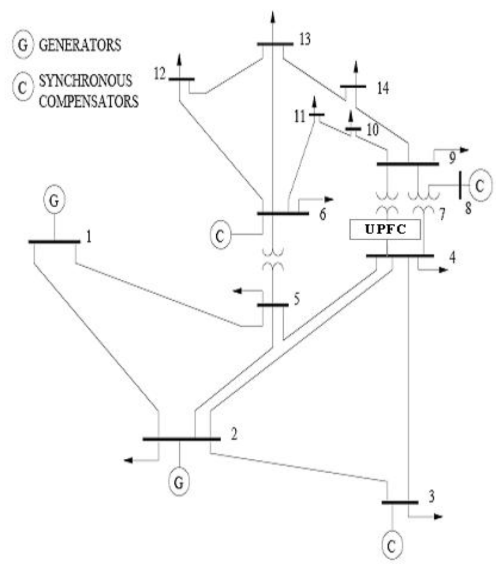


Fig.7 IEEE 14 bus system.

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Table -2 State Variables of IEEE 14-Bus System.

Bus No	Without UPFC		With UPFC	
	Voltage (pu)	Angle (deg)	Voltage (pu)	Angle (deg)
1	1.06	0.00	1.06	0.0
2	1.004	-5.762	1.010	-5.612
3	0.970	-12.268	0.973	-11.843
4	0.973	-10.279	0.981	-9.848
5	0.979	-8.944	0.986	-8.882
6	1.032	-14.716	1.050	-14.449
7	1.022	-13.769	1.020	-13.490
8	1.066	-13.893	1.050	-13.273
9	1.006	-15.054	1.013	-14.901
10	1.003	-15.468	1.006	-15.334
11	1.016	-15.220	1.018	-15.003
12	1.010	-15.660	1.032	-15.335
13	1.004	-15.362	1.023	-15.313
14	0.996	-16.616	0.997	-16.185

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Table - 3 Power Flows without UPFC.

Branch	From	To	From bus injection		To bus injection		Loss(I^2Z)	
			P(MW)	Q(MVAr)	P(MW)	Q(MVAr)	P(MW)	Q(MVAr)
1	1	2	154.37	-51.43	-149.3	61.63	5.079	15.51
2	1	5	67.84	-4.11	-65.35	9.56	2.488	10.27
3	2	3	57.33	4.38	-55.78	-2.11	1.552	6.54
4	2	4	45.15	2.88	-43.96	-2.60	1.187	3.60
5	2	5	32.88	2.84	-32.26	-4.34	0.623	1.90
6	3	4	-16.96	5.01	17.18	-5.64	0.227	0.58
7	4	5	-51.75	2.97	52.13	-1.77	0.379	1.20
8	4	7	29.59	-12.00	-29.59	14.16	0.000	2.15
9	4	9	52.13	-14.53	-52.13	-11.57	0.000	4.21
10	5	6	41.28	9.46	-41.28	-5.36	0.000	4.10
11	6	11	7.520	5.09	-7.450	-4.93	0.074	0.15
12	6	12	10.53	4.00	-10.39	-3.69	0.146	0.30
13	6	13	18.71	13.21	-18.39	-12.57	0.326	0.64
14	7	8	-5.340	-25.29	5.340	26.42	0.000	1.13
15	7	9	18.48	14.61	-18.48	-14.02	0.000	0.58
16	9	10	11.80	0.00	-11.76	0.12	0.044	0.12
17	9	14	10.60	-1.05	-10.46	1.35	0.142	0.30
18	10	11	-6.100	-4.21	6.150	4.31	0.045	0.10
19	12	13	0.220	2.97	-0.200	-2.95	0.019	0.02
20	13	14	6.170	-0.75	-6.100	0.88	0.065	0.13
Total							12.396	53.53

Table -4 Power Flows with UPFC.

Branch	From	To	From bus injection		To bus injection		Loss(I^2Z)	
			P(MW)	*Q(MVAr)*	*P(MW)*	*Q(MVAr)*	*P(MW)*	*Q(MVAr)*
1	1	2	148.19	-59.80	-143.30	69.40	4.889	14.93
2	1	5	67.13	-7.00	-64.69	12.25	2.446	10.10
3	2	3	55.90	6.28	-54.43	-4.38	1.473	6.21
4	2	4	42.79	2.11	-41.74	-2.29	1.052	3.19
5	2	5	33.94	2.15	-33.29	-3.61	0.652	1.99
6	3	4	-18.33	2.20	18.58	-2.80	0.243	0.62
7	4	5	-38.05	2.17	38.25	-1.54	0.201	0.64
8	4	7	31.10	-7.12	-31.10	9.23	0.000	2.11
9	4	9	16.73	0.76	-16.73	0.76	0.000	1.52
10	5	6	44.79	5.43	-44.79	-0.84	0.000	4.59
11	6	11	10.36	11.80	-10.14	-11.35	0.212	0.44
12	6	12	6.60	4.21	-6.53	-4.06	0.068	0.14
13	6	13	16.35	13.91	-16.07	-13.37	0.276	0.54
14	7	8	4.27	-17.08	-4.27	17.61	0.000	0.52
15	7	9	25.63	7.39	-25.63	-6.63	0.000	0.75
16	9	10	7.78	5.01	-7.76	-4.94	0.027	0.07
17	9	14	8.32	2.01	-8.22	-1.82	0.091	0.19
18	10	11	-3.24	-5.09	3.27	5.16	0.030	0.07
19	12	13	2.57	2.11	-2.55	-2.09	0.023	0.02
20	13	14	6.37	4.40	-6.28	-4.20	0.098	0.20
Total							11.781	48.84

Table 5 Comparative Results.

Power loss	P(MW)	Q(MVAr)
Without UPFC (IEEE 14 Bus System)	12.396	53.53
With UPFC (IEEE 14 Bus System)	11.781	48.84

6. CONCLUSION

This paper presents the application of particle swarm optimization technique in power system state estimation with and without UPFC. The unified power flow controller provides simultaneous or individual controls of basic system parameters like transmission voltage, impedance and phase angle, there by controlling the transmitted power. The Particle Swarm Optimization technique is used to compute the power flow. The power loss occurring in the various branches and state variables of IEEE 5 bus and IEEE 14-bus systems are evaluated using PSO. From the results it is concluded that the system performs better when the UPFC is connected .ie the state variables are improved and the total losses are minimized.

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