POWER QUALITY IMPROVEMENT OF DISTRIBUTION SYSTEM BY REACTIVE POWER COMPENSATION

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Abstract: **Reactive power management plays a vital role in improving power quality of the system. The major concern in reactive power management is location and quantity of placing capacitor at optimal location in the radial/mesh/interconnected distributions network is multi-objectives function with certain constraints. Optimally placing and sizing of capacitors reduces active power loss of the system, improves a voltage profile and power factor of the system. In this paper Particle Swarm Optimization (PSO) is used to achieve required objectives, which is a nonlinear optimization problem. The whole work is divided into two steps, identification of weaker nodes by using Voltage Sensitivity Factor (VSF) and combination of two sensitivity factors Voltage Stability Index and Voltage Sensitivity Factor (VSI, and VSF). Secondly, sizing of capacitors is done by using PSO technique, calculates the amount of reactive power compensation requires in each bus. The proposed algorithm is tested on IEEE 24-Bus system in MATLAB.**

Keywords: Load Flow (LF) Particle Swarm Optimization (PSO), power loss, reactive power, voltage profile, Voltage Sensitivity Factor (VSF), Voltage Stability Index (VSI).

I. INTRODUCTION:

There are four major parts of the power system in which distribution systems and loads sides are the crucial part. They are most affected part of the system in practical; it is somewhat difficult to fully satisfy customers demand. Most of the loads are inductive in nature and there is always deficiency of reactive power which increases loss and drop in voltage. As we know that distribution is a link between transmission and customers, and it feeds large numbers of customers at lower voltage and stretched in a large area leading to higher losses in the system and drop in the voltage. In most of literature it is found that 13% of the total power wasted as loss [1]. The system may acquire greater reliability and longer span by reducing the losses. Several methods for loss reduction in balanced Radial Distribution System (RDS) by placing capacitor at optimal location have been discussed in [2-9]. In literature many techniques mentioned for optimal capacitor placement using different optimization techniques. Previously Loss Sensitivity Factors for finding optimal capacitor placement and sizing by Particle Swarm Optimization [10-11]. Genetic Algorithm (GA) have implemented for optimal selection of capacitors in radial system [12]. Identification of optimal node for the capacitor placement was applied by Bacteria Foraging in [13,16].Plant Growth Simulation Algorithm have been implemented for selection of capacitor in radial distribution system [14].Optimal placing of a capacitor in radially connected have been solved using a Teaching Learning Based Optimization (TLBO) [15]. To optimally allocate by Loss Sensitivity Factor (LSF) and to find MVAr demand of shunt capacitors in distribution system for loss minimization by PSO in [17].In this paper optimal placement of capacitor is done by combination of two sensitivity factors (VSI and VSF) and sizing by Particle Swarm Optimization.

II. PROBLEM FORMULATION:

The key motivation for this paper is to optimally locate reactive power support by two different sensitivities factors and sizing by PSO to achieve reduction in active power loss and to enhance voltage profile of the system. The fitness function of the presented problem is defined by equation (1).

$$minimize\ P_{Tloss} = \sum_{i=1}^{N_{bus}} P_{loss,i} \quad (1)$$

Where, P_{Tloss}=Total loss of the system

N_{bus}= number of buses

A limit of the voltage at each bus is:

$$V_{min} \leq V_i \leq V_{max} \quad (2)$$

Where: V_i is the magnitude of the voltage at i^{th} bus. V_{min} and V_{max} are lower and higher limits of system voltage correspondingly.

The capacitor's size installed at selected buses must not more than the total reactive load of the system [18].

$$Q_q^c \leq Q_q^T \quad (3)$$

Where Q_q^c and Q_q^T are reactive power injection and total reactive power requirement at bus q of the system.

III. SELECTION OF BUSES FOR REACTIVE POWER SUPPORT

Selection Criteria: Optimal location for reactive power support is done using two different sensitivity factors and it has been discussed below.

A. Voltage Stability Index (VSI) can be defined as the change in voltage with respect to change in injected reactive power at i^{th} bus. It is expressed by using equation (4).

$$\frac{1}{dQ_i/dV_i} = \frac{dV_i}{dQ_i} \quad (4)$$

Equation (4) is known as Voltage Stability Index. (∂Q/∂V) can be found from Jacobian matrix. VSI values of all load buses should arrange in descending order and higher and positive values of VSI is taken because it indicate injection of reactive power results into improve in voltage.

B. Voltage Sensitivity Factor (VSF) is the ratio of base case voltages to 0.95and can be calculated by:

i. Compute normalized voltage for all load buses

$$\text{Norm (i)} = \frac{V_i}{0.95} \quad (5)$$

Norm (i) less than 1.000 is eligible for placing capacitor.

IV. METHODOLOGY

For Selection of the buses for placing or injecting the reactive power in the system Voltage Stability Index (VSI) and Voltage Sensitivity Factor (VSF) have used. Quantity of reactive power to be injected calculated using PSO technique.

In 1995 Kennedy and Eberhart introduced Particle Swarm Optimization which is an evolutionary computation method. The algorithm of PSO derived from behaviour of animal's societies which don't have any leader in their group like bird flocking and fish schooling. They find their food from random search, and follow one member of the group which is closet to the food source. Later on they achieved best position through communication among members of the group which already have best position. There are various interesting features of PSO that makes these techniques more useful and attractive than other techniques. Their features are they requires very few parameters, require simply modern mathematical operators and it is computationally inexpensive in terms of both memory usage and speed and it also don't have cross-over and mutation operators.

In PSO probing is done by means of a population of particles corresponding to individuals. Here each member is termed as 'particle', which denotes a candidate solution to the problem. Each particle flies with a velocity around in the multidimensional search space. Velocity is constantly updated by the particle's own experience and also with the experience of the neighbouring particle. The standard PSO uses the current global gbest and the individual best pbest. The updating formula of the i^{th} particle's velocity and position at (t+1) iteration can be expressed as following [13].

$$v_i^{t+1} = wv_i^t + c_1 rand_1 \left(pbest_i - x_i^t\right) + c_2 rand_2 \left(gbest - x_i^t\right) \quad (6)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (7)$$

where:

v_i^t velocity of i^{th} particle at t iteration;

x_i^t position of i^{th} particle at t iteration;

v_i, x_i represents values of injected reactive power support in MVAr;
w inertia weight factor;
c_1, c_2 acceleration coefficient and both are chosen to be 2;
$rand_1$, $rand_2$ random numbers lies in between 0 and 1;
$pbest_i$ best solution at t iteration;
$gbest$ best solution among all pbest;
$pbest_i$ represents values of losses ;
$gbest$ represents minimum loss among all losses;

The suitable value of weight factor w is selected because it provides a balance between global and local explorations and it is also used to control the convergence characteristics of PSO and is set according to equation (8).

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \quad (8)$$

where:
w_{max} maximum value of w is chosen to be 0.9;
w_{min} minimum value of w is chosen to be 0.4.
$iter_{max}$ maximum number of iteration ;
$iter$ current number of iteration ;

The particle velocity v_i should lies in the range of $[-v_{max}, v_{max}]$ and it is given by equation (9).

$$v_{max} = k \times x_{max}, \qquad 0.1 \le k \le 1.0 \quad (9)$$

In equation (9) x_{max} represents domain of search space.

PSO algorithm consists of two models they are:

1. Social only model
2. Cognition only model

$c_1 rand_1 (pbest_i - x_i^t)$ is cognition only model because it takes into account the particle's own experiences. $c_2 rand_2 (gbest - x_i^t)$ is social only model because it represents the social interaction between particles.

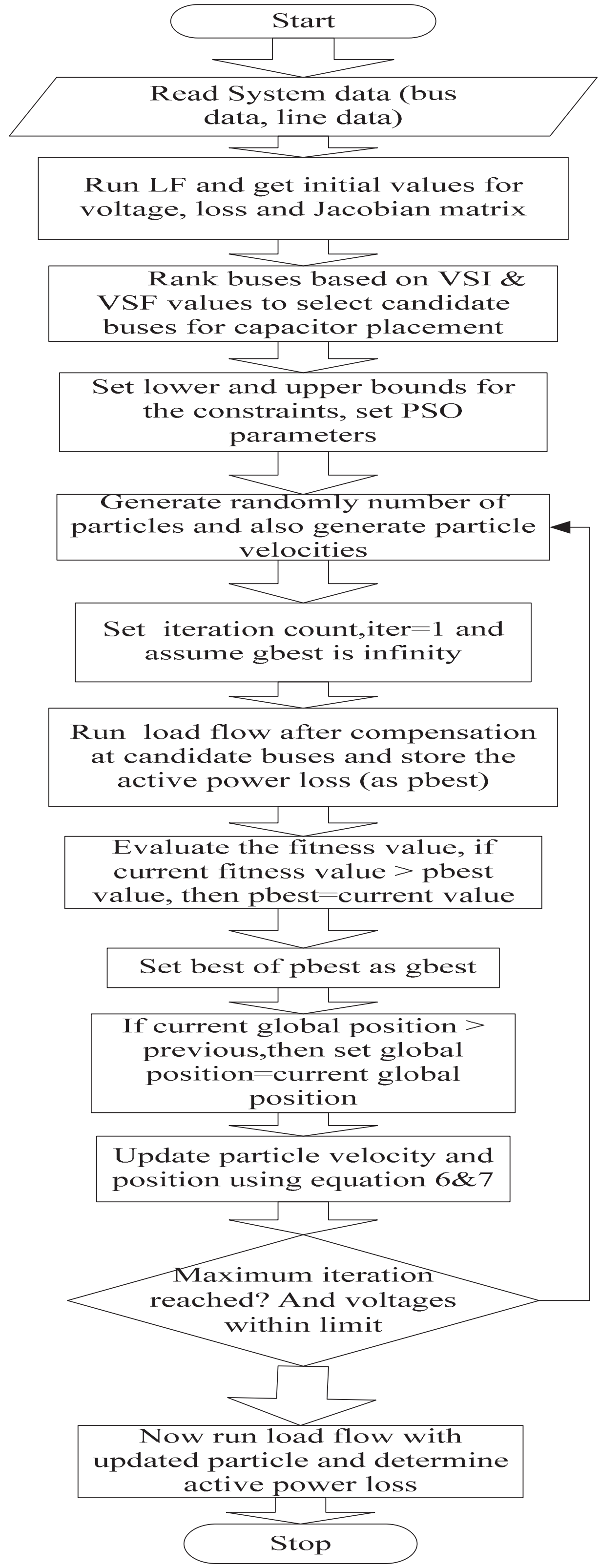

Fig.1. Flowchart of PSO

V. IEEE-24 BUS SYSTEM

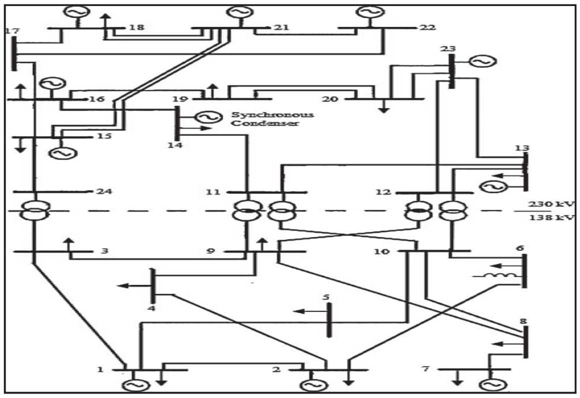

Fig.2. Diagram of IEEE-24 Bus System

TABLE I: BUSDATA OF IEEE-24 BUS SYSTEM

Bus No.	Bus Code	Load		Generator		
		MW	MVAr	MW	Q_{min}	Q_{max}
1	2	108	22	192	-50	80
2	2	97	20	192	-50	80
3	0	180	37	0	0	0
4	0	74	15	0	0	0
5	0	71	14	0	0	0
6	0	136	28	0	0	0
7	0	125	25	300	0	180
8	0	171	35	0	0	0
9	0	175	36	0	0	0
10	0	195	40	0	0	0
11	0	0	0	0	0	0
12	1	0	0	0	0	0
13	2	165	54	591	0	240
14	0	194	39	0	0	0
15	2	317	64	215	-50	110
16	2	100	20	155	-50	80
17	0	0	0	0	0	0
18	2	333	68	400	-50	200
19	0	181	37	0	0	0
20	0	128	26	0	0	0
21	2	0	0	400	-50	200
22	2	0	0	300	-60	96
23	2	0	0	660	-125	310
24	0	0	0	0	0	0

TABLE II: VOLTAGE CORRECTION DEVICE

Device	Bus No.	MVAR Capability
Synchronous Condenser	14	50 Reactive 200 Capacitive
Reactor	6	100 Reactive

VI. RESULTS:

The proposed methodology and optimization technique have been tested on IEEE-24 Bus System for optimally locating and sizing of shunt capacitor to lessen the active power loss and to enhance voltage profile. The entire work has been programmed in MATLAB R2015b.

Table III shows the values of VSI and VSF for ordering of load buses for locating reactive power support. Table IV contains the optimal location by VSF and capacitor size calculated by PSO. Total 106.398 MVAr capacity of reactive power support required for compensation at six numbers of buses. The Table V contains optimal location by combination of two sensitivity factors (VSI and VSF) and capacitor size calculated by PSO.Total 120.431 MVAr capacity of reactive power support required for compensation at seven numbers of buses. Table VI contains the comparison of voltages before and after compensation by VSF and proposed method and it was observed that there is improvement in voltage when the compensation is done .Table VII contains the comparison between VSF and proposed method for IEEE-24 bus and it is observed that active loss decreases from 75.4662MW to 70.679 MW and reactive power loss decreases from 88.834 to 46.519 when proposed method was implemented. Fig.3 shows voltage profile of IEEE-24 bus before and after compensation by VSF. Fig.4 shows voltage profile for the IEEE-24 bus before and after compensation by VSF and proposed method. It gives better voltage profile when proposed method is applied.

TABLE III: ORDERING OF LOAD BUSES BASED ON VSI AND VSF FOR IEEE-24 BUS SYSTEM

S. No	Bus No.	VSI	Bus No.	VSF
1	4	0.0660	6	0.9243
2	6	0.0620	3	0.9853
3	5	0.0490	10	0.9867
4	3	0.0460	24	0.9919
5	8	0.0400	14	0.9952
6	24	0.0350	8	0.9975
7	9	0.0230	9	1.0040
8	14	0.0220	11	1.0053
9	10	0.0190	5	1.0061
10	19	0.0155	4	1.0070
11	11	0.0150	19	1.0183
12	20	0.0145	20	1.0355
13	17	0.0080	17	1.0415

TABLE IV: OPTIMAL LOCATION BY VSF AND CAPACITOR SIZE GIVEN BY PSO

Optimal Location (Bus No) Given by VSF	Optimal Capacitor sizes (MVAr) given by PSO
3	36.9714
6	106.2201
8	21.2562
10	2.9501
14	39
24	0

TABLE V: OPTIMAL LOCATION BY COMBINATION OF TWO SENSITIVITY FACTORS (VSI, VSF) AND CAPACITOR SIZE GIVEN BY PSO

Optimal Location (Bus No) Given by VSI,VSF	Optimal Capacitor sizes (MVAr) given by PSO
3	37
4	3.2192
5	12.1055
6	101.8732
8	30.2332
9	36
24	0

TABLE VI: COMPARISON OF VOLTAGES WITHOUT AND WITH COMPENSATION BY VSF AND PROPOSED METHOD

Bus No.	Voltage p.u without compensation	Voltage p.u with compensation (VSF)	Voltage p.u with compensation (proposed method)
1	1.0000	1.0000	1.0000
2	1.0000	1.0000	1.0000
3	0.9361	0.9655	0.9700
4	0.9567	0.9639	0.9718
5	0.9558	0.9725	0.9780
6	0.8781	0.9624	0.9605
7	1.0000	1.0000	1.0000
8	0.9476	0.9657	0.9714
9	0.9538	0.9667	0.9773
10	0.9373	0.9709	0.9713
11	0.9548	0.9706	0.9694
12	1.0000	1.0000	1.0000
13	1.0000	1.0000	1.0000
14	0.9454	0.9670	0.9581
15	0.9700	0.9800	0.9800
16	0.9700	0.9800	0.9800
17	0.9894	0.9927	0.9927
18	1.0000	1.0000	1.0000
19	0.9674	0.9748	0.9748
20	0.9838	0.9864	0.9864
21	1.0000	1.0000	1.0000
22	1.0000	1.0000	1.0000
23	1.0000	1.0000	1.0000
24	0.9423	0.9602	0.9619

TABLE VII: COMPARISON BETWEEN VSF AND PROPOSED METHOD FOR IEEE-24 BUS

Items	Before Compensation	After Compensation	
		VSF and PSO	Proposed method
Total real power losses (MW)	75.4662	70.685	70. 679
Total reactive power losses (MVAr)	88.834	47.072	46.519
Optimal location	-	3 6 8 10 14 24	3 4 5 6 8 9 24
Total compensation MVAr)	-	106.398	120.431

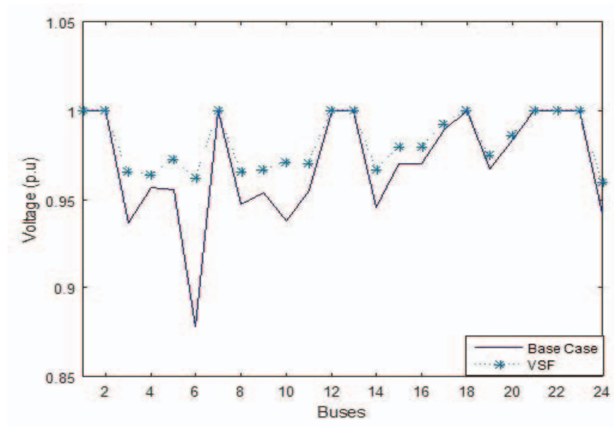

Fig.3. Voltage profile of IEEE-24 bus for base case and VSF

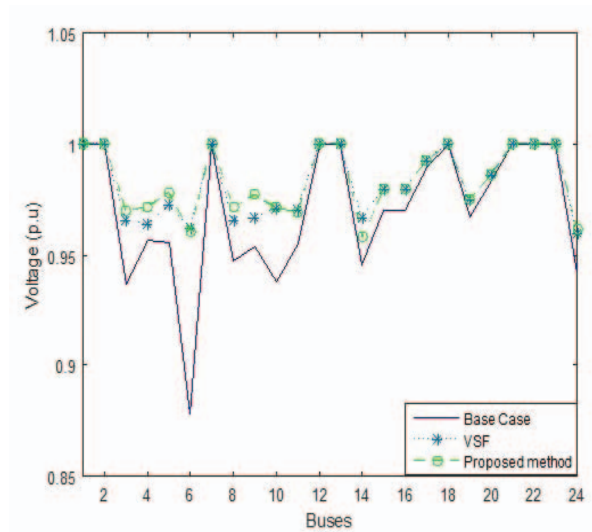

Fig.4. Voltage profile for IEEE-24 Bus without and with compensation

VII. DISCUSSION

It was found that when placement and sizing of capacitors are done by VSF and using PSO respectively, it gives better voltage profile but it increases the numbers of capacitors to be placed at critical nodes and it also increases total injected MVAr. When combination of two sensitivity factors used for the placing or locating of capacitors and sizing by PSO it gives better voltage profile and also decreases the reactive power demand of the system also decreases total injected MVAr.

VIII. CONCLUSION

The optimal location for capacitors is done by VSF and combination of two sensitivity factors (VSI, and VSF). Then optimally sizing of capacitors is achieved by Particle Swarm

Optimization (PSO) technique. The proposed method has been implemented on IEEE-24 Bus to obtained reduction in power loss [Table7] and improvement of voltage profile [Table6]. It is also observed that when capacitor sizing done based on buses selection from VSF values it increases total injected MVAr as compared to when it was considered combination of VSI and VSF values it gives appreciable results and total injected MVAr decreases[Table7].

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