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Voltage Collapse Enhancement and Loss Reduction by Reactive Power Reserve

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ABSTRACT

Now a day modern power industry is facing the problem of voltage instability due to stressed conditions and heavy load .The main cause for the voltage instability is the in sufficient reactive power at the load buses of the system. This paper deals with the problem of reactive power reserve management and voltage collapse point enhancement and loss reduction. Simulation is performed on the IEEE30 and 57 bus systems under Neuton Rapson (NR) and particle swarm optimization (PSO) methods. Additional reactive power injected by the optimally placed FACTS device (SVC) in the load bus reduced the reactive power generation of the generators and decreased the losses. The reduced reactive power generation of the generators increased the reactive power reserve management and enhanced the voltage collapse point. It is visible from the result that the optimal sizing and positioning of SVC in the PSO method is improving the reactive power reserve and enhances the voltage collapse point in a better level comparatively NR method.

Keywords

Voltage Instability; Voltage Collapse; Maximum loadability point; FACTS Devices; Reactive power reserve; PSO; NR

1. INTRODUCTION

Voltage collapse is the phenomenon of the voltage instability in the power system. This happen when the system is gradually loaded to the maximum load condition in such a way that the voltage magnitude to decrease gradually [1].Voltage magnitude alone will not give a good indication for voltage collapse point or maximum loadability limit or voltage stability limit [2].An effective voltage collapse point index indicates how far the current operating condition is from voltage collapse and witch buses are the most vulnerable. Many voltage collapse prediction methods have been presented to identify the distance to voltage collapse.

Antonio et al. [3] proposed a voltage collapse index known as full sum QV based on $\partial Qi / \partial Vi$ .The main problem is that the voltage, on its own, is often a poor indicator of voltage instability. Voltage stability index determines how far from voltage collapse the system is, and can be used for activating pre defined protective measures at the most critical buses in the system. In general, loads are dependent on bus voltage. Also, it is known that load dynamics greatly affect the voltage stability. Since voltage dependent loads play a very important role in voltage stability. The static voltage stability is primarily associated with the reactive power support. Voltage stability index proposed in [4] is based on the facts that with increase in load at a load bus the diagonal elements ($\partial Qi/\partial Vi$ and $\partial Pi/\partial \delta i$) of the load flow Jacobian matrix reduces. This reduction is quite considerable as the voltage collapse point is approached. The proposed index uses this change in value of diagonal elements $\partial Qi/\partial Vi$ and $\partial Pi/\partial \delta i$ of the Jacobian matrix. The bus voltage stability index proposed in [4] has been used in this work to determine the voltage collapse distance, because the threshold value is always 0.5 which is given in equation (1). Voltage collapse typically occurs on power system while it is heavily stressed. It may or may not be initiated by a disruption, but is usually characterized by shortage of fast-acting reactive reserves.

Reactive power demand generally increases with load increase. The fast reactive sources are generators, synchronous condensers and power electronics-based flexible ac transmission systems (FACTS) devices. During voltage emergencies, reactive resources should be activated to boost transmission voltage levels. This action will increase the reactive reserve and decrease the losses of transmission lines. It is wise to keep enough reserves in order to improve the voltage stability margin. Reactive power reserve has always been linked with voltage stability. Author in [5] discusses a reactive management program for a practical power system. The author discusses a method to supply reactive power during demands by installing properly sized and located capacitor banks which will allow generating units to operate at or near unity power factor. However, it is a cost-intensive proposition. Besides, this strategy is not always very effective since not all the shunt capacitors are fully utilized. In this paper FACTS devices (SVC) is optimally incorporated in the buses to adjust the reactive power and maintain the voltage within the limit by improving the reactive reserve when the load is increased gradually. The reactive power reserve of the generator is given in equation (2).

$$Ii = \frac{\partial Pi / \partial \delta i}{\sum_{\substack{j=1 \\ j \neq i}}^{N} BijVj} \tag{1}$$

$$Qg \max res = Qg \max - Qg \tag{2}$$

2. STATIC VAR COMPENSATOR

Static Var Compensator (SVC) as in [6] is one of the simple controllers based on Power Electronics and other static devices known as FACTS (Flexible AC Transmission Systems) Controllers which could be used to increase the capacity and the flexibility of a transmission network. The electric power quality at the low voltage level is affected, in great deal, by the disturbance due to switching actions or faults that happens in the power system at the middle and low voltage levels. SVC is one of the best devices to improve the voltages profile by providing the necessary reactive power in the load buses. Claudio et al. [7] proposed the steady state models of SVC and TCSC for the voltage collapse point improvement problem. In this the modeling of the devices and selecting the ranges are found difficult. C.J.Parkar in [8] used many devices to achieve reactive power reserve, it increased the installation cost. Muhammad Waseem Younas and Suhail A. Qureshi in his work [9] installed SVC of different ranges to increase the voltage collapse point. He concluded that SVCs of smaller ranges are suitable to use in the compensation. FACTS devices based on thyristor controlled reactor (TCR) such as static var compensators (SVC) and thyristor controlled series capacitor (TCSC) are being used by several electric utilities to compensate their system [10][11]. SVC is more suited in reactive power adjustment when connected in the load buses than in the lines with the susceptance property. The basic structure of SVC is shown in figure1.In the steady state model if an SVC is connected to a particular bus 'l' then the injected power at that bus is given by

$$Qi = Qsvc \qquad (3)$$

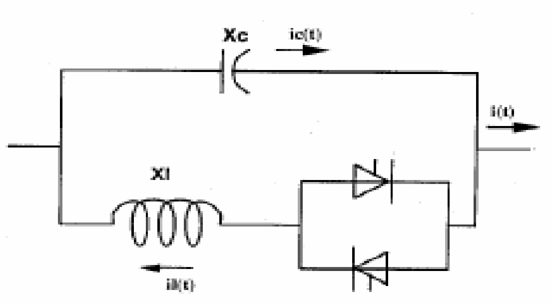

Fig1: Basic model of SVC

3. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) method is a member of wide category of population based methods for solving the optimization problems. Each particle in PSO moves through the search space with an adaptable velocity that is dynamically modified according to its own moving experience with the other particles. In PSO each particle strives to improve themself by imitating traits from their successful peers. Further, each particle has a memory and hence it is capable of remembering the best position in the search space ever visited by it. The position corresponding to the best fitness is known as pbest and the overall best out of all the particles in the population is called gbest.

The features of the searching procedure can be summarized as follows [12]:

- Initial positions of pbest and gbest are different. However, using the different direction of pbest and gbest, all agents gradually get close to the global optimum.
- The modified value of the agent position is continuous. However, the method can be applied to the continuous and discrete problem using grids and its velocity.
- There are no inconsistencies in searching procedures even if continuous and discrete state variables are utilized with continuous grid positions and velocities. The modified velocity and position of each particle can be calculated using the current velocity and the distances from the $pbest_{j,g}$ to $gbest_g$ as shown in the following formulas [13]:

$$v_{j,g}^{(t+1)} = w \times v_{j,g}^{(t)} + c_1 \times r_1() \times (p_{best_{j,g}} - x_{j,g}^{(t)}) + \dots$$

$$c_2 \times r_2() \times (g_{best_g} - x_{j,g}^{(t)}) \qquad (4)$$

$$x_{j,g}^{(t+1)} = x_{j,g}^{(t)} + v_{j,g}^{(t+1)}$$

with j = 1, 2. . .n and g=1, 2, . . ,m (5)

Where n = number of particles in the swarm; m = number of components for the vectors v_j and x_j; t = number of iterations (generations); $v_{j,g}^{(t)}$ = the g_{th} component of the velocity of particle' j' at iteration't'. The range of velocity of component is given as

$$v_g^{\min} \le v_{j,g}^{(t)} \le v_g^{\max} \qquad (6)$$

w = inertia weight factor; c1, c2 = cognitive and social acceleration factors, respectively/

r1, r2 = random numbers uniformly distributed in the range (0, 1); $x_{j,g}^{(t)}$ = the g_{th} component of the position of particle' j' at iteration t; $pbest_j$ = pbest of particle j; gbest = gbest of the group. The j_{th} particle in the swarm is represented by a'd' dimensional vector $x_j = x_{j,1}, x_{j,2}, \dots, x_{j,d}$ and its rate of position change (velocity) is denoted by another

'd' dimensional vector $v_j = v_{j,1}, v_{j,2}, \dots, v_{j,d}$. The best previous position of the j_{th} particle is represented as $Pbest_j = Pbest_{j,1}, Pbest_{j,2}, \dots, Pbest_{j,d}$.

The index of best particle among all of the particles in the swarm is represented by the $gbest_g$. In PSO, each particle moves in the search space with a velocity according to its own previous best solution and its group's previous best solution. The velocity update in a PSO consists of three parts; namely momentum, cognitive and social parts. The balance among these parts determines the performance of a PSO algorithm. The parameters c_1 and c_2 determine the relative pull of pbest and gbest and the parameters r_1 and r_2 help in stochastically varying these pulls. In the above equations, superscripts denote the iteration number. In this work C_1 and C_2 are selected as 2.5 and1.5 respectively, rand1 and rand2 are randomly selected between (0, 1) the inertia weight calculated

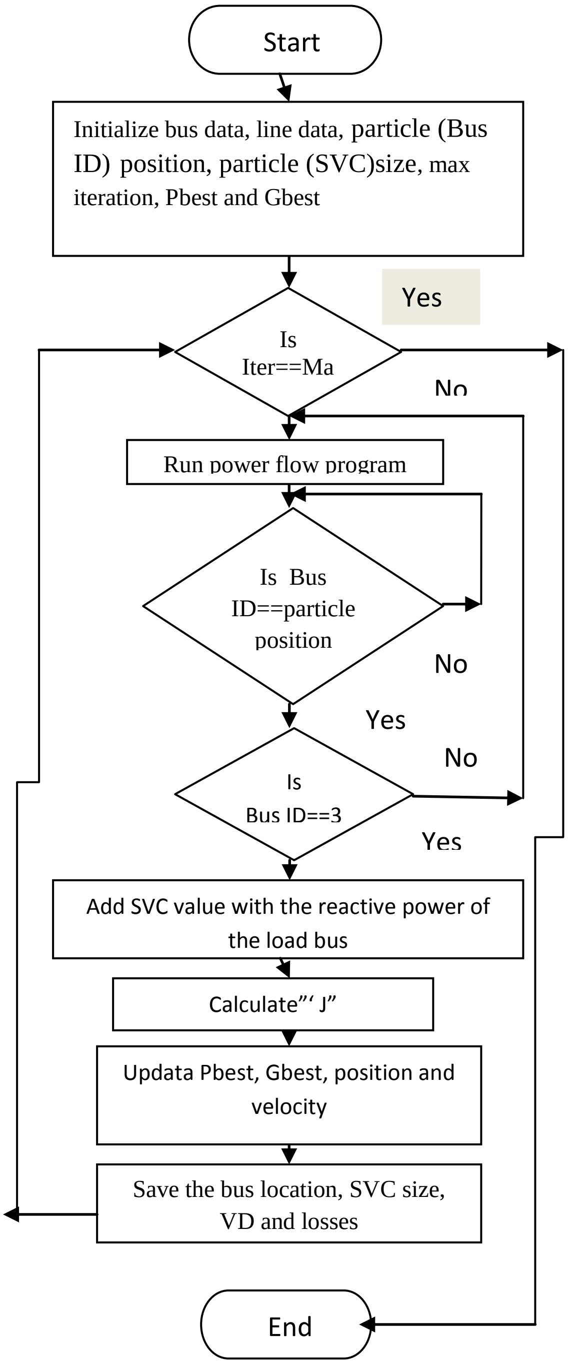

Fig 2: Flow chart of the PSO Algorithm

using the formula (7) as in [14]. Swarm Size is 10 and iteration 100. Y.Del.Valle in [15] used PSO to locate STATCOM to improve the voltage stability and showed good convergence and improved voltage stability.

$$W = \frac{W_{\max -} W_{\min}}{iter_{\max}} \times iter \qquad (7)$$

4. PROBLEM FORMULATION

The objective function 'J' is to minimize the voltage deviation, real and reactive power losses. The real and reactive power loss calculations are as in [16]. The active and reactive power losses of the transmission network depend on Rij , Xij , Zij and ΔV_{ij} . Voltage drop ΔV_{ij} is the drop across the line segment connecting bus 'i' and 'j'. When the voltage along the line changes, the real and reactive power losses also fluctuate.

$$J = pf1\left(\sum_{j=1}^{N} |Vj - Vref|^2\right) + pf2\left(\sum_{i=1}^{N}\sum_{j=1}^{N} \Delta V_{ij}{}^2 \frac{R_{ij}}{Z_{ij}}\right) + \text{pf3}\left(\sum_{i=1}^{N}\sum_{j=1}^{N} \Delta V^2{}_{ij} \frac{X_{ij}}{Z_{ij}}\right) \qquad (8)$$

Where Rij is the resistance Xij is the reactance and Zij is the impedance of the line connecting bus 'i' and 'j', pf1,pf2 and pf3 are the penalty factors, V_j is the j_{th} bus voltage and V_{ref} is the reference (specified) bus voltage.

The minimization problem is subject to the following equality and inequality Constraints:

(i) Load Flow Constraints

$$Pi = Vi \sum_{j=1}^{N} Vj(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) = 0 \qquad (9)$$

$$Qi = Vi \sum_{j=1}^{N} Vj(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) = 0 \qquad (10)$$

where 'i' and 'j' are buses and N=number of buses

(ii) Voltage Constraints:

$$V_i^{\min} \le V_i \le V_i^{\max} \qquad (11)$$

(iii) Reactive Power Generation Limit:

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \qquad (12)$$

(vi) Transmission line flow limit:

$$S_i \le S_i^{\max} \qquad (13)$$

(v) Size of the SVC

$$-200MVAR \le Qsvc \le 200MVAR \qquad (14)$$

5. SIMULATION RESULTS

Simulations are carried out on IEEE 30 and 57 bus systems. The aim of the simulations is to provide the reactive power reserve and to enhance the proximity to voltage collapse point for increasing the maximum load ability point. For this purpose, the system load was gradually increased from the base case. Because of the similarity in the output wave forms only few are shown.

Case 1:IEEE30 bus Systems

The system was loaded from its base case up to load factor (LF) of 1.4 and with an X/R ratio of 4, in (Neuton Rapson) NR and PSO methods. Table 1 shows the total real and reactive power generation (P_{gT},Q_{gT}) of the system, individual generators reactive power generation (Q_{g2},Q_{g5}.Q_{g8},Q_{g11},Q_{g13}), total real and reactive power losses (P_{Tloss}, Q_{Tloss}), SVC size and bus location. In PSO method the reactive power generation is lesser than the NR method for the proper location and size of SVC. It is approximately 20 percent from the maximum reactive power limit. The real and reactive power losses are 0.415 MW and 3 MVAR respectively in PSO method which is comparatively lesser than the NR method. The different SVC size and bus locations shown in the table 1 under various load are reducing the reactive power generation and total real and reactive power losses in the 30 bus system.

Voltage under various load conditions in NR and PSO method are given in table 3 figures (3-7) shows the voltage profile bar chart. When the load is increased from its base value to 1.3 LF in NR method the buses 5, 24,25,26,29 and 30 are going out of voltage level and also generator 5, 8 and 11 are violating their Q_{gen} limit. When the load is increased in PSO method the voltage is well within the specified level and none of the generators are violating which is below the limit in NR method. The indices and power factor of the system buses under loaded conditions are given in table5 and figures (8&9) show the indices wave forms in the load buses. The bus voltage indices are always close to 0.498 not decreasing below the threshold value and the power factor is above 0.8.Table 2 gives the individual generators (Q_{g2},Q_{g5},Q_{g8},Q_{g11},Q_{g13}) reactive power generation, real and reactive power losses (P_{Tloss}, Q_{Tloss}), system total real and reactive power generation (P_{gT}, Q_{gT}),SVC size and bus position under generator outage condition in PSO method. It is not possible to operate under generator outage condition in NR method. Table 4 shows the voltage under generator outage contingency condition in PSO method. The reactive power injected by the SVC device placed in the load bus manages the reactive power requirement and voltage profiles under the generator outage condition.

5.1 Case 2: IEEE 57 bus Systems

The system was loaded from its base case to a load factor of 1.3 and with an X/R ratio of 4 in NR and PSO method the voltages are tabulated in table 7. When the load is increased from its base value to 1.3 LF in NR method buses 29, 30, 31 and 32 are going out of voltage level and also generator 9 is violating from its Q_{gen} limit. When the load is increased in PSO method bus voltages are well within the specified limit and none of the generators are violating. Table 6 shows the reactive power generation of individual generators (Q_{g2}, Qg3, Qg6, Qg8, Qg9, and Qg12), total real and reactive power losses (P_{Tloss}, Q_{Tloss}), total real and reactive power generation (P_{Tg}, Q_{Tg}) in the system, SVC size, bus position. It is clear that individual generators are generating lesser reactive power in PSO method than the NR method. For the SVC size of 115.785 MVAR at 15th bus and 20 percent of reactive power generation has been reduced. The real and reactive power losses are reduced in PSO method and it is 1.065MW and 29.631MVAR respectively. The indices and the power factor of the system buses under loaded condition are given in table 8. The bus voltage indices are not decreasing below the threshold value and also the power factor is above 0.8.Voltage variation and indices in load buses with load change are shown in figures (10-12) and 13.

Table 1. Real and Reactive power Generation, losses SVC size and Bus No under various load condition in NR and PSO

	LF	Qg2 (Mvar)	Qg5 (Mvar)	Qg8 (Mvar)	Qg11 (Mvar)	Qg13 (Mvar)	Qg_T (Mvar)	Q_{Tloss} (Mvar)	P_{gT} (MW)	P_{Tloss} (MW)	Size of particle (SVC)	Position (Bus No)
PSO	1	38.278	31.474	36.741	15.953	23.570	145.408	68.740	300.600	17.438	72.438	13
	1.1	33.614	29.032	-2.482	12.096	7.433	162.539	84.037	305.419	22.019	99.926	6
	1.2	47.362	35.922	31.549	12.727	4.855	182.241	105.003	310.271	26.871	46.469	4
	1.3	41.461	31.475	29.216	10.384	6.642	211.425	134.704	318.792	35.392	82.179	4
	1.4	34.347	38.749	38.129	16.714	8.453	238.060	160.431	325.531	42.131	82.414	4
	X/R 4	48.365	37.225	35.553	5.223	4.564	237.972	158.998	304.710	21.310	40.408	23
NR	1	48.341	36.220	32.271	17.208	11.364	147.510	69.062	301.006	17.606	-	-
	1.1	48.357	35.164	26.230	23.334	18.722	166.499	87.200	305.514	22.114	-	-
	1.2	38.772	41.412	31.676	24.357	25.183	187.180	107.060	310.686	27.286	-	-

Table 2. Real and Reactive power Generation, losses, SVC size and Bus No under generator outage condition in PSO method

LF	Q_{g2} (Mvar)	Q_{g5} (Mvar)	Q_{g8} (Mvar)	Q_{g11} (Mvar)	Q_{g13} (Mvar)	Q_{gT} (Mvar)	Q_{Tloss} (Mvar)	P_{gT} (MW)	P_{Tloss} (MW)	PartSize (SVC)	PartPos (Bus No)	No of Gen out-age
1	-	30.567	26.417	7.437	-2.343	156.295	79.850	304.048	20.648	42.867	31	Gen2
1	48.341	-	32.271	17.208	11.364	147.510	69.062	301.006	17.606	51.983	4	Gen5
1	-	-	17.150	2.482	-4.298	161.042	85.491	306.067	22.667	33.519	3	Gen2&5
1.1	-	-	28.287	4.320	-1.401	175.689	100.011	309.414	26.014	94.351	4	Gen2&5
1	48.341	-	-	17.208	11.364	147.510	69.062	301.006	17.606	45.568	4	Gen5&8
1.1	25.710	-	-	8.096	-0.685	164.823	88.149	305.884	22.484	34.070	6	Gen5&8
1.2	-	-	1.319	16.417	13.113	192.668	113.528	313.746	30.346	99.926	6	Gen2&5
1.2	44.377	-	-	6.269	-2.345	184.061	108.004	310.929	27.529	52.366	4	Gen5&8
1.3	49.242	-	-	18.865	12.263	205.761	127.672	316.003	32.603	46.469	4	Gen5&8
1.3	40.805	-	-	-	-	213.147	136.758	319.472	36.072	70.077	4	Gen5,8, 11&13

Table 3. Voltage profile at different buses in NR and PSO method under various load condition

Bus No	LF=1		LF=1.1		LF=1.2		LF=1.3		LF=1.4	
	NR	PSO	NR	PSO	NR	PSO	NR	PSO	NR	PSO
1	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600
2	1.0430	1.0430	1.0330	1.0430	1.0230	1.0330	1.0030	1.0230	1.0130	1.0130
3	1.0213	1.0276	1.0092	1.0316	0.9999	1.0133	0.9724	1.0055	0.9842	0.9958
4	1.0124	1.0202	0.9980	1.0257	0.9871	1.0037	0.9538	0.9948	0.9692	0.9836
5	1.0100	1.0100	0.9900	1.0100	0.9800	0.9900	**0.9300**	0.9700	**0.9280**	0.9600
6	1.0116	1.0199	0.9943	1.0343	0.9828	1.0024	**0.9443**	0.9933	0.9658	0.9810
7	1.0032	1.0082	0.9836	1.0158	0.9717	0.9875	**0.9400**	0.9728	0.9512	0.9603
8	1.0100	1.0200	0.9900	1.0200	0.9800	1.0000	**0.9401**	0.9900	0.9700	0.9800
9	1.0489	1.0616	1.0371	1.0587	1.0247	1.0575	0.9788	1.0620	1.0005	1.0499
10	1.0403	1.0566	1.0257	1.0484	1.0120	1.0636	0.9655	1.0583	0.9828	1.0603
11	1.0820	1.0520	1.0520	1.0520	1.0520	1.0820	1.0220	1.0520	1.0520	1.0520
12	1.0561	1.0513	1.0465	1.0613	1.0381	1.0647	0.9909	1.0623	1.0124	1.0600
13	1.0510	1.0510	1.0510	1.0510	1.0510	1.0610	1.0210	1.0510	1.0510	1.0510
14	1.0408	1.0648	1.0289	1.0454	1.0180	1.0544	0.9691	1.0505	0.9886	1.0507
15	1.0359	1.0583	1.0228	1.0407	1.0107	1.0555	0.9618	1.0513	0.9801	1.0543
16	1.0422	1.0638	1.0297	1.0479	1.0182	1.0555	0.9701	1.0596	0.9892	1.0499
17	1.0355	1.0536	1.0210	1.0424	1.0073	1.0548	0.9594	1.0658	0.9768	1.0497
18	1.0253	1.0459	1.0102	1.0301	0.9961	1.0440	0.9459	1.0452	0.9627	1.0508
19	1.0221	1.0416	1.0063	1.0272	0.9913	1.0409	0.9410	1.0457	0.9572	1.0570
20	1.0259	1.0445	1.0102	1.0317	0.9955	1.0456	0.9460	1.0528	0.9624	1.0578
21	1.0251	1.0429	1.0090	1.0314	0.9940	1.0653	0.9456	1.0600	0.9609	1.0379
22	1.0293	1.0458	1.0131	1.0370	0.9982	1.0540	0.9529	1.0389	0.9666	1.0409
23	1.0248	1.0430	1.0088	1.0310	0.9938	1.0510	0.9456	1.0599	0.9607	1.0370
24	1.0146	1.0313	0.9963	1.0217	0.9797	1.0407	**0.9358**	1.0505	0.9449	1.0154
25	1.0139	1.0281	0.9935	1.0246	0.9767	1.0247	**0.9313**	1.0465	0.9441	0.9961
26	0.9962	1.0108	0.9735	1.0052	0.9544	1.0035	**0.9061**	1.0240	**0.9171**	0.9706
27	1.0221	1.0346	1.0015	1.0358	0.9856	1.0249	0.9408	1.0362	0.9567	0.9966
28	1.0101	1.0192	0.9916	1.0289	0.9796	1.0015	**0.9396**	0.9941	0.9620	0.9791
29	1.0023	1.0152	0.9790	1.0141	0.9605	1.0009	**0.9122**	1.0103	**0.9260**	0.9673
30	0.9908	1.0039	0.9660	1.0016	0.9460	0.9870	**0.8956**	0.9954	**0.9082**	0.9504

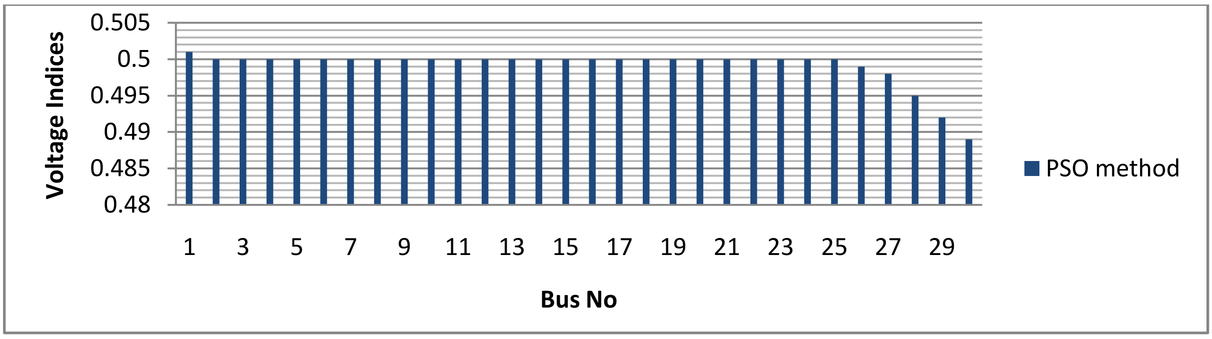

Fig 9: Voltage Indices at load buses in LF=1.2 (PSO)

Table 4. Voltage profile of different buses in PSO method in generator outage condition.

	LF=1				LF=1.1		LF=1.2		LF=1.3	
BusNo	Gen2	Gen5	Gen2&5	Gen5&8	Gen2&5	Gen5&8	Gen2&5	Gen5&8	Gen5&8	Gen5,811 &13
1	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600
2	1.0330	1.0430	1.0330	1.0430	1.0330	1.0330	1.0230	1.0330	1.0230	1.0230
3	1.0220	1.0213	1.0237	1.0213	1.0212	1.0200	1.0046	1.0155	1.0007	1.0060
4	1.0137	1.0124	1.0158	1.0124	1.0132	1.0113	0.9934	1.0064	0.9888	0.9955
5	1.0000	1.0100	1.0100	1.0100	1.0000	1.0000	0.9700	0.9900	0.9700	0.9700
6	1.0133	1.0116	1.0162	1.0116	1.0131	1.0114	0.9909	1.0050	0.9848	0.9940
7	1.0001	1.0032	1.0060	1.0032	0.9990	0.9980	0.9724	0.9891	0.9678	0.9732
8	1.0100	1.0100	1.0100	1.0100	1.0100	1.0100	0.9900	1.0000	0.9800	0.9900
9	1.0577	1.0489	1.0572	1.0489	1.0537	1.0664	1.0450	1.0699	1.0457	1.0652
10	1.0581	1.0403	1.0562	1.0403	1.0508	1.0568	1.0441	1.0578	1.0492	1.0545
11	1.0520	1.0520	1.0520	1.0520	1.0520	1.0520	1.0520	1.0520	1.0520	1.0520
12	1.0541	1.0561	1.0566	1.0561	1.0528	1.0519	1.0528	1.0541	1.0550	1.0647
13	1.0510	1.0510	1.0510	1.0510	1.0510	1.0510	1.0510	1.0510	1.0510	1.0510
14	1.0674	1.0408	1.0693	1.0408	1.0508	1.0592	1.0385	1.0674	1.0425	1.0538
15	1.0607	1.0359	1.0512	1.0359	1.0693	1.0573	1.0361	1.0516	1.0425	1.0552
16	1.0686	1.0422	1.0577	1.0422	1.0503	1.0534	1.0403	1.0512	1.0430	1.0636
17	1.0600	1.0355	1.0554	1.0355	1.0246	1.0220	1.0365	1.0566	1.0404	1.0514
18	1.0609	1.0253	1.0683	1.0253	1.0639	1.0511	1.0242	1.0632	1.0290	1.0500
19	1.0587	1.0221	1.0696	1.0221	1.0641	1.0508	1.0210	1.0618	1.0252	1.0510
20	1.0628	1.0259	1.0555	1.0259	1.0699	1.0564	1.0258	1.0674	1.0301	1.0583
21	1.0525	1.0251	1.0821	1.0251	1.0699	1.0565	1.0401	1.0410	1.0497	1.0664
22	1.0507	1.0293	1.0500	1.0293	1.0547	1.0615	1.0316	1.0575	1.0380	1.0521
23	1.0581	1.0248	1.0518	1.0248	1.0680	1.0548	1.0371	1.0572	1.0555	1.0662
24	1.0604	1.0146	1.1017	1.0146	1.0536	1.0415	1.0148	1.0633	1.0226	1.0501
25	1.0447	1.0139	1.0533	1.0139	1.0383	1.0299	1.0031	1.0403	1.0041	1.0531
26	1.0275	0.9962	1.0565	0.9962	1.0192	1.0106	0.9815	1.0195	0.9807	1.0308
27	1.0432	1.0221	1.0636	1.0221	1.0380	1.0320	1.0064	1.0361	1.0040	1.0409
28	1.0136	1.0101	1.0178	1.0101	1.0127	1.0108	0.9896	1.0046	0.9828	0.9951
29	1.0238	1.0023	1.0446	1.0023	1.0164	1.0103	0.9818	1.0124	0.9772	1.0152
30	1.0126	0.9908	1.0336	0.9908	1.0039	0.9977	0.9677	0.9987	0.9617	1.0003

Table 5. Voltage indices and power factor at different load in NR and PSO method

	NR			PSO	
S.No	System LF	Pf	Index	Pf	Index
1	1	0.953	0.492	0.954	0.489
2	1.1	0.941	0.489	0.926	0.489
3	1.2	0.926	0.489	0.915	0.495
	1.3	-	-	0.907	0.489
	1.4	-	-	0.787	0.483
	x/r Ratio=4				

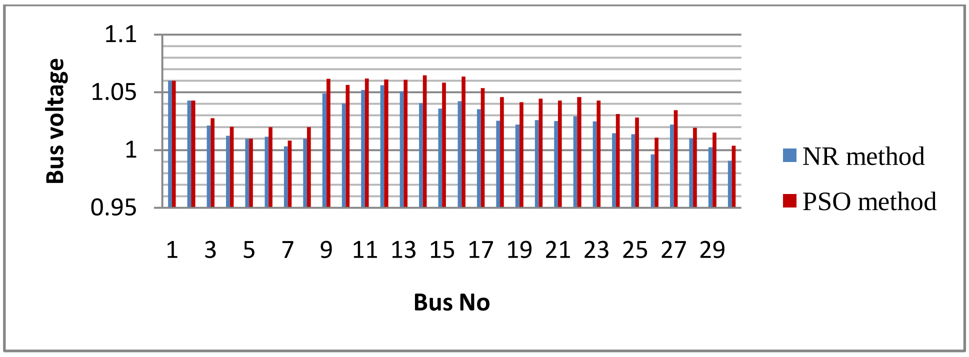

Fig3: voltage profile under base load (LF=1)

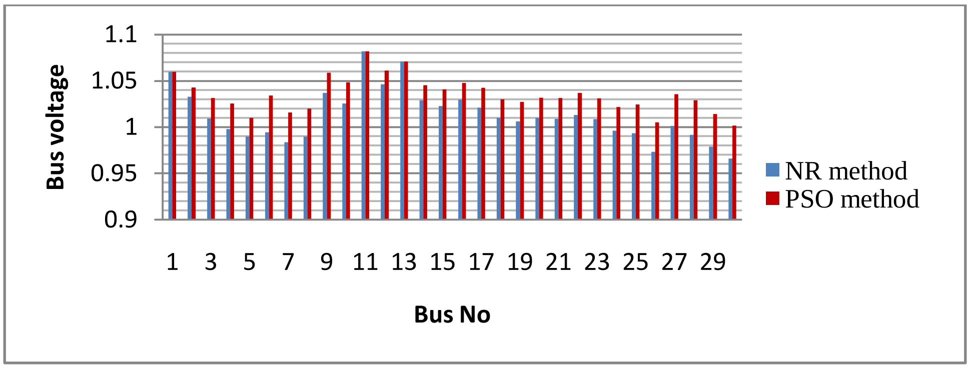

Fig 4: voltage profile under load (LF=1.1)

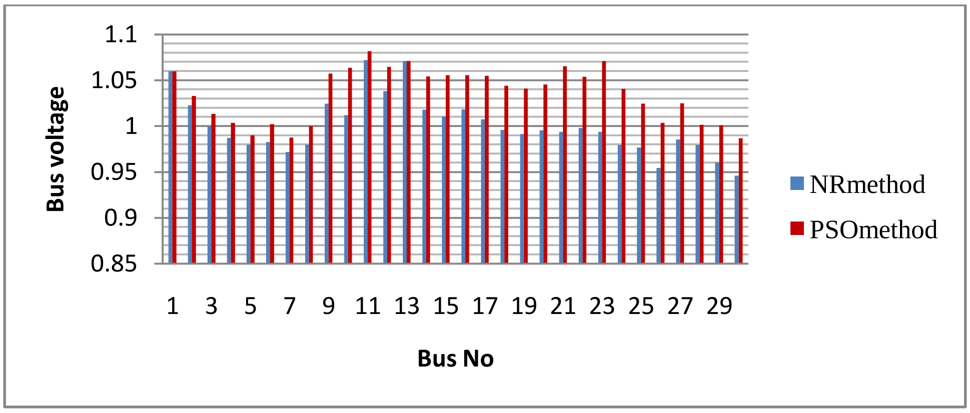

Fig 5: voltage profile under load (LF=1.2)

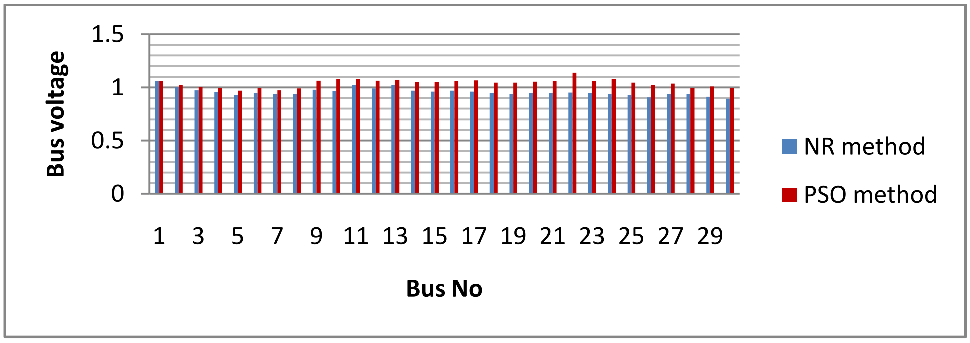

Fig 6: voltage profile under load (LF=1.3)

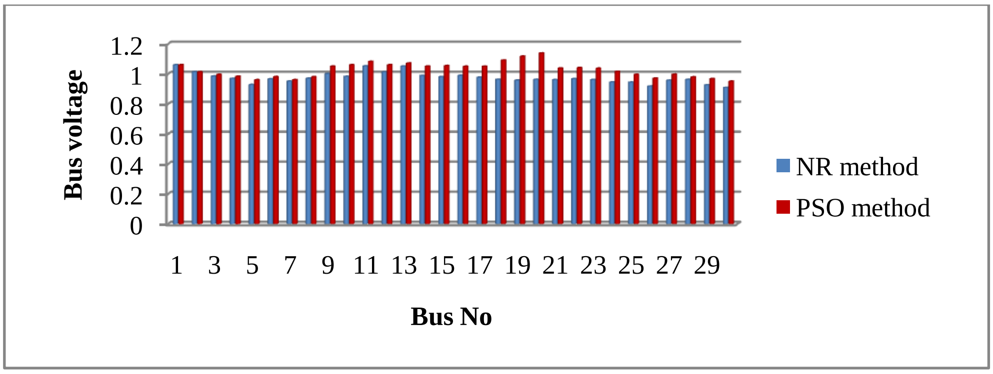

Fig7: System Voltage profile under load (LF=1.4)

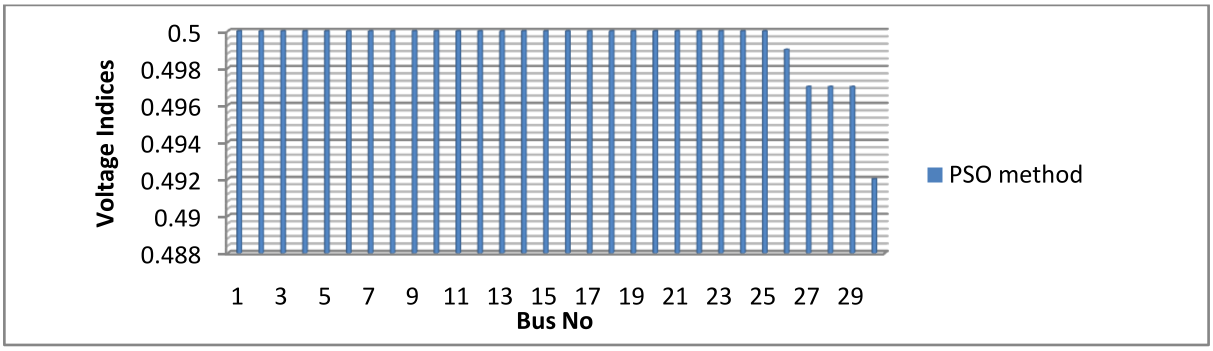

Fig8: Voltage Indices at load buses in base case (PSO)

Table 6. Real and Reactive power Generation, losses, SVC size and Bus No under load condition

	System Load	Q2 Mvar	Q3 Mvar	Q6 Mvar	Q8 Mvar	Q9 Mvar	Q12 Mvar	Q_{gT} Mvar	Q_{Tloss} Mvar	P_{gT} MW	P_{Tloss} MW	Par size SVC	ParPosi (BusN o)
NR	1	0.751	7.369	6.010	65.386	6.862	130.745	328.454	153.755	1224.262	28.462	-	-
	1.1	2.207	30.355	15.188	90.438	-	146.190	385.636	207.539	1238.043	42.207	-	-
	1.2	18.496	37.196	14.204	107.02	**3.817**	134.523	465.589	283.672	1257.472	61.672	-	-
PSO	1	-0.775	-0.470	4.369	63.528	-	121.586	324.789	155.836	1223.560	27.760	52.374	9
	1.1	7.437	-0.445	-3.301	50.149	1.854	110.561	341.418	177.908	1226.942	31.142	115.785	15
	1.2	7.132	39.175	12.047	77.472	-	136.717	463.010	283.021	1260.806	65.006	150.766	15
	X/R	46.868	14.047	7.663	70.408	1.783	78.829	454.758	284.235	1227.712	31.912	114.283	15

Table 8. Voltage indices and power factor at various loading conditions

		NR		PSO	
S.No	System LF	Pf	Index	Pf	Index
1	1	0.942	0.494	0.945	0.485
2	1.1	0.909	0.493	0.931	0.493
3	1.2	0.863	0.493	0.834	0.493
4	X/R Ratio=4	-	-	0.962	0.492

Table 7. Voltage profile at different buses under various condition

S.	LF=1		LF=1.1		LF=1.2	
	NR	PSO	NR	PSO	NR	PSO
1	1.0400	1.0400	1.040	1.0400	1.040	1.040
2	1.0100	1.0100	1.010	1.0100	1.010	1.010
3	0.9850	0.9850	0.985	0.9850	0.975	0.985
4	0.9783	0.9786	0.977	0.9785	0.966	0.976
5	0.9757	0.9758	0.974	0.9756	0.963	0.973
6	0.9800	0.9800	0.980	0.9800	0.970	0.980
7	0.9819	0.9832	0.979	0.9920	0.972	0.992
8	1.0050	1.0050	1.005	1.0050	1.005	1.005
9	0.9800	0.9800	0.970	0.9800	0.970	0.970
10	0.9857	0.9880	0.973	0.9886	0.958	0.970
11	0.9732	0.9771	0.961	0.9772	0.952	0.962
12	1.0150	1.0150	1.005	1.0150	0.985	0.995
13	0.9779	0.9821	0.967	0.9837	0.952	0.967
14	0.9688	0.9748	0.957	0.9774	0.941	0.962
15	0.9871	0.9909	0.980	0.9924	0.966	0.982
16	1.0133	1.0134	1.002	1.0126	0.982	0.990
17	1.0174	1.0175	1.009	1.0163	0.995	0.999
18	0.9751	0.9777	0.969	0.9776	0.953	0.972
19	0.9515	0.9612	0.939	0.9694	0.918	0.957
20	0.9497	0.9639	0.935	0.9777	0.912	0.965
21	1.0004	1.0227	0.983	1.0487	0.959	1.038
22	1.0029	1.0263	0.985	1.0538	0.961	1.043
23	1.0010	1.0242	0.983	1.0583	0.959	1.049
24	0.9842	1.0045	0.965	1.1507	0.940	1.173
25	0.9378	0.9713	0.910	1.0824	0.876	1.091
26	0.9453	0.9632	0.928	1.0906	0.906	1.110
27	0.9727	0.9816	0.961	1.0428	0.946	1.049
	0.9896	0.9951	0.981	1.0324	0.969	1.035
	0.9727	0.9816	0.961	1.0428	0.946	1.049
28	0.9896	0.9951	0.9815	1.0324	0.9696	1.0350
29	1.0043	1.0076	0.9982	1.0309	0.9887	1.0318
30	0.9201	0.9579	0.8904	1.0583	0.8525	1.0623
31	0.8999	0.9475	0.8666	1.0199	0.8245	1.0140
32	0.9259	0.9857	0.8953	1.0141	0.8566	1.0021
33	0.9236	0.9835	0.8927	1.0119	0.8535	0.9995
34	0.9491	1.0217	0.9245	0.9964	0.8934	0.9752
35	0.9575	1.0310	0.9341	1.0014	0.9044	0.9808
36	0.9682	1.0264	0.9462	1.0098	0.9182	0.9905
37	0.9778	1.0265	0.9571	1.0184	0.9303	1.0006
38	1.0071	1.0311	0.9900	1.0464	0.9667	1.0331
39	0.9758	1.0241	0.9549	1.0160	0.9279	0.9976
40	0.9653	1.0226	0.9431	1.0061	0.9151	0.9863
41	0.9938	1.0117	0.9761	1.0053	0.9584	0.9865
42	0.9631	0.9879	0.9409	0.9792	0.9174	0.9553
43	1.0083	1.0161	0.9945	1.0143	0.9821	0.9980
44	1.0121	1.0320	0.9970	1.0442	0.9755	1.0315
45	1.0334	1.0446	1.0244	1.0510	1.0089	1.0432
46	1.0570	1.0691	1.0436	1.0753	1.0244	1.0613
47	1.0292	1.0465	1.0135	1.0561	0.9917	1.0416
48	1.0229	1.0418	1.0066	1.0530	0.9843	1.0384
49	1.0328	1.0478	1.0163	1.0558	0.9945	1.0389
50	1.0207	1.0320	1.0026	1.0367	0.9798	1.0151
51	1.0513	1.0555	1.0364	1.0568	1.0187	1.0360
52	0.9676	0.9703	0.9553	0.9871	0.9425	0.9779
53	0.9546	0.9569	0.9397	0.9704	0.9260	0.9569
54	0.9866	0.9879	0.9730	0.9952	0.9646	0.9824
55	1.0276	1.0279	1.0164	1.0295	1.0143	1.0193
56	0.9641	0.9938	0.9414	0.9843	0.9163	0.9608
57	0.9600	0.9932	0.9366	0.9833	0.9099	0.9595

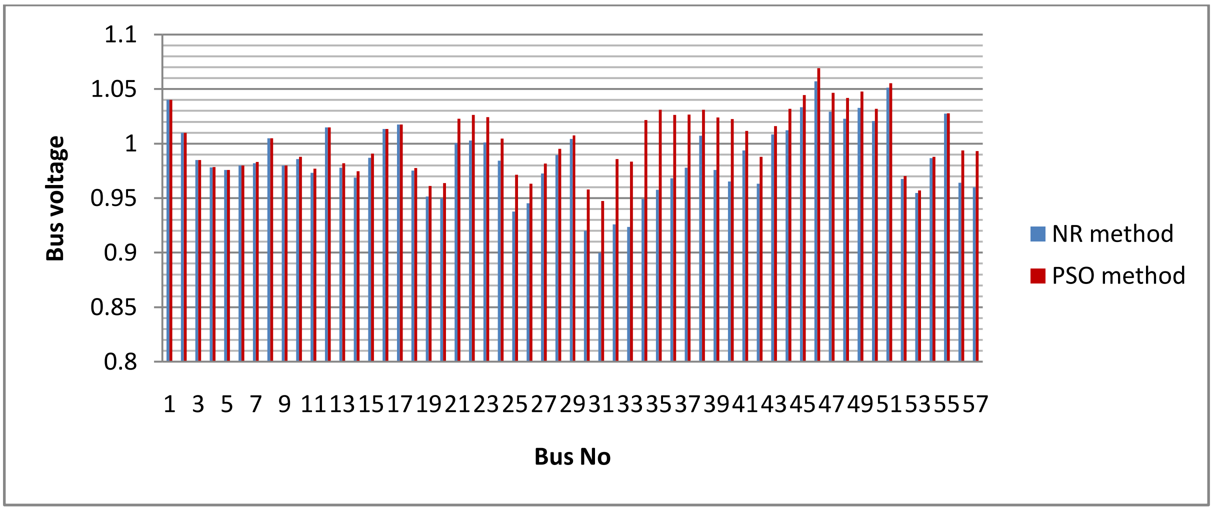

Fig 10: System voltage profile under base load (LF =1)

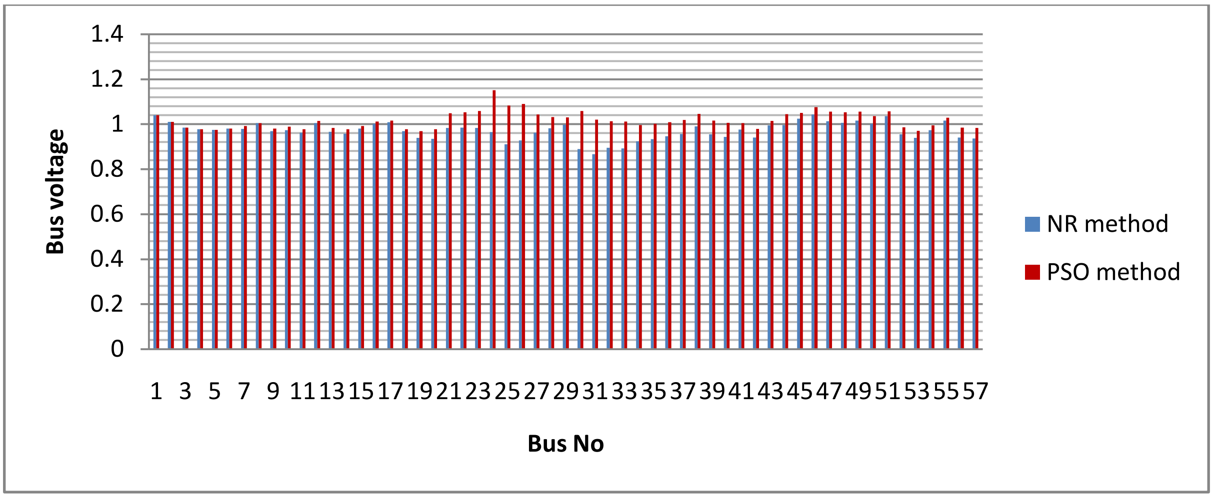

Fig11: System voltage profile under load (LF =1.1)

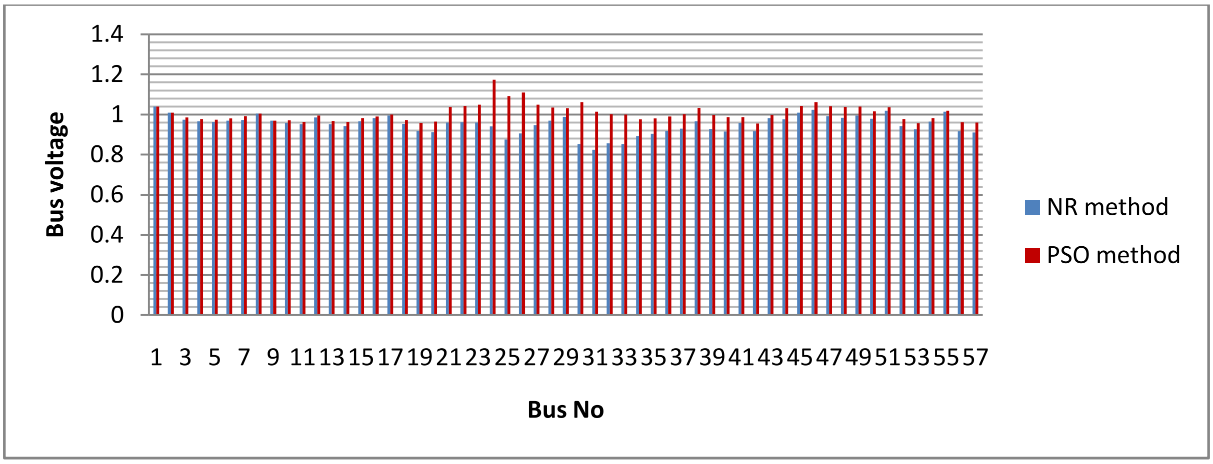

Fig12: System voltage profile under load (LF =1.2)

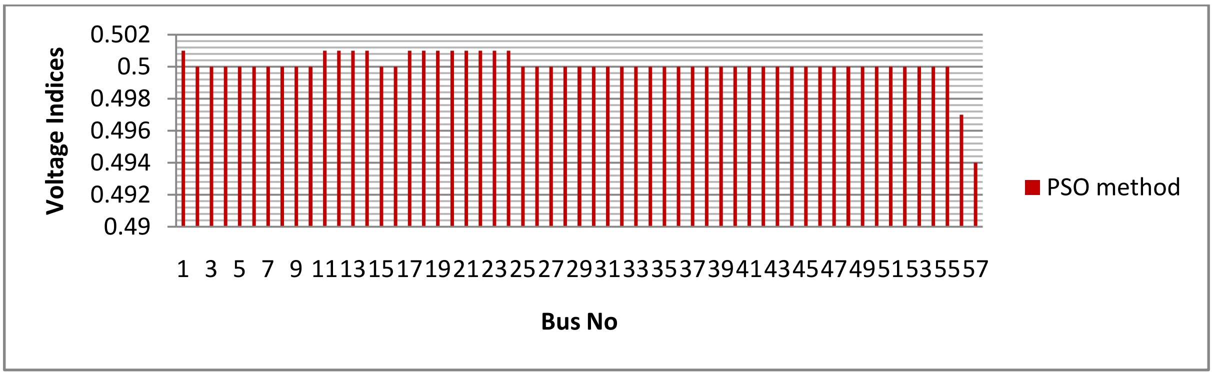

Fig13: Voltage Indices in PSO method under load condition (LF =1.2)

6. CONCLUSION

In this work the reactive reserve has been maintained and the voltage collapse point enhanced by the proper location and sizing of the SVC device using PSO. The generators are generating lesser amount of reactive power for the suitable location of SVC under various load condition the saving is 20 percent from the system total reactive power generation. The real and reactive power losses are reduced noticeably and Voltage in the buses and power factor is maintained within the limit under generator outage contingency condition also. The voltage stability index used in the work is a good candidate to determine the voltage collapse point under loaded condition

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