FACTS BASED VOLTAGE ENHANCEMENT IN HYBRID DG DISTRIBUTION SYSTEM WITH MIXED LOAD MODEL

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Abstract: *In a complex interconnected ac transmission network, problems like voltage deviation during load changes and power transfer limitation are observed due to reactive power unbalances. Also, the loads of the system are uncontrolled and depend on voltage and frequency of the system. Therefore, static mixed load models are considered here to include the voltage dependability nature of loads. Conventionally fixed type shunt capacitors and reactors used for balancing reactive power supply and demand. Power Electronics based Flexible AC Transmission systems (FACTS) controllers are fast, flexible and highly reliable reactive power compensators .In FACTS controllers, second generation (Inverter based) controllers are superior to first generation (Passive elements based) controllers in power system voltage stability improvement. This work compares the performances of fixed compensator (capacitor), first generation (Static VAR Compensator-SVC) and second generation (Static Compensator-STATCOM) FACTS controllers in voltage profile improvement of IEEE 34 bus radial distribution system. The optimal placement of compensating devices is found using voltage sensitivity and loss sensitivity factors. The impact of inclusion of hybrid DGs (Distributed Generators) on the three methods of reactive power compensation of the same system is also deeply studied for the mixed load model.*

Keywords: *Voltage profile, SVC, STATCOM, hybrid DGs, WECS, PV cell.*

1. Introduction

The conventional approaches for voltage regulation and reactive power compensation are mechanically controlled at low speed and the system is not fully controlled and optimized from a dynamic and steady-state point of view. Flexible AC transmission systems (FACTS) have gained a great interest during the last few years, due to recent advances in power electronics. FACTS devices have been mainly used for solving various power system steady state control problems such as voltage regulation, power flow control, and transfer capability enhancement. Among the FACTS controllers, Static Var Compensator (SVC) and STATCOM provide fast acting dynamic reactive compensation for voltage support during contingency events which would otherwise depress the voltage for a significant length of time. It also dampens power swings and reduces system losses by optimized reactive power control.

The[3],[7]increasing penetration of Distributed Generation, in particular wind generation, causes some major operating problems in voltage stability, power flow control, transient stability etc in the power system. Flexible Alternating Current transmission system (FACTS) devices can be a solution to these problems.

Mamandur K.R.C and Chenoweth, R.D [11] studied the optimal control of reactive power flow for improvements in voltage profiles and for real power loss minimization by developing a mathematical formulation.

The potential of FACTS controllers to enhance power system stability has been discussed by H.K.Tyll [6] where a comprehensive analysis of FACTS Technology for Reactive Power Compensation and System Control was presented. An overview is given on existing shunt and series compensation FACTS devices like SVC, STATCOM, UPFC and TCSC/TPSC.

Mark Ndubuka [15] investigated the effects of SVC on voltage stability of a power system. The functional structure for SVC built with a Thyristor Controlled Reactor (TCR) and its model are described.

Optimal Siting and Sizing of Hybrid Distributed Generation was[2] carried out by the same author, to minimize the total losses for a mixed realistic load model on IEEE -34 bus radial distribution system.

This work compares the performances of fixed compensator (capacitor), first generation (SVC) and second generation (STATCOM) FACTS controllers in voltage profile improvement of IEEE 34 bus radial distribution system with mixed load model before after hybrid distributed generators placement.

2. Modelling

2.1 Static Load models

The loads connected to the distribution system are certainly voltage dependent; thus, these types of load characteristics should be considered in load flow studies to get accurate results and to avoid costly errors in the analysis of the system. Exponential load model is a static load model that represents [13] the power relationship to voltage as equation (1) and (2).

$$P = P_o \left(\frac{V}{V_o}\right)^{np} \quad (1)$$

$$Q = Q_o \left(\frac{V}{V_o}\right)^{nq} \quad (2)$$

Where, P_O and Q_O stand for the real and reactive powers consumed at a reference voltage V_O. The exponents np and nq [4] depend on the type of load that is being represented given in Table 1.

Table 1

Load Type and Exponent Value

Type	np	nq
Constant	0	0
Industrial	0.18	6.00
Residential	0.92	4.04
Commercial	1.50	3.40

2.2 Voltage compensators

Traditional shunt capacitors/inductors or FACTS controllers can be used for the purpose of voltage compensation. This section presents mathematical modeling of two major FACTS controllers.

(a) Static VAR compensator (SVC)

An SVC is a shunt-connected static generator and/or absorber of reactive power in which the output is varied to maintain or control specific parameters of an electrical power system. In practice the SVC can be seen as an adjustable reactance with either firing-angle limits or reactance limits.[1],[9] The equivalent circuit is shown in Fig.1.

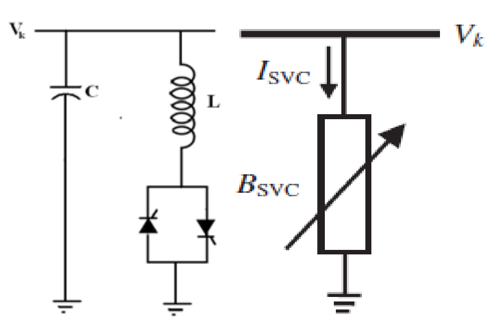

Fig.1 Variable Shunt Susceptance Model

The current drawn by the SVC is

$$I_{SVC} = jB_{SVC} * V_k \quad (3)$$

and the reactive power drawn by the SVC, which also the reactive power injected at bus k, is

$$Q_{SVC} = Q_k = -V_k^2 * B_{SVC} \quad (4)$$

(b) STATCOM

Similar to SVC, STATCOM can provide instantaneous and continuously variable reactive power in response to grid voltage transients, enhancing the grid voltage stability. The STATCOM operates according to voltage source principles, which together with unique PWM (Pulsed Width Modulation) switching of IGBTs (Insulated Gate Bipolar Transistors) gives it unequalled performance in terms of effective rating and response speed. Unlike the SVC, the STATCOM is represented as a voltage source for the full range of operation, enabling a more robust voltage support mechanism. The STATCOM equivalent circuit is shown in Fig.2.The detailed model is available reference [1].

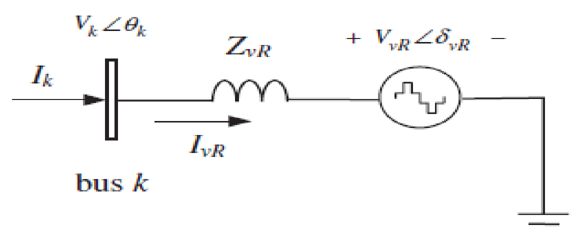

Fig.2. Static Compensator (STATCOM) equivalent circuit

3. Power flow modeling

The power flow Newton–Raphson algorithm[12] is expressed in equation (5) using linearised form of power flow equations. The real power mismatch takes angle and reactive power mismatch takes voltage as state variables. They are related by Jacobean matrix.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}^{(i)} = -\begin{bmatrix} \frac{\partial P}{\partial \theta} & \frac{\partial P}{\partial V} V \\ \frac{\partial Q}{\partial \theta} & \frac{\partial Q}{\partial V} V \end{bmatrix}^{(i)} \begin{bmatrix} \Delta \theta \\ \frac{\Delta V}{V} \end{bmatrix}^{(i)} \quad (5)$$

(a)SVC

The N-R method power mismatch equations (6) and (7) for the SVC are derived by considering its variable shunt susceptance [1] as state variable corresponding to reactive power. (where i is the iteration count)

$$B_{SVC}^{(i)} = B_{SVC}^{(i-1)} + \left(\frac{\Delta B_{SVC}}{B_{SVC}}\right)^{(i)} B_{SVC}^{(i-1)} \quad (6)$$

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \end{bmatrix}^{(i)} = \begin{bmatrix} 0 & 0 \\ 0 & Q_k \end{bmatrix}^{(i)} \begin{bmatrix} \Delta \theta_k \\ \Delta B_{svc} / B_{svc} \end{bmatrix}^{(i)} \quad (7)$$

(b)STATCOM

The power flow equations for the STATCOM are derived from basic principles and the assumption is the voltage source representation as given in [1] Using these power equations, the linearised STATCOM model is given below, where the voltage magnitude V_{vR} and phase angle δ_{vR} are taken to be the state variables:

$$\begin{bmatrix}\Delta P_k\\ \Delta Q_k\\ \Delta P_{vR}\\ \Delta Q_{vR}\end{bmatrix}=\begin{bmatrix}\frac{\partial P_k}{\partial\theta_k} & \frac{\partial P_k}{\partial V_k}V_k & \frac{\partial P_k}{\partial\delta_{vR}} & \frac{\partial P_k}{\partial V_{vR}}V_{vR}\\ \frac{\partial Q_k}{\partial\theta_k} & \frac{\partial Q_k}{\partial V_k}V_k & \frac{\partial Q_k}{\partial\delta_{vR}} & \frac{\partial Q_k}{\partial V_{vR}}V_{vR}\\ \frac{\partial P_{vR}}{\partial\theta_k} & \frac{\partial P_{vR}}{\partial V_k}V_k & \frac{\partial P_{vR}}{\partial\delta_{vR}} & \frac{\partial P_{vR}}{\partial V_{vR}}V_{vR}\\ \frac{\partial Q_{vR}}{\partial\theta_k} & \frac{\partial Q_{vR}}{\partial V_k}V_k & \frac{\partial Q_{vR}}{\partial\delta_{vR}} & \frac{\partial Q_{vR}}{\partial V_{vR}}V_{vR}\end{bmatrix}\begin{bmatrix}\Delta\theta_k\\ \frac{\Delta V_k}{V_k}\\ \Delta\delta_{vR}\\ \frac{\Delta V_{vR}}{V_{vR}}\end{bmatrix} \quad (8)$$

4. Optimal placement of shunt compensators

The optimal buses for the placement of compensating device are to be found based on two factors.

(a)Voltage sensitivity factors

Voltage stability index at a load bus identifies critical buses i.e. buses which are prone to voltage collapse in power system. Voltage stability index is calculated using voltage equation.The voltage stability index is given by,

$$L_i=4[V_{oi}V_{Li}\cos\theta_i - V_{Li}^2\cos\theta_i^2]/V_{oi}^2 \quad (9)$$

V_{Li}, V_{oi} load and no load voltage at bus i

$\theta_i=\theta_{oi}-\theta_{Li}$; θ_{Li}, θ_{oi} load and no load angle at bus i

The first sensitivity factor is the change in L_i with respect to the injected real power P_i at i^{th} bus and the second sensitivity factor is the change in L_i with respect to the injected reactive power Q_i in i^{th} bus.

$$\frac{\partial L_i}{\partial Q_i}=\frac{\partial L_i}{\partial V_{Li}}\times\frac{\partial V_{Li}}{\partial Q_i}+\frac{\partial L_i}{\partial\theta_{Li}}\times\frac{\partial\theta_{Li}}{\partial Q_i} \quad (10)$$

Elements of the column matrix are obtained from the inverse of load flow jacobian matrix.

(b) Loss sensitivity factor

Loss sensitivity factor of a bus gives the deviation in the real power loss of the system when the injected power at that bus is varied [13]. Two components are calculated: real power loss with respect to real power injection and real power loss with respect to reactive power injection.The real power loss in a system can be calculated using the following formula

$$P_L=\sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}\left(P_iP_j+Q_iQ_j\right)+\beta_{ij}\left(Q_iP_j-P_iQ_j\right)\right] \quad (11)$$

$$\alpha_{ij}=\frac{r_{ij}}{V_iV_j}\cos(\delta_i-\delta_j)\ \beta_{ij}=\frac{r_{ij}}{V_iV_j}\sin(\delta_i-\delta_j)$$

Z_{ij} is the ij^{th} element of [Zbus] matrix with $[Zbus]=[Ybus]^{-1}$.Loss sensitivity factors are given by first derivatives of equation(11).

5. Simulation study I-Shunt Compensation without DG

In the present work, a modified IEEE-34 bus radial distribution network [2],[7] is used to analyze the effect of various compensation devices in distribution system voltage regulation. The single line diagram of the test system is given in Fig.3 and system data are given in Appendix I.

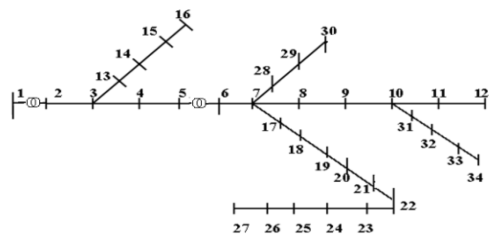

Fig.3.Single line diagram of test system

The base power flow analysis is performed on the system with the effect of static load model. This resultant voltage profile for the uncompensated system is shown in Fig 4.

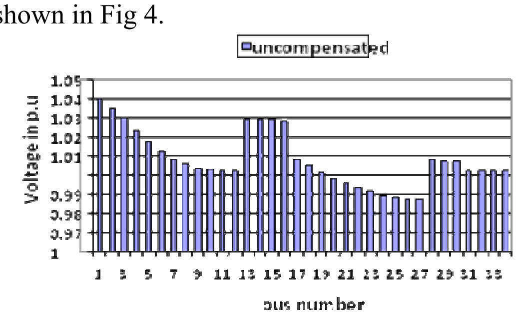

Fig.4.Voltage profile of the uncompensated system with mixed Load model

Active power loss is found to be 203kW and the reactive power loss is 61kVAR. It is seen that there is minimum voltage at bus numbers in between 21-27.This would justify the need for shunt compensation.

5.1 Optimal Siting of Shunt Compensators

The sensitivity factors derived in section 4 are used to find the optimal siting of compensation devices [2]. The sensitivity values for the test system are tabulated in Table 2.

Voltage sensitivity factor is calculated for all the load buses. In this system buses 2 to 34 are load buses. Loss sensitivity factor is calculated for all the buses. Buses with highest sensitivity values are selected for the location of the embedded generators. The top most bus in both the factors are given more priority, therefore bus no 27 and 33 are chosen. It can be seen that bus no

21 is sensitive both in voltage and loss so this bus is also chosen for placement of compensation devices. With the three optimal locations found, simulations are carried out with compensation devices at different locations.

Table 2

Top four sensitive buses and their values

Voltage sensitivity factor			Loss sensitivity factor		
Bus	δLi/ δPi	δLi/ δQi	Bus	$\delta P_L/\delta P_i$	$\delta P_L/\delta Q_i$
27	119.62	21.268	33	.8696	.9995
26	100.05	19.29	27	.8649	.9933
23	89.34	17.63	21	.8588	.8700
21	75.39	19.94	22	.8575	.8075

5.2 Analysis with shunt compensators

The simulation done for the base case using MATLAB with capacitors, SVCs and STATCOM placed at sensitive buses proved that power loss can be reduced by improving the voltage profile using shunt compensators. Three different cases are studied for each shunt compensator.

- Compensator placed at single sensitive bus
- Compensator placed at two sensitive buses
- Compensator placed at three sensitive buses

A Compensation using shunt capacitor

Shunt capacitors are fixed size reactive power suppliers. The size of capacitors considered here (based on availability) are 1.5 MVAR, 2 MVAR and 2.5 MVAR. To find the optimal size of capacitor among them, each value is used separately in all the optimal buses individually and in all possible above said siting combination.

I) Capacitor placed at single sensitive bus

When the highest value of capacitor i.e. 2.5 MVAR is placed at bus no 21, it can be seen that voltage at few buses are still below 1 p.u but the real and reactive power losses are reduced to 0.167MW and 0.048 MVAR respectively. If it is placed at bus no 27 the real and reactive power losses increased more than the uncompensated case.

2) Capacitor placed at two sensitive buses

The capacitors were distributed in two buses at a time i.e. simulation is done with capacitors placed at 21 and 27, 21 and 33 and the final combination 27 and 33 and results are listed out in Table 3.It is seen that the voltage optimality is reached in the case also but the rating of capacitor is greater than the previous case which is not economical.

3) Capacitors placed at all three sensitive buses

Capacitor rating can be reduced when it is added at all the three sensitive buses. Capacitor with rating 1.5 MVAR was installed at buses 27, 21 and 33. Fig.5 shows a graph comparing voltage profile of this case with the uncompensated case. The result obtained from simulation is shown in Table 3. It is seen that the voltage optimality is reached with this reduced rating of capacitors. It is found that 1.5 MVAR placed at buses 21, 27 and 27, 33 gives a reasonably good reduction in system loss. Optimal location can be obtained by comparing the voltage profile of both the cases.

Table 3

System power loss of various cases simulated with capacitor

C rating in MVAR	Apparent loss when compensated at bus no					
	21 and 27		*27 and 33*		*21, 27 and 33*	
	MW	*MVAR*	*MW*	*MVAR*	*MW*	*MVAR*
1.5	.189	.053	.177	.049	.224	.062
2	.253	.069	.225	.060	.343	.093
2.5	.351	.094	.303	.078	.521	.140

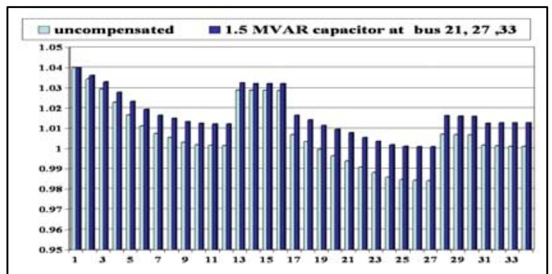

Fig.5 Voltage profile with capacitor at three buses.

4) Optimal location of Capacitor

It is observed that voltage profile of capacitor placed at buses 21 and 27 is better than the other case. Even though the losses of this case is little higher than the other case, this can be compromised for the better voltage profile. Therefore optimal location is found as placement of capacitor at buses 21 and 27. Optimality is achieved with 1.5 MVAR capacitor placed at buses 21 and 27.

B. Compensation using SVC

Similar to capacitors, SVCs are placed at different optimal buses found from sensitivity analysis. SVCs are placed at different locations and they provide the exact amount of VAR needed to improve voltage profile with reduced losses.

1) SVC placed at single bus

The improvement in the system voltage profile when single SVC is placed in either bus 21or 27 or 33 was studied. It was seen that the system voltage profile had no great improvement for SVC at bus 33. The voltage profile of other two cases is shown in Fig 6. It can be seen that the voltage profile of the system with SVC at bus 27 is better than the other case, where the voltage at certain buses are still under 1 p.u. When

SVC is placed at bus 21 or 27 the injected reactive power was 0.82 MVAR and 2.00 MVAR. The amount of injected power depends on the initial voltage of the bus where SVC is placed.

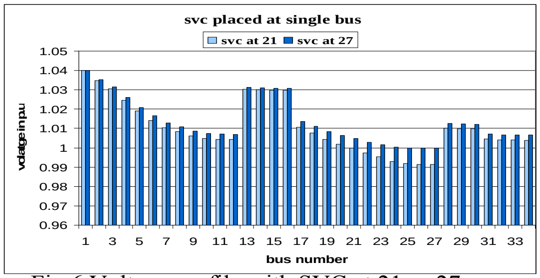

Fig 6 Voltage profile with SVC at 21 or 27

2) SVC placed at two buses

SVCs with the same rating were placed in two buses and all the three combination viz. SVC at 21 & 27, 21 & 33 and 27 & 33 is studied. The voltage profile of other case was found to be lower than the two cases shown. For the case SVC at 21 and 27, injected MVAR at 21 is 3.73 (capacitor) and at 27 is -5.61(reactor) whereas for other case SVC at 27 and 33, injected MVAR at 27 is -3.02 (reactor) and at 33 is 1.7(capacitor).

3) SVC placed at all three sensitive buses

SVC was placed at buses 21, 27 and 33. This case is not economical, as the cost of SVC is greater compared to shunt capacitor. System losses also increased around twice the uncompensated case. So it is clear that this case is inefficient.

4) Optimal location of SVC

When the system is compensated using SVC the losses are lower than the system compensated using shunt capacitor. Table 4 shows that system with SVC placed at 21 or 27 separately gives reduced losses. Optimal location from the two cases can be found by comparing their voltage profile as shown in Fig. 6. Voltage profile of system with SVC at bus 27 is better than the other cases.

Table 4

System power loss for the different cases with svc

location / Loss	21	27	33	21 & 27	21 & 33	27 & 33
MW	.153	.175	.212	.44	.199	.302
MVAR	.045	.048	.063	.096	.056	.073

C. *Compensation using STATCOM*

Similar to SVC, STATCOM is also made to operate to achieve a target voltage which is set at 1p.u. Converter's reactance is 10p.u. Now STATCOMs are placed in place of shunt capacitor in the sensitive buses.

1) STATCOM placed at single sensitive bus

STATCOM was placed at one sensitive bus at a time and load flow was carried out. Fig. 7 shows the voltage profile of system with STATOM at one of the sensitive buses. It can be seen that voltage profile of system with STATCOM at bus 21 is better than the other case. The converter voltage and angle of STATCOM in p.u is: at 21st bus 1.0427, 0.9214 and at 27th bus 1, 0.7802.

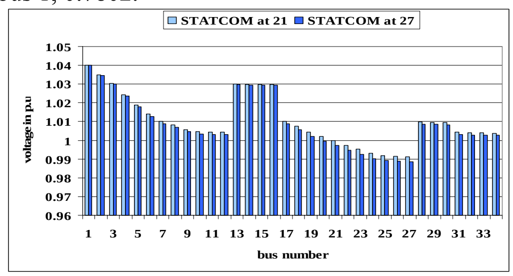

Fig. 7 Voltage profile with STATCOM at 21 or 27

2) STATCOM placed at two buses

Similar to previous section STATCOM was placed at two sensitive buses at a time and the system was studied. Result of this system is shown in Fig 8. From the graph it can be seen that the voltage profile is not improved as required. Therefore this case is not efficient.

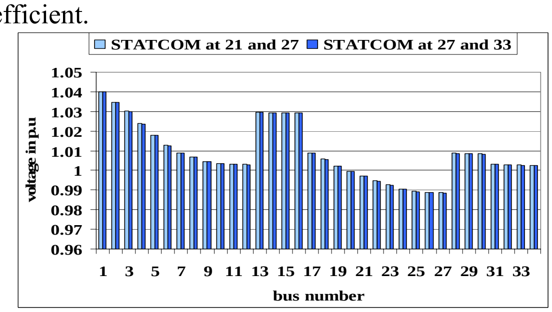

Fig 8 Voltage profile with STATCOM at 21, 27 and 27, 33

3) Optimal location of STATCOM

Table 5 shows the system losses of various cases simulated. System losses are decreased compared to uncompensated case. It can be seen that system with STATCOM at bus 21 gives reduced loss (0.172 MW) compared to the other cases. Even the voltage profile of this case was found to be better than the other cases. Thus bus 21 is found as the optimal location for STATCOM.

Table 5

System losses in all the cases

location / Loss	21	27	21 & 27	27 & 33
MW	0.1727	0.1779	0.1767	0.1789
MVAR	0.0518	0.0536	0.0532	0.0539

6. Simulation study II-Shunt Compensation with DG

As FACTS devices have been successfully used for reactive compensation and voltage profile improvement in conventional power systems, it has been found relevant to study their impact as compensation units in dispersed generation networks.

The impact of different DG technologies on the power system has already been studied in the reference [2] for a 34-bus radial distribution system connected to a substation. In that work, fixed wind energy conversion system and Photo voltaic cell are connected as a hybrid system with grid. They are modeled as injected or consumed power at the corresponding bus.

The different DG technologies used:

DG1: supplying real power only (Photovoltaic cell).

DG2: supplying real power but consuming proportionately reactive power. The reactive power consumed by a DG (fixed speed wind turbine generator) in a simple form can be represented as

$$Q_{DG} = -(0.5 + 0.04 \times P_{DG}^{2}) \quad (8)$$

The actual test system is taken for the study which has capacitors at bus no 1, 21 and 30 and tap changing transformers at bus 1 and 5.Since optimal siting and sizing of DGs [10],[14] is beyond the scope of this paper, the optimal location and size for the two cases; (1) DG one at a time (2) DG two at a time, are directly taken from reference [2]. DG2 reactive power consumption increases with wind velocity and number of turbines which poses a challenge for siting of DGs as well as of compensators.

So only the effect of SVC and STATCOM is to be addressed here. They are placed based on sensitivity factors as same as previous simulation study which leads to two cases. Two SVCs placed for case1 (DG1-21;DG2-27) at bus 21 and 27, whereas one SVC is chosen at bus 27 for case2.

6.1 *Compensation Using SVC*

1) *Case 1: DGs with Compensators at bus 21and 27.*

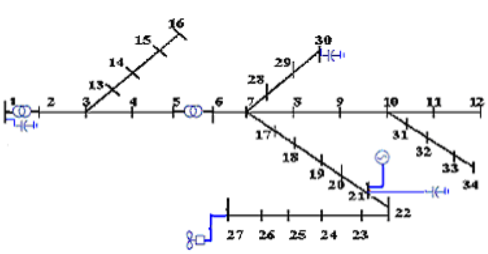

Fig. 9 Case 1 - DG1-21, DG2-27

Fig. 9 shows the system investigated in this study.SVC is placed at buses 21 and 27 along with DGs and steady state performance is simulated. Improved voltage profile is obtained as shown in Fig 10. It is also seen that the % reduction in loss is 56% for real power and 65% for reactive power of the total loss. Hence, there is a substantial reduction in loss by using SVC. Also the SVC injects 1.93 MVAR into 21 and 2 MVAR into 27 and keeps the nodal voltage magnitude at specified value.

Table 6

Input Details for the System [2]

P_{DG} loc (MW)	C[1] (kVAR)	C[21] (kVAR)	C[30] (kVAR)	T[1] (p.u)	T[5] (p.u)
1.2157 **[21]** 1.2998 **[27]**	0.529	0.116	0.047	1.015	1.047
0.7981 **[27]** 0.5806 **[27]**	0.160	0.393	0.071	1.022	1.047

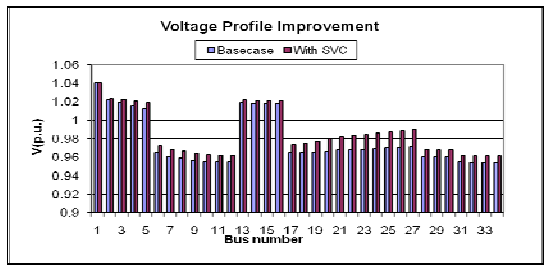

Fig. 10 voltage profile Improvement for case1

2) *Case 2: DGs with Compensator at 27*

Similar to case 1, the system configuration using DG1 and DG2 placed at bus 27 is studied with SVC at 27. As it can be seen from the Table 7 the loss reduction is 60.88% for real power and 62.95% for reactive power. Also the SVC injects 1.85MVAR into 27 and keeps the nodal voltage magnitude at specified value.

Table 7

Results Obtained With SVC for Case 1 and Case 2

Cases	Case 1(21,27)		Case 2(27)	
	No SVC	With SVC	No SVC	With SVC
P_L(kW)	132.9	88.2	116.9	79.4
QL (KVAR)	37	21	34.5	22.6
Reduction (%)	56.6	65.2	60.88	62.95

6.2 *Compensation Using STATCOM*

1) *Case 1: DGs with Compensators at bus 21and 27.*

Unlike the SVC, the STATCOM is represented as a voltage source for the full range of operation, enabling a more robust voltage support mechanism.

The power flow result indicates that the STATCOM generates 19.4 MVAR in 21 and 19.7 MVAR at 27 in order to keep the voltage magnitude at specified value at the sensitive buses. The STATCOM parameters associated with this amount of reactive power generation are Vvr -1 p.u. and Tvr -1.342 for bus 21 and Vvr-1 p.u and Tvr-1.91 for bus 27 .Use of the STATCOM results in an improved network voltage profile. The slack generator reduces its reactive power generation by almost 28% compared with the base case. In general, more reactive power is available in the network than in the base case .As expected active power flows are only marginally affected by the STATCOM installation. Fig. 11-16 show the performance of STATCOM for case 1 and case 2.

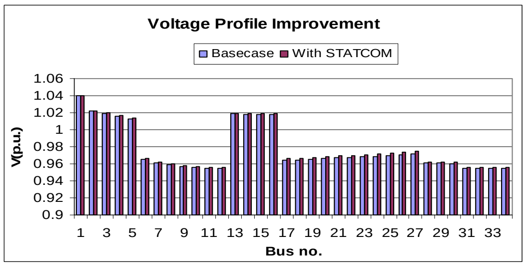

Fig. 11 Network voltage profile for case 1 with STATCOM

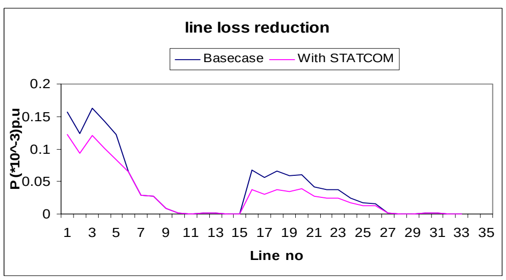

Fig. 12 Real power line loss reduction with STATCOM for case 1

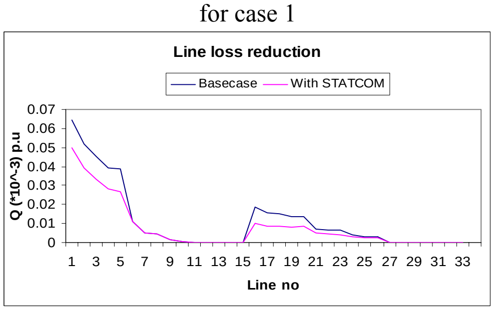

Fig. 13 Reactive power line loss reduction with STATCOM for case 1

2) Case 2: DGs with Compensator at 27

For the case with both DG's connected to the bus 27, simulation is carried out with STATCOM placed at 27.As earlier case, improved voltage profile with much prominent decrease in transmission loss is obtained. The power flow result indicates that the STATCOM generates 22.6 MVAR at 27 in order to keep the voltage magnitude at specified value at the sensitive buses. The STATCOM parameters associated with this amount of reactive power generation are Vvr -1.1 p.u. and Tvr is -0.21 .The transmission losses are reduced to 31.8% when compared to the base case. The line losses are also found to be reduced when STATCOM is used in the system

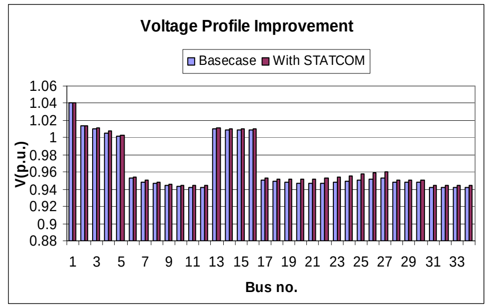

Fig. 14 Network voltage profile for case 2 with STATCOM

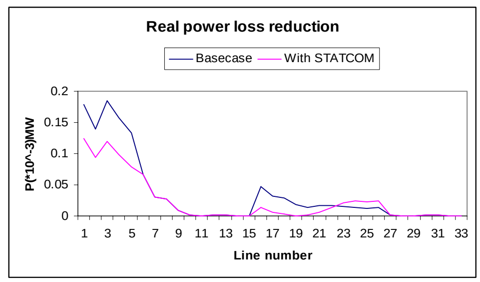

Fig. 15 Real power line loss reduction in case 2

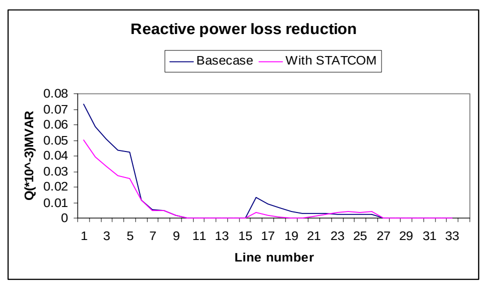

Fig. 16 Reactive power line loss reduction in case 2

7. Conclusion

The following conclusions are made after the complete analysis of test system performance with shunt compensators.

1) Optimal placement of compensation device was achieved by considering both loss and voltage sensitivity factor. The more realistic mixed load models are considered for the study. So this provided the best location for compensation devices which improves voltage profile and reduces system losses.
2) Shunt capacitors have the problem of poor voltage regulation. But, FACTS controllers would strictly maintain the voltage at set point.
3) Both SVC and STATCOM reduce line losses

and improve voltage profile.SVC based compensation is better than STATCOM (High cost) for voltage enhancement. But, STATCOM is better (Fast & provides dynamic support) for stability improvement.

4) It's good to have a SVC/STATCOM nearer to fixed WECS since it needs reactive power from the grid.

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APPENDIX I

Table shows the data for 34-bus radial system.

Node no	r (Ω/Km)	X (Ω/Km)	Length (Km)	P (KW)	Q (KW)	L_T
1	-	-	-	0	0	R
2	0.195	0.080	0.60	230	142.5	I
3	0.195	0.080	0.55	0	0	C
4	0.299	0.083	0.55	230	142.5	R
5	0.299	0.083	0.50	230	142.5	I
6	0.299	0.083	0.5	0	0	C
7	0.524	0.090	0.6	0	0	C
8	0.524	0.090	0.4	230	142.5	I
9	0.524	0.090	0.6	230	142.5	C
10	0.524	0.090	0.4	0	0	C
11	0.524	0.090	0.25	230	142.5	R
12	0.524	0.090	0.20	137	84	C
13	0.524	0.090	0.3	72	45	R
14	0.524	0.090	0.4	72	45	C
15	0.524	0.090	0.2	72	45	I
16	0.524	0.090	0.1	13.5	7.5	C
17	0.299	0.083	0.60	230	142.5	I
18	0.299	0.083	0.55	230	142.5	R
19	0.378	0.086	0.55	230	142.5	C
20	0.378	0.086	0.50	230	142.5	I
21	0.378	0.086	0.50	230	142.5	R
22	0.524	0.090	0.50	230	142.5	C
23	0.524	0.090	0.50	230	142.5	C
24	0.524	0.090	0.60	230	142.5	C
25	0.524	0.090	0.40	230	142.5	C
26	0.524	0.090	0.25	230	142.5	I
27	0.524	0.090	0.20	137	85	C
28	0.524	0.090	0.30	75	48	C
29	0.524	0.090	0.3	75	48	C
30	0.524	0.090	0.3	75	48	R
31	0.524	0.090	0.3	57	34.5	R
32	0.524	0.090	0.4	57	34.5	C
33	0.524	0.090	0.3	57	34.5	I
34	0.524	0.090	0.2	57	34.5	C

L_T=Load type, R=Residential, I=Industrial, C=Commercial