Effect Of Reactive Power Compensation On Voltage Profile

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Abstract *- The Reactive power management play an important role in voltage profile of the power transmission systems. Adequate reactive power control solves power quality problems like flat voltage profile maintenance at all power transmission levels, improvement in power factor, transmission efficiency and system stability. The Series and Shunt Capacitor compensation techniques are used to modify the natural electrical characteristics of the electric power system. Providing reactive shunt compensation with shunt-connected capacitors and reactors in optimal location is a well-established technique to get a better voltage profile in a power system. This paper presents the comparison of performance analysis the performance of series and shunt capacitors to improve the voltage profile. To demonstrate the comparison, a case study of 5 bus system is considered. The performance analysis of the change in voltage and reactive power with series and shunt compensation at the load side and generator side is done using the Power World Simulator software package (Version 16GSO). The outcome of this work helps in design and operational reactive power planning for the voltage and reactive power management.*

***Keywords:* Reactive power, Voltage Profile, Series compensation, Shunt compensation, optimal location of capacitors.**

1. Introduction

Reactive power management has become a most challenging task in power system operation and management. Some of the characteristics of the power systems and their loads can deteriorate the quality of the supply. The deterioration can be corrected by compensation that is by the supply or absorption of an appropriately variable quantity of the reactive power. However, most high voltage transmission systems are operating below their thermal rating due to such constraints as stability limits, on an alternating current power system voltage is controlled by managing the production and absorption of reactive power [4]. A reactor or a capacitor stores the reactive power generated by the ac power source during a quarter of a cycle and returns the same power to the source in the next quarter cycle. In other words, the reactive power oscillates between the source and the reactor or capacitor at a frequency equal to twice the rated value. However in nature, most of the loads are inductive loads absorbing reactive power and resulting in low lagging power factor [3]. So the compensation for these problems can be provided by means of connecting the capacitors of different ratings along the lines. However, the voltage at the receiving end in the transmission end is allowed to vary between the range of ±5% which further restricts the transfer of the reactive power. Load compensation is the management of the reactive power to improve the quality of the supply in ac power systems [5]. The voltage can be controlled by providing reactive power control margin to modulate the supply needs through the following compensations as given below:

1. Shunt compensation.
2. Series compensation.
3. Dynamic compensator.

Any device which is connected in series or parallel with the load and which is capable of supplying reactive power demand to the load is called reactive power compensation device. Major industrial loads for ex: Induction furnace, Induction motors, etc., needs reactive power for their operation. Reactive power cannot deliver effective mechanical power output unlike its counter real power because the reactive power is utilized as active power which is achieved by providing reactive power compensator at load end [4].

This paper deals with the improvement in the voltage profile and reactive power compensation in five bus system taken for simulation purpose and the simulation of the system is done by using POWER WORLD SIMULATOR software packages. Here the performance evaluation of the Bus Voltages, Line flows and line losses are calculated before the compensation is given to the lines and all the tabulation are done as per the requirements. The shunt compensation is provided for 5 bus system and series compensation is provided to the radial transmission line in order to boost up the active power generation as well voltage profile at the bus. Simulations are done for different load. Hence the performance evaluation of the five bus system can be analyzed for the voltage profile and the reactive power generation in it, and the plot for the same can be plotted for the shunt compensation as well as for the series compensation. By comparing the simulation results, the change in the voltage and the losses can be clearly analyzed. Also by this method we can have the optimal location of the capacitor for the improvement of the voltage profile and reduced system losses with increased efficiency.

A. Need of Reactive power

- Reactive power is required to maintain the voltage profile and to meet the active power demand.
- Motor loads and other loads require the reactive power for excitation.
- When there is no enough reactive power, the voltage dips down and it is not possible to meet the power demand.

B. Effects of increased Reactive Power demand in the network [2]

- ✓ Poor transmission efficiency.
- ✓ Poor voltage regulation.
- ✓ Low power factor.
- ✓ Need of large sized conductor.
- ✓ KVA Overrating of the system equipment.

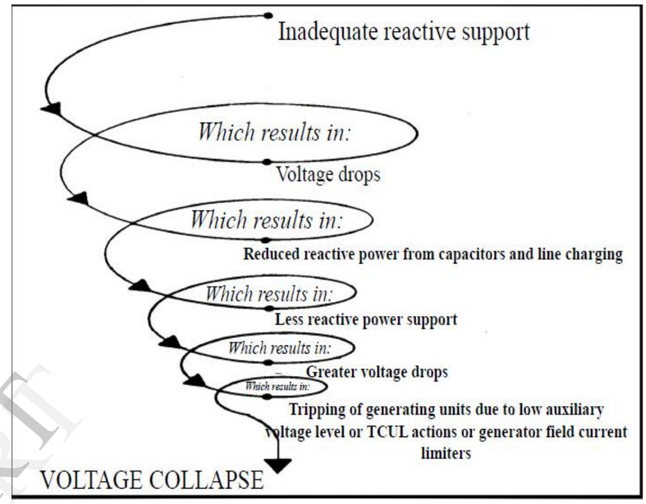

Figure 1. Effect of reactive power on voltage collapse

Figure 1 shows how the reactive power affects the voltage profile in the transmission systems. Inadequacy in the reactive power leads to the voltage drop to some extent and if continues in the same state and the tripping is not achieved properly in the system connected then the generator will go out of step and finally it leads to the blackout in the power system. Hence in this type of conditions the compensation is very much essential.

C .Compensating Techniques

There are many types of the compensating Techniques available in the practice like static VAR compensation, series compensation, shunt compensation, synchronous condensers, etc., but in this paper we are giving more importance to the series and shunt capacitor compensation technique and they are discussed in detail as given below.

Shunt compensation: Shunt capacitors are connected in parallel to feed the reactive power and are used mainly for voltage profile improvement. These are used across an inductive load so as to supply the part of the reactive VAR's required by the loads so that the reactive VAR's transmitted across the lines are reduced, thereby the voltage across the load is maintained .Shunt capacitor banks can be connected in parallel to the load bus [1]. The phasor diagram for the uncompensated transmission line is given in the fig.1 and the phasor for the compensated transmission line is given in figure 2. The mathematical expression for voltage drop in the line with lagging power factor can be approximated as,

$$V_D = I_R + I_X\ X_L\ \ V$$

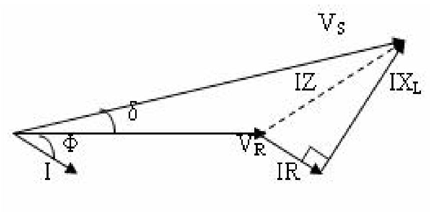

Figure 2. Phasor diagram for an uncompensated transmission line

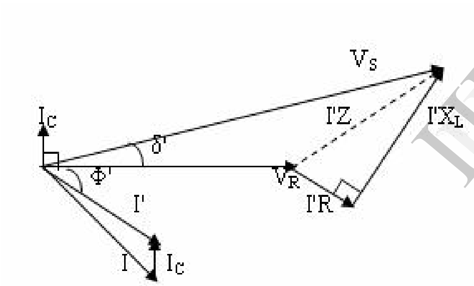

Figure 3. Phasor diagram for a shunt compensated transmission line.

The expression for the voltage drop with lagging power factor after shunt compensation can be approximated as,

$$VD = I_R + I_X X_L - I_C X_L\ V.$$

The difference between the voltage drops is the voltage rise due to installation of the capacitor and can be expressed as [2],

$$V_R = I_C\, X_L\,.$$

Series compensation: Series capacitors are connected in series especially for long lines are used mainly for boosting receiving end voltage, thereby increasing in transmission efficiency through reduction in line losses. The phasor diagram for series compensated transmission line is given in the figure 3. Mathematical expression for voltage drop when load with lagging power factor is connected at the end can be expressed as [8],

$$\mathrm{VD} = IR \cos\theta + IX_L \sin\theta$$

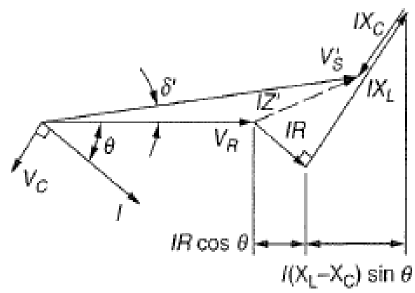

Figure 4. Phasor diagram for a series compensated transmission line.

The advantages of compensations stated here can be given as follows:

- Better efficiency of the power generation, transmission and distribution.
- Improvement in the voltage profile.
- Reduced KVAR demand.
- Higher load capability.
- Reduced system losses.

C. Comparison between Series and shunt capacitors:

The various comparisons can be made to distinguish between the series and shunt capacitors, some of the comparison can be listed with respect to the different parameter and they are listed below [5]:

- The voltage boost due to a shunt capacitor is evenly distributed over the transmission line, where as the change in voltage between the two ends of the series capacitors where it is connected, is sudden .The voltage drop along the line is least affected.
- It is evident that for the same voltage boost the reactive power capacity of a shunt capacitor is greater than that of series capacitors.
- The shunt capacitor improves the power factor of the load whereas the series capacitor has little effect on the power factor.

- For a long transmission lines where the total reactance is high, series capacitor are effective for improvement of the system stability.

II. Simulation

The simulation in this paper is carried out by using the **Power World Simulator Software Package (Version 16GSO).** The five bus system is drawn using the package and the data considered for the study like generator parameters and also the load parameters are given in the table, they are given as the input to generator and also the load, then the five bus system is simulated before giving the compensation to it and the values of voltage, line losses are tabulated as shown in table no. .after this compensator is added to the bus having least voltage, then the output is tabulated. Similarly for different loading conditions the compensation is given and the readings are tabulated, parallel to tabulation the graphs for the same are plotted as shown.

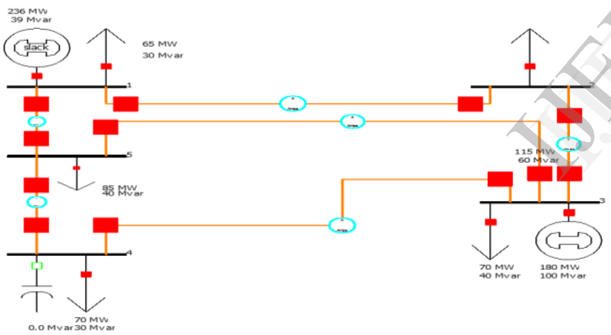

Figure 5.Five bus system before compensation.

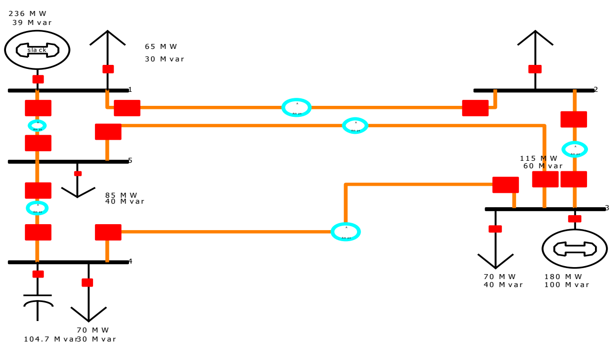

Figure 6. Five bus system with Shunt Compensation

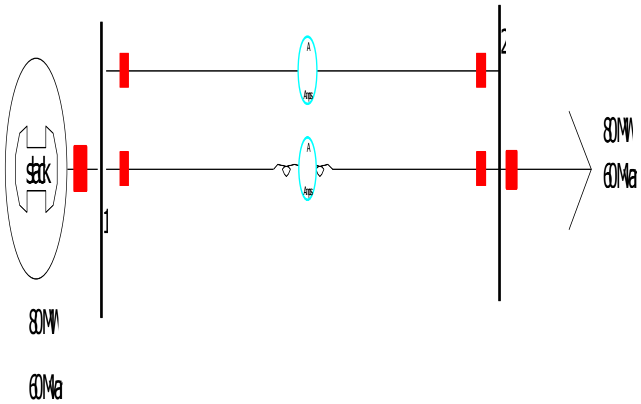

Figure 7.Two bus system using Series compensation

Table: 1
Transmission line Details

Line	Length	Resistance	Reactance	Changing MVAR
1-2	64.4	0.042	0.168	4.1
1-5	48.3	0.031	0.126	3.1
2-3	84.8	0.031	0.126	3.1
3-4	128.7	0.084	0.336	8.2
3-5	80.5	0.053	0.210	5.1
4-5	96.5	0.063	0.252	6.1

Table: 2
Schedule Generation and Loads

Bus	Generation		Load		V in p.u	Remarks
	P in Mw	Q in MVAr	P in MW	Q in MVAr		
1	-	-	65	30	1.04	Slack bus
2	0	0	115	60	1.00	Load bus
3	180	-	70	40	1.02	PV bus
4	0	0	70	30	1.00	Load bus
5	0	0	85	40	1.00	Load bus

III. Simulation Results:

Table: 3

Bus records without compensation

Bus Records Without Compensation					
Bus	Voltage	Generation		Load	
no.	P.U	MW	MVAR	MW	MVAR
1	1	236.21	99.57	65	30
2	0.99			115	60
3	1	180	146.11	70	40
4	0.87			70	30
5	0.92			85	40
		416.21	245.68	405	200
		Total Generation		Total Load	

Table: 4

Bus record after Shunt compensation

Bus Records after Shunt compensation						
BUS	Voltage	Generation		Load		Switched Shunt
NO.	P.U	MW	MVAR	MW	MVAR	MVAr
1	1	235.79	39.95	65	30	
2	0.95			115	60	
3	1	180	100	70	40	
4	1.02			70	30	104.67
5	0.99			85	40	
		415.79	139.95			
		Total Generation				

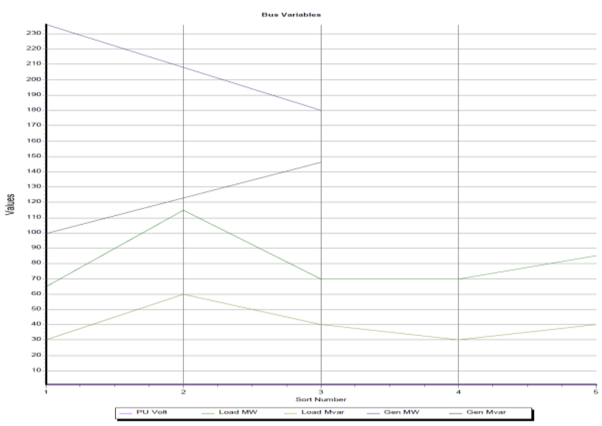

Figure 4.Plot of Bus Variables

Table: 5

Line records without compensation

Line Records without compensation			
Bus		Loss	
From	To	MW	MVAR
1	2	2.66	10.66
5	1	3.43	13.96
2	3	1.31	5.33
3	4	2.03	8.7
3	5	0.82	3.24
4	5	0.95	3.81
		11.2	45.7
		Total loss	

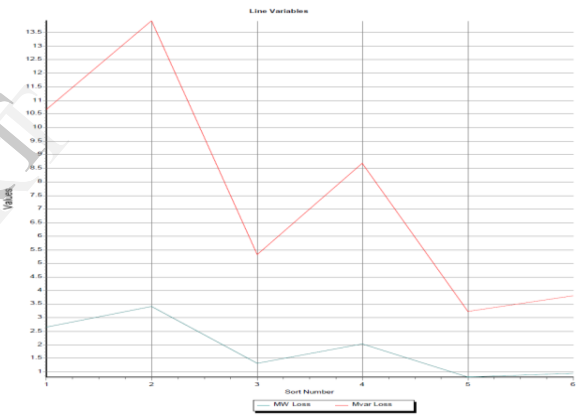

Figure 5.Plot of Line records without Compensation

Table: 6

Line records with series compensation

Bus		Loss	
From	To	MW	MVAR
1	2	2.4	9.61
5	1	2.92	11.88
2	3	1.64	6.65
3	4	1.54	6.61
3	5	0.47	1.84
4	5	1.85	7.42
		10.82	44.01
		Total loss	

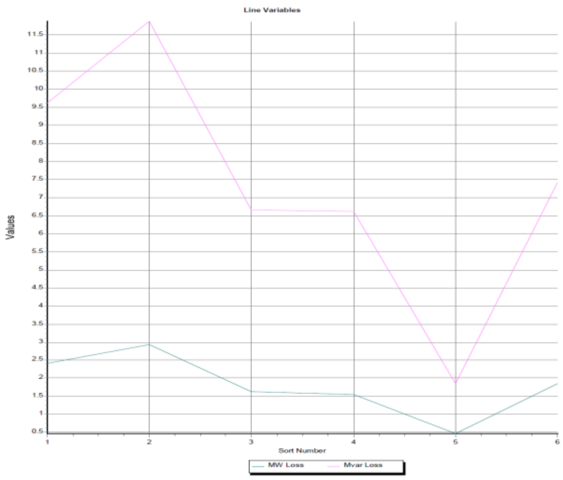

Figure 6.Plot of Line records with Shunt compensation

Table: 7

Bus records without compensation

Bus records without compensation at reduced loads						
BUS	Voltage	Generation		Load		Switched Shunt
NO.	P.U	MW	MVAR	MW	MVAR	MVAr
1	1	202.26	91.86	65	30	
2	0.93			115	60	
3	1	180	122.71	70	40	
4	0.92			70	30	0
5	0.94			85	40	
		382.26	214.57			
		Total Generation				

Table: 8

Bus records without compensation at reduced load

Bus records with shunt compensation at reduced loads						
BUS	Voltage	Generation		Load		Switched Shunt
NO.	P.U	MW	MVAR	MW	MVAR	MVAr
1	1	202.26	60.96	65	30	
2	0.94			115	60	
3	1.02	180	100	70	40	
4	1.03			70	30	52.97
5	0.97			85	40	
		382.26	160.96			
		Total Generation				

Table: 9

Line records without compensation at reduced loads

Line records at reduced loads			
Bus		Loss	
From	To	MW	MVAR
1	2	2.04	8.14
5	1	2.03	8.2
2	3	1.583	6.43
3	4	0.99	3.47
3	5	0.81	2.62
4	5	0.15	0.61
		7.603	29.47
		Total loss	

Table: 10

Line records with compensation at reduced loads

Line records at reduced loads			
Bus		Loss	
From	To	MW	MVAR
1	2	1.88	7.53
5	1	1.72	7.01
2	3	1.72	6.99
3	4	0.65	2.78
3	5	0.87	2.03
4	5	0.55	2.21
		7.39	28.55
		Total loss	

Table: 11
Bus records without Series Compensation

Bus records before series compensation					
BUS	Voltage	Generation		Load	
No.	P.U	MW	MVAR	MW	MVAR
1	1	133.25	59.87		
2	0.68346			79.86	59.92

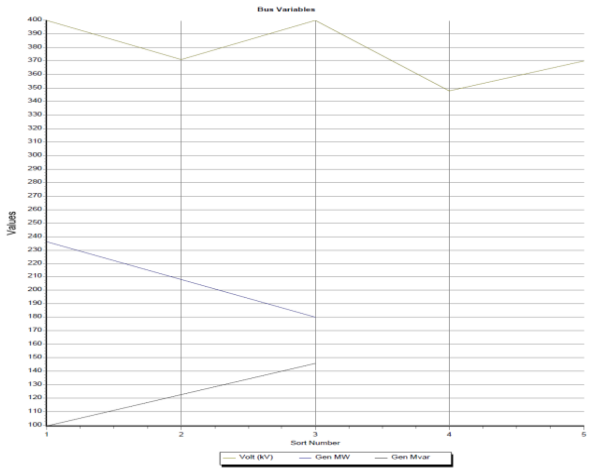

Figure 7.Plot of Bus records before Series compensation

Table: 12

Bus records with series compensation

Bus records after series compensation					
BUS	Voltage	Generation		Load	
No.	P.U	MW	MVAR	MW	MVAR
1	1	80	60		
2	0.9999			80	60

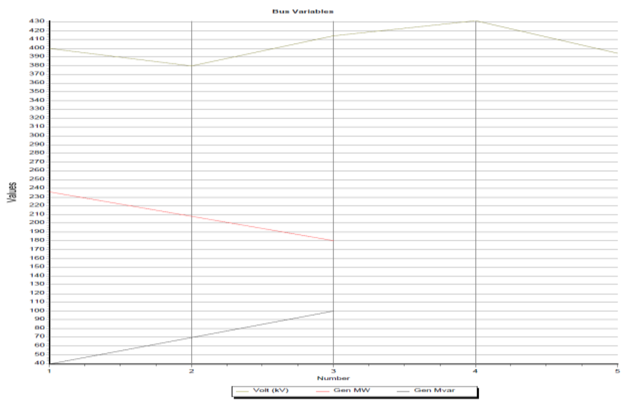

Figure 8.Plot of Bus variables after Series compensation

Comparison of Voltage profile and losses at Normal and Reduced loads

Table: 13

Comparison of Voltage profile

Voltage at normal loads		Voltage at reduced loads	
Before compensation	After compensation	Before compensation	After compensation
1	1	1	1
0.99	0.95	0.93	0.94
1	1	1	1.01
0.87	1.02	0.92	1.02
0.95	0.99	0.94	0.97

Table: 14

Comparison of losses

Losses before compensation				Losses after compensation			
Normal loads		Reduced loads		Normal loads		Reduced loads	
MW	MVAR	MW	MVAR	MW	MVAR	MW	MVAR
11.2	45.7	7.603	29.47	10.82	44.01	7.39	28.55

Table no.13 and 14 gives comparison of the voltage profile, line losses before and after the compensation at the normal as well as at reduced loads for the reactive power compensation at the lines. Here the voltage Profile and line losses are less before giving the compensation and if we add a capacitor of series or shunt type across the transmission line then the voltage profile and the line losses can be improved to some extent, hence From this tables we can infer that the effective compensation by using the capacitors at the transmission lines can lead to the improved voltage profile and line losses in the transmission lines.

IV. CONCLUSION

A capacitor is said to be the generator of the reactive power. When a capacitor is connected across the load bus, it reduces the reactive power demand from the line and boosts the voltage profile of the system. Through this paper, we conclude that the voltage profile improvement can be met by adding series compensation for long transmission lines and the reactive power demand at load end can be achieved through shunt compensation. This is done for only single capacitor connected at bus no.4, and results of that are tabulated in the paper, further the simulation can be extended by connecting the capacitors at all other buses depending upon the voltage profile of the buses and Hence we can have the optimal location of the capacitor based on the simulation results and the cost of operation can be reduced. The dielectric materials make it possible to increase the output per unit and to reduce the losses, thus making compensation by means of the capacitor effectively and also profitable as the cost of operation is considered. Shunt capacitive arrangement reduces the total active power loss. From this paper we infer that the compensation is more effective for economical operation of the system with increased efficiency.

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