Reactive Power Compensation for LV Distribution Network

S. S. Kanojia, Suketu Rajyaguru

Abstract: In the LV distribution system, the reactive power compensation is done by using the decentralized capacitors banks. But there are certain issues of using this capacitor banks in decentralized manner. Those issues can be overcome by using the centralized reactive power compensation method. By centralizing capacitor banks together, it can help to maintain bus voltages and power factors as well as reduces the power cable losses. Also the centralized reactive power system can be easily expanded to meet any future load increase which cannot be done by using the decentralized compensation system. A reasonably sized centralized reactive power compensation system will be capable of meeting the requirements of the network with optimal solutions. Hence in this paper optimization has been done for centralized reactive power compensation system. It has been observed that by optimizing the sizing of capacitor bank, the bus voltage has maintained and power losses have also been reduced by using the centralized reactive power compensation with capacitor bank. The simulation of the centralized reactive power compensation used distribution network has been done in MATLAB software.

Index Terms: Centralized Capacitor bank, Reactive Power Compensation, and Distribution Network.

I. INTRODUCTION

Active power is necessary for running of any type of the electrical load. To transmit this active power from generation to the electrical loads, Reactive power is necessary. Generally the reactive power regulates the voltage level of power system. If voltage of the system is not sufficient, essential active power cannot be supplied. So reactive power is used to maintain the enough voltage for active power to do useful work [1].

Now a days power systems are being more reliable so that they can meet customers load demand without any interruption and with sufficient voltage. Generation facilities produces the required amount of power to meet the customers load demand. This power must be reached to the customer end through transmission and distribution systems.

Sometimes voltage may get to lower value and current increases to high value, causes power losses in a distribution system. Total power loss is the sum of both active and reactive power losses. Reactive power compensation reduces the transmitted apparent power or total power and ohmic transmission losses decrease by the square of the currents.

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So, reactive power compensation strategies in power distribution systems is needed to reduce resistive power losses, to maintain system voltage levels and to improve power factors..

II. METHOD USED FOR REACTIVE POWER COMPENSATION

Generally two methods are there for reactive power compensation.

A. Decentralized Method

In decentralized reactive power compensation, the individual capacitor bank is installed locally in the network. The optimal size of capacitor bank can be obtained and install it wherever it is required for different period of times.

B. Centralized Method

All the individual capacitor banks installed in the network are centralized. This will use for maintaining bus voltages and power factors. Reactive power control units are used for central compensation [2].The current industry practice uses the decentralized method for reactive power compensation. In decentralized reactive power compensation, the individual capacitor bank is installed locally in the network. It is very costly and uneconomical to buy a capacitor bank and install it wherever it is required for different period of times. For that optimal size of capacitor bank can be obtained.Also the decentralized method provide optimal capacitor placement for only one particular load situation. If the loading condition changes, the new set of optimal capacitor placement has been given by the decentralized method. Also it is not possible practically to move capacitor bank from one location to other.Another problem is the capacity of the capacitor bank is fixed to the maximum level. So capacitor banks at some buses with low load are unable to share their excess capacity of reactive power with other buses that have heavy load. So there are certain problems of decentralized method.The solution of the above said problem can be done by changing the method of reactive power compensation. By using the centralized reactive power compensation method instead of conventional method gives certain advantages over said problem.In centralized reactive power compensation method, all the individual capacitor banks installed in the network are connected in centralized manner. This is used for maintaining bus voltages and to improve the power factors of the system. By centralizing all capacitor banks, the total capacity can be shared by each connected bus. It can also help to reduce the total installed capacity of capacitor banks instead of installing individual capacitor banks locally.

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This method takes into account the different load situations to classify the bus load groups into different load scenarios. The proposed centralized capacitor bank can also connect to as many buses as they require so there is no need to move the centralized capacitor bank around. Also it can be easily expanded to meet any future increase in the load demand.

Different devices can be used for the reactive power compensation: Flexible AC transmission system (FACTS) devices and Capacitor banks. The FACTS devices depend on power electronics control techniques for reactive power compensation. The cost of these power electronics devices is very high. So the capacitor bank is more preferable as economical point of view for distribution system. This paper basically gives the comparison between centralized and decentralized reactive power compensation method for the distribution system [2].

III. CASE STUDY

Fig-3.1 shows the single line diagram of the IEEE 13 bus test feeder. This system is taken as 13 bus distribution system for this case study for different comparison.

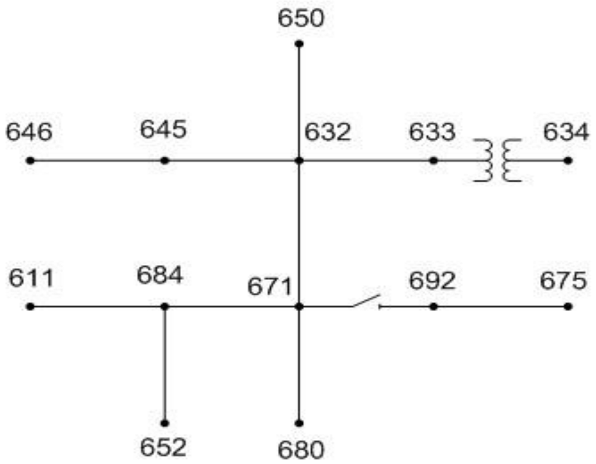

Fig. 3.1 Single Line Diagram

The load flow simulations of 13 Bus Distribution System are carried out in MATLAB software. The voltage level for this system is 4.16 kV. One 4.16 / 0.48 kV three-phase transformer is connected. All the data for different components of the distribution system is taken from the standard IEEE test feeder.

The simulation for the different cases have been done and discussed in subsequent section as follows.

A. 13 Bus Distribution System without Capacitor

Simulation of the 13 bus distribution system is done without any external capacitor.

B. 13 Bus Distribution System with Decentralized Capacitor

For decentralized capacitor, 3 three-phase delta connected capacitors of 200 kVAR (in each phase) are connected to the buses 671, 692, 675 and 2 single-phase capacitor of 200 kVAR are connected to the buses 684, 611.

C. 13 Bus Distribution System with Centralized Capacitor at Bus-632 (Case-1)

For the centralized capacitor, one three-phase capacitor of 700 kVAR capacity in each phase is connected to bus 632 in case-1.

D. 13 Bus Distribution System with Centralized Capacitor at Bus-680 (Case-2)

For the centralized capacitor, one three-phase capacitor of 600 kVAR capacity in each phase is connected to bus 680 in case-2.

IV. RESULTS ANALYSIS

Various parameters at different buses are obtained after the load flow simulation for this distribution system without capacitor, with decentralized and with centralized capacitor (case 1 & 2) in this section. The comparison and analysis of these parameters for different cases to be done in this section [3].

A. Voltages at different Buses

The results of bus voltages at each buses for 13 bus distribution system without capacitor, with decentralized and with centralized capacitor (case 1 & 2) after load flow simulation have been obtained. It was observed that voltage level at some buses of this 13 bus system are much lower when simulation is done without any external capacitor. As the distance increases from the bus-650, the voltage level reduces accordingly. This is due to the requirement of the high reactive power and line loss of the system. To overcome this problem and to improve the voltage level, the external reactive power is needed. Hence the external capacitor is used for reactive power compensation in this system. The main purpose of this case study is the comparison between the Decentralized and Centralized methods for reactive power compensation in this 13 bus distribution system. Table-I shows the voltage levels of some weak buses for different simulations i.e. without capacitor, with decentralized and with centralized capacitor (case 1 & 2). For the decentralized reactive power compensation method, 3 three-phase and 2 single-phase 200 kVAR (in each phase) capacitors are connected at the different buses where the voltages level are much lower. From the result of this simulation we can see that the voltages are improved. The total capacity of the capacitor is 2200 kVAR in this decentralized method. There are two different cases taken for the centralized reactive power compensation method for this system. In the fiRs.t case, 1 three-phase capacitor of 700 kVAR (in each phase) is connected at the bus-632 i.e. 2100 kVAR total capacity. In the second case, 1 three-phase capacitor of 600 kVAR (in each phase) is connected at the bus-680 i.e. 1800 kVAR total capacity. The voltage levels have been improved at every buses in both cases.

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Table-I Voltages at different buses

Bus ID	Bus Voltage (pu)			
	Without Capacitor	Decentralized Capacitor	Centralized Capacitor	
			At Bus 632	At Bus 680
632 C	0.9395	0.9717	0.9657	0.9625
633 C	0.9368	0.9691	0.9630	0.9599
634 A	0.9316	0.9611	0.9623	0.9579
634 C	0.9163	0.9494	0.9432	0.9400
645 C	0.9378	0.9700	0.9639	0.9608
646 C	0.9359	0.9680	0.9620	0.9588
671 A	0.9312	0.9886	0.9617	0.9822
671 C	0.8836	0.9485	0.9111	0.9302
680 A	0.9312	0.9886	0.9617	0.9945
680 C	0.8836	0.9485	0.9111	0.9411
692 A	0.9302	0.9877	0.9607	0.9813
692 C	0.8828	0.9477	0.9103	0.9295
675 A	0.9306	0.9869	0.9611	0.9816
675 C	0.8720	0.9355	0.8998	0.9192
684 A	0.9312	0.9888	0.9617	0.9822
684 C	0.8803	0.9473	0.9078	0.9270
652 A	0.9294	0.9870	0.9599	0.9803
611 C	0.8770	0.9447	0.9045	0.9237

Here the graphical comparison of voltages at different buses for 13 bus distribution system without capacitor, with decentralized capacitor and with centralized capacitor (case 1 & 2) is shown in Fig 4.1.

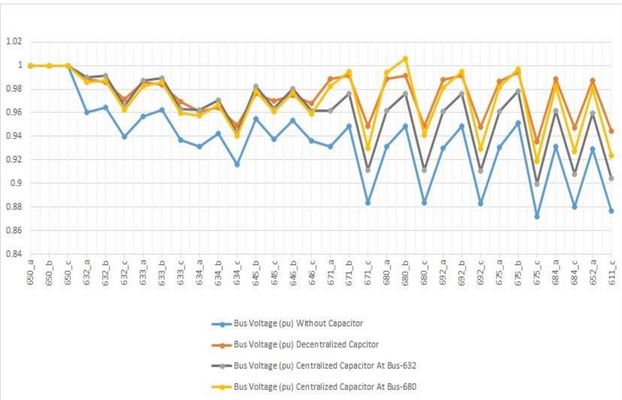

Fig. 4.1 Voltages at different buses

The voltage at different buses without capacitor, with decentralized, with centralized capacitor at bus-632 and with centralized capacitor at bus-680 are represented by the lines of blue, orange, grey, and yellow color respectively. It can be seen from the graph that the voltage at bus-650 is remain constant at 1pu for all the load flow simulations. The voltages at all the buses are improved by using of any type of reactive power compensation method.

The voltages are highly improved at weak buses for decentralized method as compare to centralized methods but the total capacity of capacitor is also much higher (2200 kVAR) in decentralized method.

As comparing two centralized methods i.e. case 1 and 2; The capacitor of total 2100 kVAR capacity is connected at bus-632 far from the weak buses in case 1 and the capacitor of total 1800 kVAR capacity is connected at bus-680 near to the weak buses in case 2. The voltages at every buses are better and also the capacity of capacitor is also lesser in case 2 than case 1. This is because of the capacitor is connected near to the weak buses in case 2.

B. *Power Loss*

Total active and reactive power losses for this 13 bus distribution system without capacitor, with decentralized capacitor, with centralized capacitor (case 1 & 2) after load flow simulation are shown in Table-II.

Table-II Power Losses

	Total Power Losses			
	Without Capacitor	Decentralized Capacitor	Centralized Capacitor	
			At Bus 632	At Bus 680
Active loss P(kW)	143.70	101.84	116.64	112.77
Reactive loss Q(kVAR)	410.07	282.99	324.19	309.42

It can be seen that the active and reactive power losses are high in the distribution system without capacitor i.e. 143.7 kW and 410.07 kVAR. The losses reduces as the reactive power compensation system is introduced by any of the methods. As compared to centralized capacitor method, the losses are less in the decentralized capacitor method i.e. 101.84 kW and 282.99 kVAR. This is because of the capacitors are connected nearer to the load. Also the large capacity of capacitor is used in decentralized method. In centralized method there are two cases; the active and reactive power losses are 116.64 kW and 324.19 kVAR for case 1 and 112.77 kW and 309.42 kVAR for case 2 respectively. The improved results are given by case 2 along with lower capacity of capacitor.

V. OPTIMIZATION TECHNIQUE

A. *Objective Function*

The goal is to minimize the cost of the total real power loss and that of the shunt capacitor installation. So the objective function includes the cost of installed capacitor and cost of power loss.

The cost function is given by

$$F_i = K_C *Q_C + K_L *P_L \quad (01)$$

Where K_C- Cost of capacitor (Rs./kVAR), Q_C- Capacity of installed capacitor (kVAR), K_L- Cost of power loss (Rs./kW), P_L- Power loss (kW).

B. Constraints

1. Equality Constraint

The equality constraints are the power balance constraints with shunt capacitor. The active and reactive power must be balanced at generation and demand side. It can be formulated as,

$$P_G = P_D + P_L \quad (02)$$

$$Q_G + Q_C = Q_D + Q_L \quad (03)$$

Where P_G & Q_G - Active and Reactive power generation (kW and kVAR), P_D & Q_D - Active and Reactive power demand/load (kW and kVAR), P_L & Q_L - Active and Reactive power loss (kW and kVAR), Q_C - Capacity of installed capacitor (kVAR)

2. Inequality Constraint

The inequality constraint is voltage level at every bus. Voltage limit includes the upper and lower voltage magnitude limits at each bus, which can be expressed as

$$V_{I\,MIN} < V_I < V_{I\,MAX}$$

Where V_{IMIN} and V_{IMAX} are the minimum and maximum voltage limits respectively.

C. Flowchart

Flowchart to finding the minimum value of objective function is shown in Fig. 5.1.

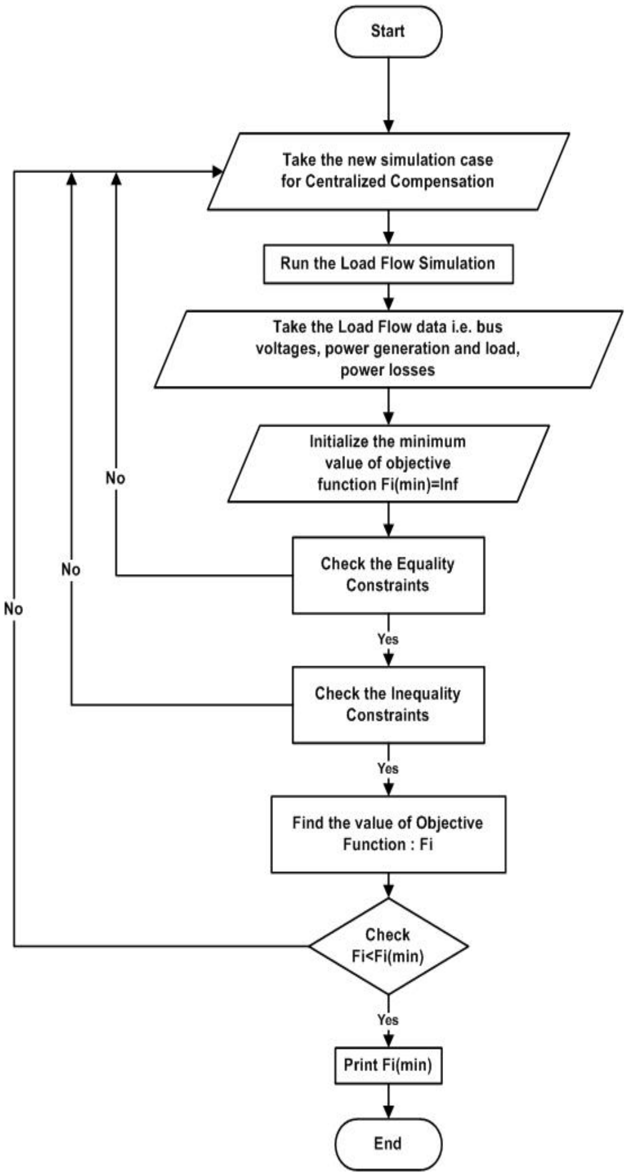

Fig. 5.1 Flowchart

VI. Comparative Results

The comparison between Centralized capacitor method and Decentralized capacitor method is done in this section. For centralized capacitor method, five different cases are considered as below.

700 kVAR (per phase) is connected to bus – 680
700 kVAR (per phase) is connected to bus – 692
700 kVAR (per phase) is connected to bus – 671
700 kVAR (per phase) is connected to bus – 632
700 kVAr (per phase) is connected to bus – 633

The above five cases are compared with the Decentralized capacitor case which is mentioned in section III–B.

Voltage and Cost comparison for the above centralized and decentralized cases at different load conditions is done. The value of voltage at different buses are found after doing the load flow simulation for each cases. The value of cost for each case is found by suing the objective function discussed in section V-A.

A. Normal loading

Above all cases of 13 bus distribution system are simulated with the normal loading condition. The voltage and cost for above cases are compared as shown below.

1. Voltage Comparison (Normal Loading)

The graphical comparison between all centralized capacitor cases with decentralized capacitor case is shown in Fig 6.1.

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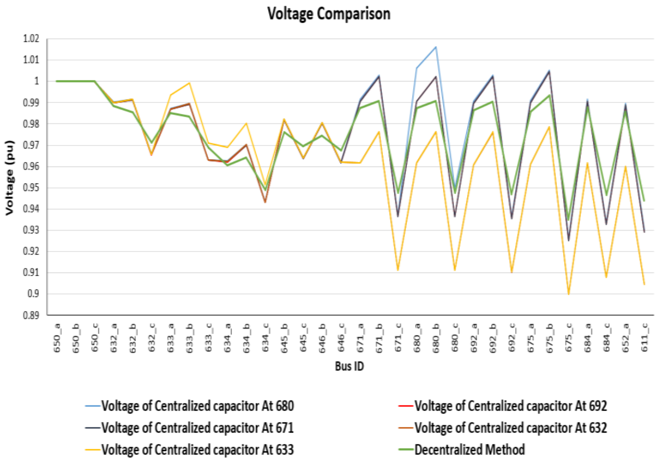

Fig. 6.1 Voltage profile of system for normal loading

It can be seen that the voltage at different buses are within the limit between 0.935 to 1.00 pu when decentralized capacitor is used for reactive power compensation. This is shown by Green colour line in the figure 6.1. While comparing centralized capacitor cases with this decentralized capacitor case, voltage at different buses are between 0.90 to 1.00 pu for two centralized capacitor cases i.e. capacitor is connected to bus-632 and capacitor is connected to bus-633. This is shown by Brown and Yellow colour line respectively. The voltage at buses connected to higher load are lower value in these both centralized capacitor cases. Blue, Orange and Black colour line represent the voltage at different buses with centralized capacitor is connected to bus-680, bus-692 and bus-671 respectively. The value of voltage at different buses of these cases are nearer to that decentralized capacitor case. The voltage for the centralized cases at bus-692 and at bus-671 are between 0.925 to 1.002 pu. And the voltage at different buses for the centralized capacitor case at bus-680 are within limit between 0.926 to 1.016 pu.

2. Cost Comparison (Normal Loading)

The cost for above centralized and decentralized cases are shown in the Table-III. It can be seen that the cost of decentralized capacitor case is high as compare to all the centralized capacitor cases. The cost of decentralized capacitor case is Rs. 1100509.21. There is less difference in cost among the centralized capacitor cases. The cost of centralized capacitor case at bus-632 and case at bus-633 are almost same amount i.e. Rs. 1050583.23 and Rs. 1050582.92 respectively. Also the cost of centralized capacitor case at bus-680, case at bus-692 and case at bus-671 are nearly same amount i.e. Rs. 1050529.58, Rs. 1050535.26 and Rs. 1050530.53 respectively.

Table-III Cost for normal loading

Method	Bus ID	Cost in Rs.
Centralized Capacitor	At 680	105052.58
	At 692	1050535.26
	At 671	1050530.53
	At 632	1050583.23
	At 633	1050582.93
Decentralized Method		1100509.21

B. 10% load increment in the system

The voltage and cost for above centralized capacitor and decentralized capacitor cases for 10% load increment are compared in this section.

1. Voltage Comparison (10% load increment)

The graphical comparison between all centralized capacitor cases with decentralized capacitor case is shown in Fig 6.2.

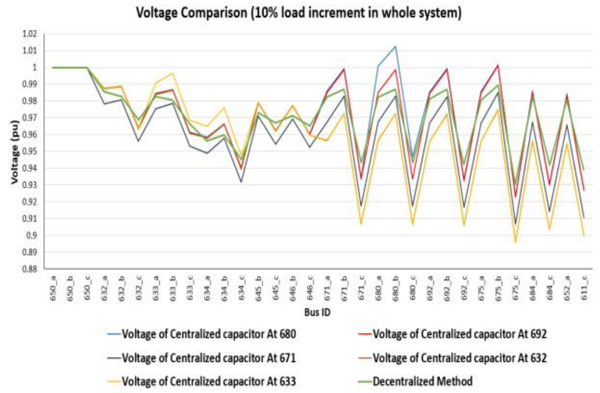

Fig. 6.2 Voltage profile of system for 10% load increment

It can be seen that the voltage at different buses are within the limit between 0.930 to 1.00 pu when decentralized capacitor is used for reactive power compensation. This is shown by Green colour line in the figure 6.2. While comparing centralized capacitor cases with this decentralized capacitor case, voltage at different buses are between 0.895 to 1.00 pu for two centralized capacitor cases i.e. capacitor is connected to bus-632 and capacitor is connected to bus-633. This is shown by Brown and Yellow colour line respectively. The voltage at buses connected to higher load are lower value in these both centralized capacitor cases. Also the voltage for centralized capacitor case at bus-671 is between 0.906 to 1.00 pu which is shown by Black colour line. Voltage for the centralized capacitor case at bus-680 and at bus-692 are shown by Blue and Orange colour lines respectively. It can be seen that these both lines are closed to the Green colour line. The voltage at different buses are within the limit between 0.923 to 1.012 pu and 0.922 to 1.00 pu respectively.

2. Cost Comparison (10% load increment)

It can be seen that the cost of decentralized capacitor case is high as compare to all the centralized capacitor cases. The cost of decentralized capacitor case is Rs. 1100381.06. The lowest cost among all centralized capacitor cases is Rs. 1050536.25 which is for the case of centralized capacitor at bus-692. Also the cost for other centralized cases at bus-680, at bus-671, at bus-632 and at bus-633 are Rs. 1050577.46, Rs. 1050559.00, Rs. 1050602.61, and Rs. 1050649.28 respectively.

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Table-IV Cost for 10% load increment

Method	Bus ID	Cost in Rs.
Centralized Capacitor	At 680	1050577.46
	At 692	1050536.25
	At 671	1050559.00
	At 632	1050602.61
	At 633	1050649.28
Decentralized Method		1100381.06

C. 20% load increment in the system

The voltage and cost for above centralized capacitor and decentralized capacitor cases for 20% load increment are compared in this section.

1. Voltage Comparison (20% load increment)

The graphical comparison between all centralized capacitor cases with decentralized capacitor case is shown in Fig 6.3.

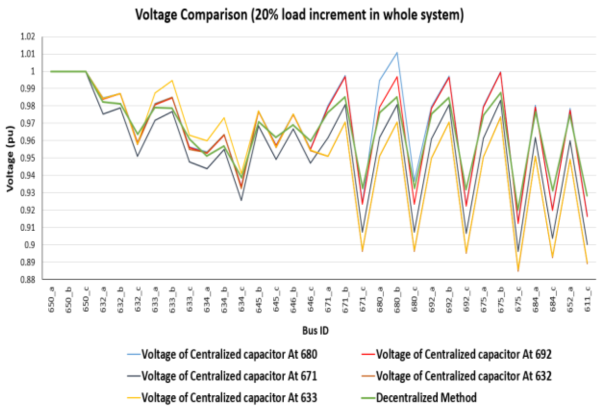

Fig. 6.3 Voltage profile of system for 20% load increment

It can be seen that the voltage at different buses are within the limit between 0.920 to 1.00 pu when decentralized capacitor is used for reactive power compensation. This is shown by Green colour line in the figure 6.3. While comparing centralized capacitor cases with this decentralized capacitor case, voltage at different buses are between 0.885 to 1.00 pu for two centralized capacitor cases i.e. capacitor is connected to bus-632 and capacitor is connected to bus-633. This is shown by Brown and Yellow colour line respectively. The voltage at buses connected to higher load are lower value in these both centralized capacitor cases. Also the voltage for centralized capacitor case at bus-671 is between 0.896 to 1.00 pu which is shown by Black colour line. It can be seen that the Black colour line is below than the Green colour line for all the buses. Voltage for the centralized capacitor case at bus-680 and at bus-692 are shown by Blue and Orange colour lines respectively. It can be seen that these both lines are closed to the Green colour line. The voltage at different buses are within the limit between 0.913 to 1.010 pu and 0.912 to 1.00 pu respectively.

2. Cost Comparison (20% load increment)

It can be seen that the cost of decentralized capacitor case is high as compare to all the centralized capacitor cases. The cost of decentralized capacitor case is Rs. 1100533.63. The lowest cost among all centralized capacitor cases is Rs. 1050554.81 which is for the case of centralized capacitor at bus-692. Also the cost for other centralized cases at bus-680, at bus-671, at bus-632 and at bus-633 are Rs. 1050596.00, Rs. 1050591.07, Rs. 1050641.59, and Rs. 1050683.79 respectively.

Table-V Cost for 10% load increment

Method	Bus ID	Cost in Rs.
Centralized Capacitor	At 680	105052.58
	At 692	1050535.26
	At 671	1050530.53
	At 632	1050761.39
	At 633	1050797.13
Decentralized Method		1100596.29

D. 25% load increment in the system

The voltage and cost for above centralized capacitor and decentralized capacitor cases for 25% load increment are compared in this section.

1. Voltage Comparison (25% load increment)

The graphical comparison between all centralized capacitor cases with decentralized capacitor case is shown in Fig 6.4.

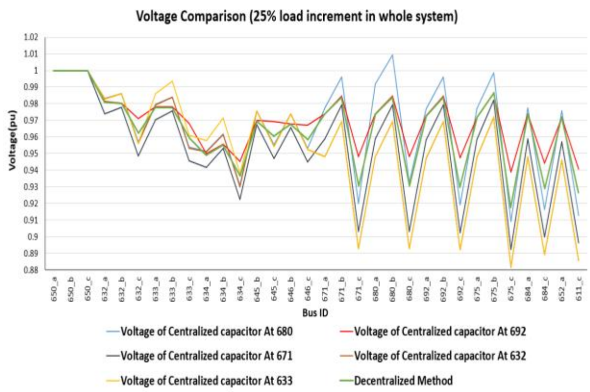

Fig. 6.4 Voltage profile of system for 25% load increment

It can be seen that the voltage at different buses are within the limit between 0.917 to 1.00 pu when decentralized capacitor is used for reactive power compensation. This is shown by Green colour line in the figure 6.4. While comparing centralized capacitor cases with this decentralized capacitor case, voltage at different buses are between 0.881 to 1.00 pu for two centralized capacitor cases i.e. capacitor is connected to bus-632 and capacitor is connected to bus-633. This is shown by Brown and Yellow colour line respectively. The voltage at buses connected to higher load are lower value in these both centralized capacitor cases. Also the voltage for centralized capacitor case at bus-671 is between 0.892 to 1.00 pu which is shown by Black colour line. It can be seen that the Black colour line is below than the Green colour line for all the buses.

The voltage at different buses are between 0.919 to 1.00 pu for the centralized capacitor case at bus-680. This is shown by the Blue colour line. The best voltage profile is seen by the centralized capacitor case at bus-692 which is shown by Orange colour line in the figure 6.2. Orange colour line has given better voltage at every buses in the system than the Green colour line. The voltage at different buses are between 0.938 to 1.00 pu for this case. So the centralized capacitor case at bus-692 has given better voltage than the decentralized capacitor case for 25% load increment.

2. Cost Comparison (25% load increment)

It can be seen that the cost of decentralized capacitor case is high as compare to all the centralized capacitor cases. The cost of decentralized capacitor case is Rs. 1100536.40. Also the lowest cost among all centralized capacitor cases is given by the case at bus-692 i.e. Rs. 1050531.48. The cost for other centralized cases at bus-680, at bus-671, at bus-632 and at bus-633 are Rs. 1050605.56, Rs. 1050606.87, Rs. 1050658.00 and Rs. 1050700.52 respectively.

Table-VI Cost for 25% load increment

Method	Bus ID	Cost in Rs.
Centralized Capacitor	At 680	1050605.56
	At 692	1050531.48
	At 671	1050606.87
	At 632	1050658.00
	At 633	1050700.52
Decentralized Method		1100536.40

E. 50% load increment in the system

The voltage and cost for above centralized capacitor and decentralized capacitor cases for 50% load increment are compared in this section.

1. Voltage Comparison (50% load increment)

The graphical comparison between all centralized capacitor cases with decentralized capacitor case is shown in Fig 6.5.

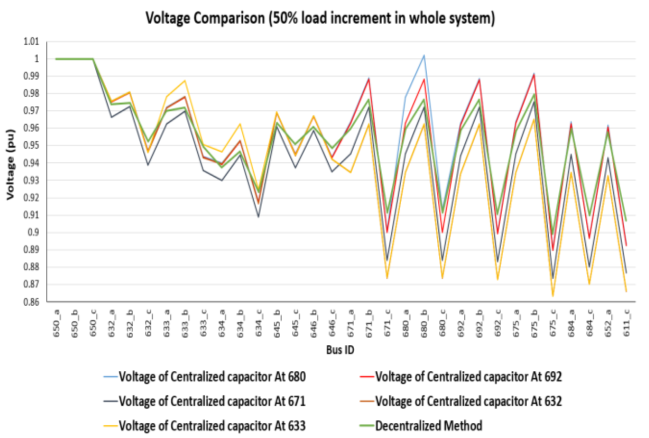

Fig. 6.5 Voltage profile of system for 50% load increment

It can be seen that the voltage at different buses are within the limit between 0.899 to 1.00 pu when decentralized capacitor is used for reactive power compensation. This is shown by Green colour line in the figure 6.5 . While comparing centralized capacitor cases with this decentralized capacitor case, voltage at different buses are between 0.863 to 1.00 pu for two centralized capacitor cases i.e. capacitor is connected to bus-632 and capacitor is connected to bus-633. This is shown by Brown and Yellow colour line respectively. The voltage at buses connected to higher load are lower value in these both centralized capacitor cases. Also the voltage for centralized capacitor case at bus-671 is between 0.973 to 1.00 pu which is shown by Black colour line. Voltage for the centralized capacitor case at bus-680 and at bus-692 are shown by Blue and Orange colour lines respectively. It can be seen that these both lines are closed to the Green colour line. The voltage at different buses are within the limit between 0.890 to 1.001 pu and 0.889 to 1.00 pu respectively.

2. Cost Comparison (50% load increment)

It can be seen that the cost of decentralized capacitor case is high as compare to all the centralized capacitor cases. The cost of decentralized capacitor case is Rs. 1100596.29. The lowest cost among all centralized capacitor cases is Rs. 1050627.88 which is for the case of centralized capacitor at bus-692. Also the cost for other centralized cases at bus-680, at bus-671, at bus-632 and at bus-633 are Rs. 1050668.55, Rs. 1050700.15, Rs. 1050761.39, and Rs. 1050797.13 respectively.

Table-VII Cost for 25% load increment

Method	Bus ID	Cost in Rs.
Centralized Capacitor	At 680	1050668.55
	At 692	1050627.88
	At 671	1050700.15
	At 632	1050761.39
	At 633	1050797.13
Decentralized Method		1100596.29

VII. CONCLUSION

Load flow simulations on standard 13 bus distribution system has been performed considering decentralized capacitor and centralized capacitor bank method with different loading conditions i.e. normal loading, 10%, 20%, 25% and 50% load increment are considered for all the simulation cases. The 13 bus distribution system with centralized capacitor of 700 kVAR (per phase) at bus 692 has given overall better voltage profile of system with economic cost for each loading condition.

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