12

12-1 Application Of Capacitors To Electrical Power Systems

The application of capacitors to electrical power systems can produce several desirable effects. Improved voltage regulation, power factor correction, reduced line losses, and released system capacity are a few of the advantages. Capacitors are usually installed on a power system in a three-phase configuration, rather than single phase. The individual capacitor units making up a bank may be either three phase or single phase. Capacitors may be installed on the customer service or on the utility system.

The primary function of capacitors is to supply reactive power to the system. As a result, capacitors supply a portion of the reactive power required by various lagging power factor loads in the system. A reduction in line current magnitude, overall system apparent power loading, and I^2R line losses are obtained. In addition, voltage drop is reduced due to the decrease in line current magnitude and improvement in power factor.

This chapter will discuss the general construction and ratings of capacitors, three phase connections of single-phase units, switching, and control of capacitor banks. Additional emphasis will be placed on sizing capacitors for power factor improvement and locating capacitors for maximum loss reduction and voltage improvement.

Capacitor Construction and Standard Ratings

Figure 1a shows a view of a single-bushing, single-phase, medium-voltage capacitor unit commonly used on utility power systems. Note that there is only one high-voltage bushing for connection to the phase conductor. These units are suitable for connection in a grounded-wye configuration.

A two-bushing, single –phase, medium-voltage capacitor unit is shown in Fig 1(b). these units are typically connected in a delta or floating-wye configuration, in much the same fashion as the distribution transformers.

Low-voltage (less than 1000V) capacitor units may be either single phase or three phase. The low-voltage, single-phase units typically have two bushings for connection to the line. Three-phase low-voltage units are typically supplied with three bushing for connection to all three-phase conductors on a three-phase system. Low-voltage capacitors are usually connected in a delta configuration.

In accordance with the National Electrical Code ®, all capacitor units are supplied with an internal discharge resistor. The discharge resistor is connected in parallel with the capacitor unit and provides a path for current to flow in the event that the capacitor is disconnected from the source. For low-voltage capacitors, the residual voltage trapped on the capacitor unit must decrease to less than 50 V within 1 min after de-energizing. For medium-voltage capacitors, the residual voltage must decrease to less than 50 V within 5 min after de-energizing.

Table 1 lists standard voltage and kVAR ratings for medium-voltage capacitors. Standard voltage ratings for low-voltage capacitor units are 240, 480, and 600V. Standard kVAR ratings for low-voltage capacitor units are too numerous to list here. The reader is referred to manufacturer's product literature.

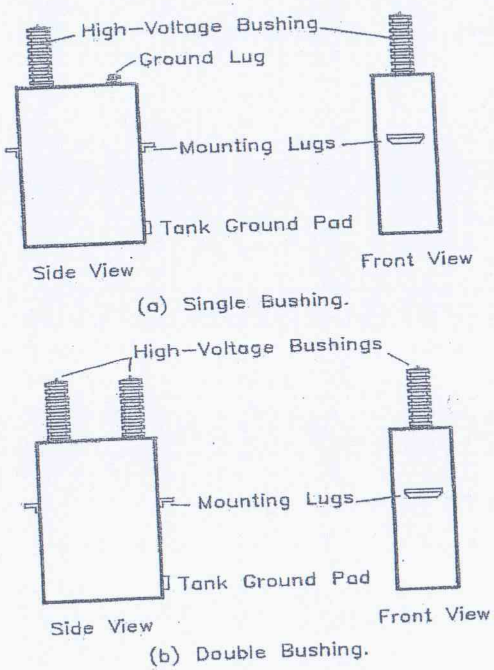


Figure 1 Capacitor construction features.

Table 1 Voltage and kVAR Ratings, Single-Phase, Medium-Voltage Capacitors

Voltage		kVAR
2400	12,470	50
2770	13,280	100
4160	13,800	150
4800	14,400	200
6640	15,125	300
7200	19,920	400
7620	20,800	500
7960	21,600	
8320	22,130	
9540	22,800	
9960	23,800	
11,400	24,940	

Connections

Capacitors installed on medium-voltage, multigrounded, neutral utility distribution systems are usually either solidly grounded wye or floating wye connected. Figure 2 shows some of the more common capacitor connections. A typical installation of a fixed capacitor bank on a 12.47-kV distribution feeder is shown in Fig 3. A switched capacitor bank installed on a 12.47-kV distribution feeder is shown in Fig 4. These capacitors are switched off and on by the oil switches located next to the capacitor units. In both figures, the capacitors are installed in a grounded-wye configuration.

Solidly Grounded Wye Connection

The solidly grounded wye connection shown in Fig. 2a is typically used on medium-voltage distribution feeders. The voltage rating of the capacitor units in the solidly grounded wye bank must be equal to or greater than the nominal line to neutral voltage of the feeder. The kVAR rating of the capacitor units is selected to provide the desired amount of reactive compensation. Additional single-phase capacitor units may be connected in parallel per phase to increase the rating of the bank. The individual capacitor units in the bank must have the same kVAR and voltage ratings. Group fusing of the capacitors is typically provided by fused cutouts. Since the capacitor units are solidly connected between line and neutral, the failure of any individual capacitor unit will not result in an overvoltage across the remaining units in the bank.

In large capacitor banks installed on distribution or subtransmission substation busses, individual fusing of the capacitor units may be employed. Figure 4 shoes a capacitor bank installed on a 23-kV substation bus. With the solidly grounded wye connection using individual fusing of the capacitor units, a blown fuse detection scheme is needed to detect operation of any of the individual fuse elements. One such blown fuse detection scheme employs a current transformer connected between the neutral point of the bank and ground. Under normal operating conditions with all capacitor units energized, the current flow from the bank neutral to ground is zero. However, if any of the individual capacitor fuse elements operate, an unbalanced current will result. The secondary of the current transformer could be connected to an overcurrent relay to detect the unbalanced current. Tripping of the capacitor bank breaker or switch could be initiated or an alarm condition reported.

Delta Connection

In the delta connection shown in Fig. 2b, the individual capacitor units are connected phase to phase. Therefore, the required voltage rating of the capacitor units must be equal to or greater than the normal line to line voltage of the system. Similarly to the grounded-wye connection, the failure of any of the individual capacitor units will not result in an overvoltage across the remaining units in the bank.

Floating-Wye Connection

The floating-wye connection shown in Fig. 2c is commonly used for larger kVAR rated capacitor banks installed on distribution substation and subtransmission substation buses.

in this connection, the common or neutral point of the capacitor bank is not directly connected to ground. Since the potential of the bank neutral is allowed to float with respect to ground, the capacitor units should have two bushings. In some installations, however, single-bushing units are used, with the neutral connection made between the individual capacitor units and the capacitor mounting rack. The capacitor mounting rack itself is insulated from ground potential and is allowed to float with respect to ground. With this type of connection, it is possible for the capacitor housings to become energized.

The voltage rating of the capacitor units must be equal to or greater than the nominal line to neutral voltage of the system. Individual capacitor may be series connected to achieve higher voltage ratings and parallel connected to achieve higher kVAR ratings. Each unit in the bank should have the kVAR and voltage rating.

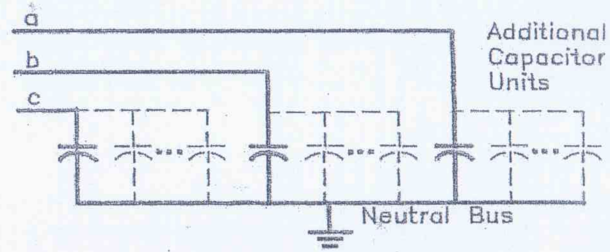
Because of the higher current rating of these larger banks, individual capacitor unit fusing is recommended, rather than group fusing of entire bank. To detect individual blown fuses, a voltage transformer may be connected between the floating neutral point of the bank and the substation ground grid. Under normal operating conditions with all capacitor units energized, the voltage between the floating neutral and ground will be essentially zero. In the event of an individual fuse operation, the voltage between the floating neutral and ground will increase. An overvoltage relay connected to the secondary of the voltage transformer can be set to trip in the event of a capacitor unit failure. This overvoltage relay may cause the circuit breaker or switch protecting the bank to trip or may merely indicate an alarm condition.

The operation of individual fuses will also produce an overvoltage on the remaining capacitors in the phase with the blown fuse. Capacitors are designed to operate satisfactorily at up to 110% of rated voltage. Any voltage higher than this will cause breakdown of the dielectric and subsequent failure. The following example illustrates the method used to calculate the neutral to ground voltage and the voltage across the remaining capacitors in a floating-wye bank.

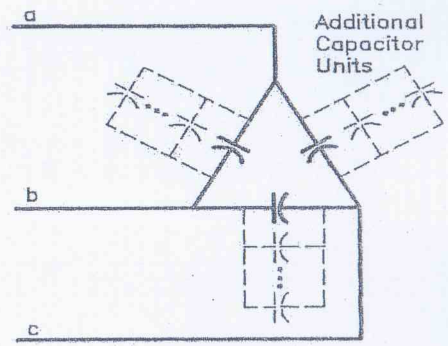
Split-Wye Connection

Two groups of capacitors may be connected in the form of the split-wye connection shown in Fig. 2d. series and parallel combinations of capacitor may be employed in a manner similar to the floating-wye connection to increase voltage and kVAR ratings. The voltage rating of the capacitor units is selected based on the nominal line to neutral system voltage.

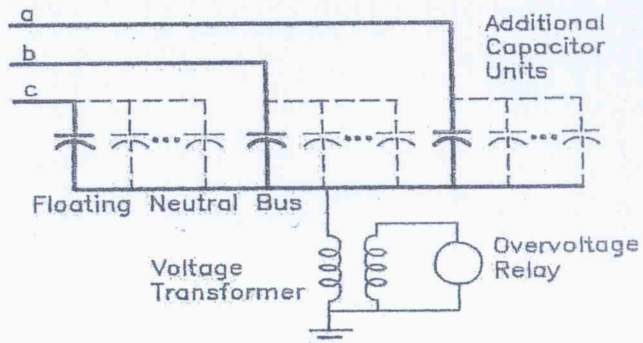
To detect the operation of individual fuses, a current transformer is connected between the floating neutrals of the two groups. Under normal conditions, each group of capacitors represents a balanced three-phase load. The resulting neutral current is therefore equal to zero. In the event of a blown fuse on one or more of the units, an unbalanced current will result. This unbalanced current is detected by the overcurrent relay connected to th- current transformer secondary. The overcurrent relay may trip a circuit breaker or switch merely signal an alarm.



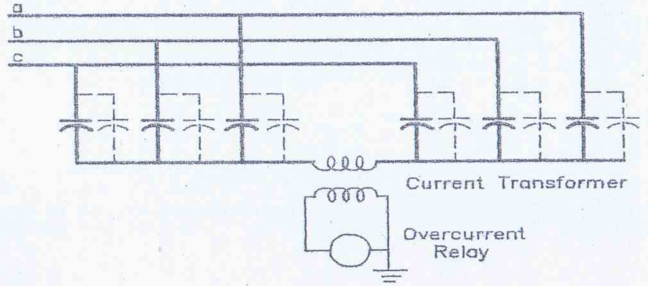
(a) Solidly Grounded Wye



(b) Delta



(c) Floating-Wye



(d) Split-Wye

Figure 2 Capacitor connections.

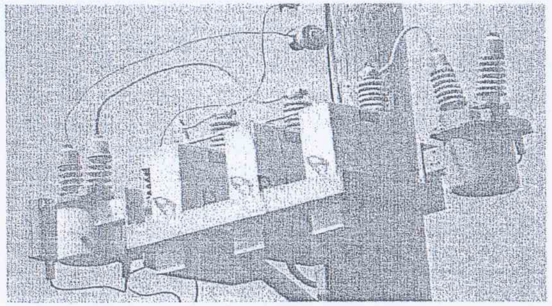


Figure 3 Close-up of switched capacitor bank installation on 12.47-kv distribution feeder

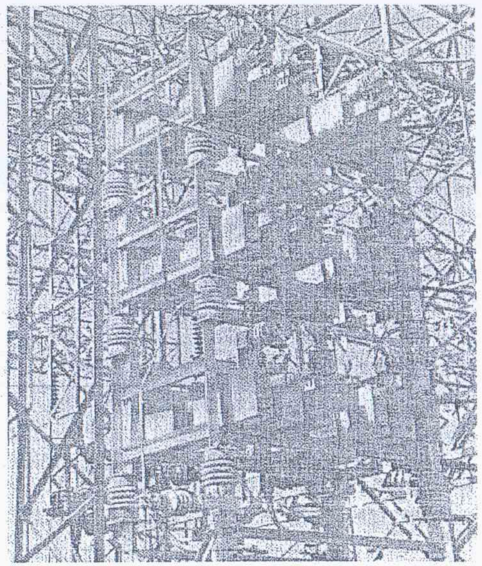


Figure 4 Capacitor bank installation on 23-kv substation bus

12-2 Find the Persian equivalents of the following terms:

1- Application 2- Improved 3- Regulation 4- Voltage drop 5- Rating 6- Construction
7- Improvement 8- Reduction 9- Single bushing 10- Utility 11- Commonly
12- Connection 13- Typically 14- Distribution 15- Configuration 16- Accordance
17- Disconnected 18- De-energize 19- Decrease 20- Solid 21- Grounded
22- Feeder 23- Subtransmission 24- Individual 25- Employ 26- Tripping
27- Breaker 28- Momentary 29- Remaining 30- Achieve 31- Split
32- Floating 33- Overvoltage 34- Cutout 35- Neutral 36-Compensation

12-3 Answer the following questions:

1- Explain briefly the operation of a single bushing, single phase, medium voltage capacitor shown in Fig 1(a).
2- Draw a sketch and discuss the two bushing, single phase, medium voltage capacitor.
3- Describe solidly grounded wye connection and sketch split wye configuration.
4- Explain floating-wye connection and sketch floating wye configuration.

12-4 Translate the following passage into Persian

The calculation of currents during switching is an extremely important consideration in capacitor applications. Contactors and circuit breakers used for capacitor switching are limited in the amount of momentary current the contacts can safely withstand. This momentary current rating is specified by the switch or breaker manufacturer. Failure to limit momentary current below specified values will result in contact welding, increased pitting of the contacts, or severe damage to the switch.

The high-magnitude currents that occur during capacitor switching are also of relatively high frequency compared to the system frequency. These high-frequency currents produce high-frequency voltage spikes on the system may interfere with the operation of various control circuits. When switching large capacitor banks, it is important to provide overvoltage protection or isolated power supplies for proper operation of the control circuitry.

12-5 Fill in the blanks with the following words:

A :

1- More	6- Circuit
2- Location	7- Common
3- Addition	8- Power
4- Plant	9- Operate
5- Length	10- Factor

Determinig the optimum .... and size of capacitor banks to be installed on radial distribution feeders is slightly .... complicated than determining the requirements for an