GUIDELINES TO INSTALL, OPERATE AND MAINTAIN HT CAPACITORS & IT'S ASSOCIATED EQUIPMENT

GENERAL:

1. The selection of switchgear for switching the capacitors should be done carefully. The circuit breaker used for controlling the capacitor bank should be re-strike free and it is recommended that the user takes a confirmation of this aspect from the breaker manufacturer and if possible also take a certificate from the breaker manufacturer that the circuit breaker is suitable for switching of capacitor bank of the required output and voltage. Usually it is recommended that Vacuum Circuit Breaker or SF6 gas Circuit Breaker is used for capacitor bank switching. However other types of breaker can also be used provided the suitability of the breaker for capacitor switching is ascertained.

2. For capacitor bank the following protections are recommended:
   a. Over Current and Earth Fault:
   This protection is provided to trip the capacitor bank in case of overloading due to over voltage or harmonic current. IDMTL type over current relay is suggested to trip the capacitor bank before the current exceeds 130&% of the rated current of the capacitor bank. To avoid tripping due to inrush switching or transients, the relay shall be used with a timer to give a fixed time lag. Over current relays should be provided on two phases and earth fault relay should be provided on the third phase with minimum setting of 10%.

   b. Over Voltage:
   IDMTL type over voltage relay, having settings of 10% and its multiples, should be provided for tripping the capacitor bank when the system voltage exceeds the maximum permissible voltage i.e. 110% of the rated voltage (see chart below).

Operation on	Voltage Factor (multiple of rated voltage)	Maximum Duration
Power Frequency	1.1	Continuous
Power Frequency	1.3*	Five (5) minutes
Power Frequency	1.4	One (1) minute
Power Frequency having harmonics	Such that the current does not exceed 1.43 times the rated current	

   * Voltage rise on light loads

   c. Under Voltage:
   During power failure it is essential that the capacitor bank should trip and should not be re-energized till it discharges to a safe value of 50 volts or less. This relay should be instantaneous type with low voltage setting.

d. Neutral Displacement:

Voltage Unbalance Relay: Required in case of a single star connected capacitor bank. The secondary of the Residual Voltage Transformer (RVT) in connected in open delta. Under balanced condition of the capacitor bank the voltage across the open delta terminals is almost zero. But in event of failure of one or partial unit in a capacitor bank the neutral is shifted and this is reflected on the open delta terminals which should be set to a specified value which can differ depending on the number of units in a capacitor bank. IDMTL relay is suggested to avoid spurious tripping.

Current Unbalance Relay: Required in case of a double star connected capacitor bank. The neutral points of both the stars are connected through a Neutral Current Transformer (NCT). Under balanced condition the current at the star points is almost zero. But in event of failure of one of partial unit in a capacitor bank the neutral is shifted causing flow of current in the neutral. Current Unbalance Relay is connected to the secondary of the NCT, which is set at a specified setting depending on the number of units in the capacitor bank. An instantaneous type relay with fixed time delay is suggested for this purpose.

e. ***Timer for re-energisation after 5 minutes:***

This is provided to block the re-switching of capacitor bank in less than 5 minutes.

f. Leading Power factor Relay (Optional):

In case it is envisaged that the power factor of the electrical system is close to unity and due to sudden variation in the load the power factor shoots above unity it is recommended that a leading power factor relay be provided to avoid leading power factor condition.

3. For 11 KV capacitor bank up to rated voltage of 11 KV it is recommended that voltage unbalance protection be adopted with single star connected capacitor bank while for capacitor banks of rated voltage of 22 KV and above current unbalance protection be adopted with double star connected capacitor bank.

4. Type of Compensations :

In principal, maximum benefits are obtained by locating the capacitors as near to the load (or load center) as possible. However at times it may not be practical to locate the capacitors close to the load. The types of compensation that can be adopted are as follows:

a) Individual Compensation: In this case the compensating capacitors are connected parallel to the equipment that has to be compensated and both are switched ON/OFF through common switchgear. Individual compensation can be used for equipment like induction motors, transformers, induction furnace etc.

Ideal method under circumstances:

i. The size of the inductive load is large enough to select the minimum size of capacitors that is practical. For HT capacitors the minimum ratings that are practical are as follows:

System Voltage	Minimum rating of capacitor bank
3.3 KV and 6.6 KV	75 KVAr
11 KV	200 KVAr
22 KV	400 KVAr
33 KV	600 KVAr

Note: Unit sizes lower than above is not practical and economical to manufacture.

ii. The load on equipment to be compensated is fairly constant and no load conditions should be minimum.

iii. When it is practically difficult to include as separate switchgear for capacitors.

At the same time care must be taken:

i. When capacitors are connected directly across motors it must be ensured that the rated current of the capacitor bank should not exceed 90% of the no-load current of the motor to avoid self-excitation of the motor and also over compensation.

ii. Precaution must be taken to ensure the live parts of the equipment to be compensated should not be handled for 10 minutes (in case of HT equipment) after disconnection of supply.

iii. Crane motors or like, where the motors can be rotated by mechanical load and motors with electrical braking systems, should never be compensated by capacitors directly across motor terminals.

iv. For direct compensation across transformers the capacitor rating should not exceed 90 % of the no-load KVA of the motor.

b) Group Compensation: In this case capacitors are connected in parallel to a group of loads that are connected in parallel. Depending upon the variations in the loads on the bus the sections of capacitors are selected which can be manually of automatically switched ON/OFF depending upon the requirement of compensation. In this care necessary care must be taken when two or more capacitor banks are connected in parallel. The parameters should be carefully studied especially regarding the inrush switching current across the capacitor bank at the time of switching when other capacitor bank(s) connected in parallel are already in energized condition. Generally capacitors can withstand up to 100 times the rated current at the instant of switching. In case this inrush current is more than the limit specified above it would be necessary to provide 0.2% series reactor on the neutral end of the capacitor bank for limiting the switching inrush current within permissible limits.

c) Central Compensation : The compensation will be as shown in the diagram given below:
Capacitors of central compensation could be of high or low voltage. Here also capacitors sections will have to be decided depending on the variation in the loads and the power factor of the loads to be compensated. Even in case of central compensation the capacitors should be located as close to the loads as is practicably possible.

In short the compensation of reactive power should be made judiciously taking into consideration the composition of loads and practical situation. The prime factor to be considered is that compensation of reactive power should be as close to the load as possible and if required all the three types of compensation can be adopted in certain industries.

5. Selection of rated voltage of Capacitor Bank: While selecting the rated voltage of a capacitor bank it should be note that the rated voltage of the capacitor bank should be as close to the highest service voltage of the system as possible. If the actual service voltage varies up to 10% of the system voltage it should be brought to the notice to the manufacturer. The following aspects have to be taken care while selecting the rated voltage of the capacitor bank:
   a) Service voltage higher than the rated voltage of the capacitor bank could adversely effect the life of the capacitor due to over stress on the capacitor dielectric
   b) Service voltage lower than the rated voltage of the capacitor bank results in output lower than the rated value of the capacitor bank.
   c) Over voltage should not exceed 10% of the rated voltage of the capacitor bank.
   d) Capacitor will cause voltage rise at the point where it is located.
   e) The voltage on capacitor might increase in light load conditions.
   f) Series Reactor will cause rise in voltage on the capacitor terminals.

6. Temperature category of Capacitors :
While selecting the temperature category, it should be borne in mind that higher temperature might cost more at the same time temperature category lower than the actual temperature in the service condition can endanger the operation of capacitors. For tropical climate like in India 50deg C temperature category is considered as most ideal. However if capacitors are installed close to heat-generating equipment forced air-cooling must be seriously considered. While selecting the temperature category all the two means i.e. 24 hours and 1year should be considered simultaneously. As a guide line the table for selection of temperature category as per IS are given below:

Ambient Air Temperature in degrees centigrade		
Maximum Highest 24 hours	Mean over period of 1 year	
40	30	20
45	35	25
50	40	30
55	45	35

7. Capacitors unless specially designed should not be installed highly harmonic infested system. In case of capacitors to be installed in system having Arc Furnaces, Rectifiers, DC drives, etc, the same will have to be designed specially to take care of the overload conditions due to the effect of harmonics.

8. Series Reactors used for different applications are as under :
   a. ***Inrush suppression Series reactor***: It is used to suppress the inrush current during switching of capacitor bank and transients. The series reactor should be of rating of 0.2% of the capacitor bank reactance and should be connected on the neutral end of the capacitor bank.

   b. ***Detuned Series Reactors***: The Series Reactor of rating of 6% of the capacitor bank reactance in connected on the line end of the capacitor bank. The capacitor bank and reactor group id tuned 4^{th} harmonic such that it will be inductive at 250 Hz and prevent the possibility of occurrence of any resonant condition. This capacitor will block the higher order of harmonics and protect the capacitor bank from harmonics.

   c. ***Tuned Series Reactors (Filter circuit reactor):*** The Series Reactor is designed such that the capacitor bank and reactor combination filters out any particular order of harmonic that is predominant in the system by creating a low impedance path of the order of harmonic that it predominant. The reactor and capacitors in such cases are designed to withstand the overloads due to harmonics. An electrical system can be provided with one or more filter circuit depending upon the presence of harmonics.

The rating of series reactor is crucial and has to be selected properly which should be based on the application of capacitors. Improper selection of series reactor rating can adversely affect the life of the capacitors.

Surge Arresters :

Inrush surge current and voltage are notorious factors which determine the life of capacitor banks and hence these factors have to be tackled appropriately. Majority of failures cases in capacitors are under switching surges. For precisely this reason it is mandatory to provide surge arresters in the capacitor circuit. For capacitor bank application it is recommended to provide Metal Oxide, Gapless type Surge Arresters with discharge class III. It is also important that 2 nos. earthing pits are provided which will be dedicated only for surge arresters to have an effective functioning of the arresters.

External fuses:

HT capacitors are categorized under 2 basic designs viz. internal fuse design and external fuse design. In case of internal fuse design providing external fuses is not mandatory as the internal element fuses takes care of capacitor unit protection. For external fuse design the fuse must be de-rated by a factor of 2. There are 2 types of fuses that are used for capacitor unit protection as under:
Expulsion fuses : These are drop out type fuses with fuse links which can be replaced. But it should be ensured that the fuse links are of the precise rating and should not be substituted with commonly available copper wires.
HRC fuses : These are provided with a porcelain body and are more reliable than expulsion fuse although they are very uneconomical.

INSTALLATION GUIDELINES

1. It is very important that the capacitors are stored securely after its receipt from the transporter. The capacitor should be thoroughly checked for damage or leakage. The bushings of the capacitor should be intact. All the welded soldered joints should be examined.

2. In case it is observed that in any capacitor unit the bushing(s) are broken or any leakages are observed the same should be covered with a clean and dry polythene cover to avoid ingress of dirt, dust or moisture inside the capacitor container. It must be assured that capacitors with leakage are not put in service. At times very minor leakage can be attended at site by application of sealing compound. This should be done only after ascertaining that very little oil has leaked. The oil level inside the capacitor should be sufficient that it immerses the dielectric column. The dielectric columns are generally 10 to 15 mm from the top of the container. It is essential that a recommendation of Energe Capacitors Pvt. Ltd. is taken in such cases.

3. In case capacitors are installed indoor there should be proper ventilation is provided. While installing capacitors inside a panel care must be taken to provide sufficient apace between adjacent capacitors (minimum 100 mm) and capacitor unit and the panel body. This will ensure free circulation of air. Ventilating louvers should be provided on the two opposite ends of the panel. If required even exhaust fans should also be provided. As per guidelines and IS standards the highest operating temperatures should be less than 50 deg. C. The temperature rise in capacitor bank is maximum 15 deg. C above the average ambient temperature. Incase the temperatures at the container are above the specified temperature providing forced ventilation if mandatory. If the temperatures continue to be higher the matter should be reported to Energe Capacitors Pvt. Ltd.

4. For outdoor clearances ground clearances and sectional clearances as per IE rules must be maintained for safety purpose. The clearances between phases and phase and earth are maintained as per IE rules. The installation and connections should be strictly as per drawings provided. For your guide lines the minimum electrical clearance to be provided as per BS 162 is given below:

MINIMUM ELECTRICAL CLEARANCES AS PER BS : 162		
1. INDOOR:		
Voltage in KV	Phase to earth in mm	Phase to phase in mm
0.415	15.8	19.05
0.600	19.05	19.05
3.3	50.8	50.8
6.6	63.5	88.9
11	76.2	127.0
15	101.6	165.1
22	139.7	241.3
33	222.25	355.6
2. OUTDOOR		
6.6	139.7	177.8
11	177.8	228.6
22	279.4	330.2
33	381	431.8
66	685.8	787.4
110	863.6	990.6
132	1066.8	1219.2
220	1778	2057.4

MINIMUM WORKING CLEARANCES IN OUTDOOR SWITCHYARD		
Voltage in KV	To ground in mm	Between section in mm
11	2750	2500
33	3700	2800
66	4000	3000
132	4600	3500
220	5500	4500

5. In case capacitors are installed in location which is dominated with chemical industries and the pollution levels are high the same should be informed to Energe Capacitors Pvt. Ltd., prior to manufacture so the special care could be taken in the surface treatment of the CRCA containers of the capacitor units.

6. While tightening the connection in the capacitor bushings necessary care should be taken to avoid undue stress on the on bushings. To be precise there should not be any attempt to over tighten and at the same time there should not be loose connection. The connectors, busbars, conductors, cables etc. should be adequate current carrying capacity.

7. The series and parallel connections in case of outdoor capacitors should be strictly as per approved drawings. This is very important as any faulty connection could lead to massive failure. The series groups in the capacitor bank increases with higher rated voltage and this aspect should be carefully checked at the time of erection. In case of any doubt please immediately contact Energe Capacitors Pvt. Ltd.

8. All the three phases of the capacitors should be in balanced condition in case of externally star/delta connected capacitor banks wherein the basic unit is of single phase. This balancing can be carried out based on the capacitance value of each capacitor unit. The capacitance value of each unit is given in the routine test certificate of the capacitor units.

9. The capacitor bank and all the associated equipment should be properly earthed in two points of each equipment as shown in the respective drawings. If capacitors are provided with base insulators (generally provided for 22KV capacitor banks and above) than only the elevating structures i.e. structures below the base insulators should be earthed. In such case the capacitors and the mounting structures of the capacitors should not be earthed. General guidance for earthing method is given below only for information purpose. But it is mandatory to flow the recommendation by the local electrical inspectorate authority for earthing of HT equipment

General Guidelines for earthing of equipment :

All the non-current metal parts of electrical installation shall be earthed properly. All metal conduits trunking, switchgear, distribution boards, switch boxes, outlet boxes, and all other parts made of metal shall be bonded together and connected by means of specified earthing conductors to an efficient earthing system. Earthing work shall conform to CPWD General Specifications for Earthing work shall conform to Internal) -1994 and Indian Electricity Rules 1956 amended upto date and in the regulations ofthe local Electricity Supply Authority.

Earth continuity conductor along with sub-main wiring from Main/Sub Distribution boards to various distribution boards shall be of copper. Earth continuity conductor from distribution board onward upto outlet point shall also be of bare copper. Earth continuity conductor connecting Main & Sub Distribution boards to earth electrode shall be with galvanised MS strip.

Single phase distribution board shall have one earth continuity conductor while three phase distribution board shall be provided with two earth continuity conductors. Earthing of main switch board and sub switch boards shall be earthed with two independent earth electrodes or as indicated elsewhere. Earth conductor laid in ground shall be protected for mechanical injury & corrosion by providing GI pipe. 8.04 GI pipe shall be of medium class 40mm dia and 4.5 metre in length. Galvanising of the pipe shall conform to relevant Indian Standards. GI pipe electrode shall be cut
tapered at the bottom and provided with holes of 12mm dia drilled not less than 7.5cm from each other upto 2 metre of length from bottom. The electrode shall be buried in the ground vertical with its top not less than 20cm below ground level as per detail enclosed. Earth electrode shall not be situated less than 2metres from the building. The location of the earth electrode will be such that the soil has reasonable chance of remaining moist as far as possible. Masonry chamber of size 300 x 300 x300mm shall be provided with water funnel arrangement a cast iron or MS frame & cover having locking arrangement at the top.

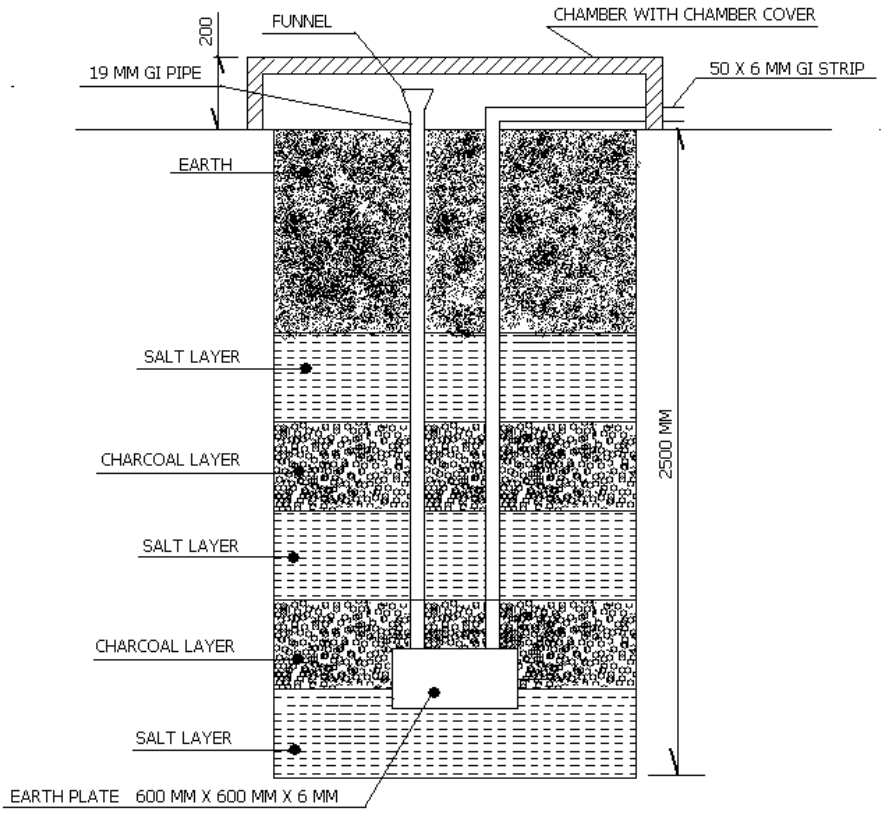
Earthing shall be provided with either GI plate electrode or copper plate electrode of following minimum dimensions.

- ⇒ GI Plate Electrode : 600mm x 600mm x 6mm thick
- ⇒ Copper Plate Electrode : 600mm x 600mm x 3mm thick

The electrode shall be buried in ground with its faces vertical and not less than 3 metres below ground level. 20mm dia medium class GI pipe shall be provided and attached to the electrode. A funnel with mesh shall be provided on the top of this pipe for watering and earth electrode. Earth electrode the watering funnel attachment shall be housed in masonry enclosure of not less than 300 x 300 x 300mm deep. A cast iron or MS frame with cover having locking arrangement shall be provided at top of metres from the building. Care shall be taken that the excavation for earth electrode may not affect the column footing or foundation of the building. In such cases electrode may be further away from the building.

If the earth resistance is too high and the multiple electrode earthing does not give adequate low resistance to earth, then the soil resistivity immediately surrounding the earth electrodes shall be reduced by addition of sodium chloride calcium chloride, sodium carbonates copper sulphate, salt and soft coke or charcoal in suitable proportions.

The resistance of earthing system shall not exceed 1(One) Ohm.



TYPICAL EARTHING PIT DIAGRAM

10. If it is envisaged that the outdoor locations are prone to bird faults, the complete capacitor bank should be covered with fine wire mesh enclosures (opening of minimum one inch opening) or all the live parts should be covered with sheet steel of wire mesh enclosures. In case this is not possible due to practical reasons, all live busbars and live parts should be insulated with heat shrinkable sleeves or insulating tapes of adequate voltage grade.

COMMISSIONING AND OPERATION:

1. Check that all the connections are made as per the drawing and required clearances are as per IE rules and drawings are maintained. Please ensure that there are no loose connections at any point, which can lead sparking.

2. Check if all the porcelain parts i.e. bushings, post insulators etc. are thoroughly cleaned and free from cracks breakage etc.

3. The insulation resistance of the complete installation should be checked with a megger before put the capacitor bank into service. Please do not switch on the capacitor bank if the megger values are low and once clean the bushings and other porcelain parts of the complete installation.

4. Connect the capacitor bank to a 3-phase low voltage supply (415/440) for checking the balancing. The current across all the 3 phases should be measures, which must be almost equal.

5. Disconnecting one unit must create an unbalance condition at low voltage supply. Measure the voltage (incase of external single star connected capacitor bank) or current (incase of external double star connected capacitor bank) at the terminal of the NDR relay. Under healthy condition the voltage or current will be almost zero but on unbalance condition some voltage or current will appear in the terminals of the NDR relay. This test will assure that the connections are proper and the NCT or RVT operations are proper.

6. All the protective relay of the relay panels should be tested with a relay testing kit before commissioning of the capacitor bank.

7. The load current and the voltage of the system should be noted prior to the commissioning of the capacitor bank.

8. After all the pre-commissioning test results are satisfactory the capacitor bank can be charged at high voltage. After switching ON the capacitor bank all the reading like capacitor bank current, load current, system voltage and power factor must be recorded. The parameters like power factor, load current and voltage will change compared to the reading prior to the commissioning of the capacitor bank. The load current will reduce, power factor will improve and slight improvement in the voltage of the system will be experienced. The current of all the three phases on the capacitors must be equal.

9. A couple of hours after the commissioning, the capacitor bank must be switched OFF and after 10 minutes (time taken for capacitor to discharge to a safe value) the capacitor bank should be grounded with GOD if available. If GOD is not available the grounding can be done with a discharge rod. Check if any connections are getting excessively hot and tighten the connection at that point. Also check for any leakages etc. or any other abnormality. If any abnormality is observed please immediately contact Energe Capacitors Pvt. Ltd.

10. It is recommended that all the tests mentioned above are carried out periodically especially during shut down condition to ascertain the healthiness of the capacitor bank and for a long and trouble free service of the capacitor bank.

MAINTENANCE OF CAPACITOR BANK:

1. Daily records of capacitor current, load current, power factor, system voltage etc. should be maintained on hourly basis. The tripping of relays and the number of switching operations must be systematically recorded. These information are necessary to ascertain the causes of any fault in future and will help in taking precise remedial measures.

2. It is advisable to restrict the number of switching operations of the capacitor bank. Indian Standards specifies that the switching operation should be less than 1000 operation per year.

3. The voltage across the capacitor bank must be within permissible limits. It is good practice to switch OFF large rating capacitor bank during light load conditions to over leading power factor conditions.

4. During shut down conditions maintenance work like cleaning the bushing tightening the connections etc. must be carried out. Also leakages, damages, crack on bushings and insulators must be checked.

5. In case the corrosion is observed in the capacitor container in a period of time the same must be attended by re-painting the surface of the capacitor container. In humid and polluted atmosphere repainting of the capacitor container must be done periodically.

6. Maintenance of breaker and all other equipment must be carried out periodically along with all other equipment in the switchyard.