

Internal fuses in capacitor units

There are two types of fuses used for capacitors; internal and external. When the reactive power of a capacitor unit was only a few kvar, the most natural method to protect the capacitor was with an external fuse, since in the case of a breakdown the lost reactive power was small. However, now that one capacitor element has a capacity about the same value as a unit had previously it is reasonable to protect each separate element with an internal fuse.



Internally fused capacitor unit

When using units protected by internal fuses the number of internal series connections is determined by the bank voltage and size. The breakdown of one element and the subsequent fuse operation causes an overvoltage over the healthy units. In units where all the elements are in parallel this overvoltage is very often under 0.5 %. When the unit voltage is low (approximately 500 volts), it is relatively easy to construct units where the fuse operation is completely reliable and breaks the current from the parallel elements and units. However, when the element voltage is approximately 1500-2500 volts the breaking capacity of such a fuse is not adequate to break the high current of a short circuit, even with several kilovolts recovery voltage, unless the fuse is specially constructed, as are ours. In the event of a fault it is operated quickly and reliably by part of the unit energy before high energy from parallel connected units has any adverse effect.

Externally fused capacitor unit

In units protected by external fuses, the fuse does not operate quickly in the event of a short circuit of one element group, due to the other requirements stated for its fuse dimensioning. According to IEC standard, the rated current of a fuse must be at least 1.43 x the rated current of the unit and usually this coefficient is 1.5 to avoid unnecessary fuse operations.

Therefore the fuse cannot operate when the first element group is short circuited and does not operate quickly when second group is short circuited. At these breakdown points inside the unit a continuous arc could, therefore, exist for several hours, leading to a development of excessive pressure. The unit could then burst before the operation of the fuse.

When using an external fuse, there is always a possibility that the capacitor unit will blow up (case rupture). This can clearly be read in the following standards of IEEE and NEMA and in the guides.

1. IEEE C37.99-1990
IEEE Guide for the protection of Shunt Capacitor Banks
2. IEEE Std 18-1992
IEEE Standard for Shunt Power Capacitors
3. IEEE Std 1036-1992
IEEE Guide for Applications of Shunt Power Capacitors
4. NEMA CPI-1988 Shunt Capacitors
5. IEC 60871-1
Shunt Capacitors for a.c. power systems having a rated voltage above 1000 V

As it can be seen in the above mentioned standards and guides, the case rupture has been handled very complexly and seriously in connection with externally fused capacitors. In connection with internally fused capacitors the case rupture tests have not even been requested in any standard (NEMA, IEEE, IEC...). The reason why the case rupture matters of the externally fused capacitors have been treated very strictly is that when using the external fuses the customers around the world have had the experience that the case rupture is a very common event. For that reason they have wanted special demands for the standards and guides.

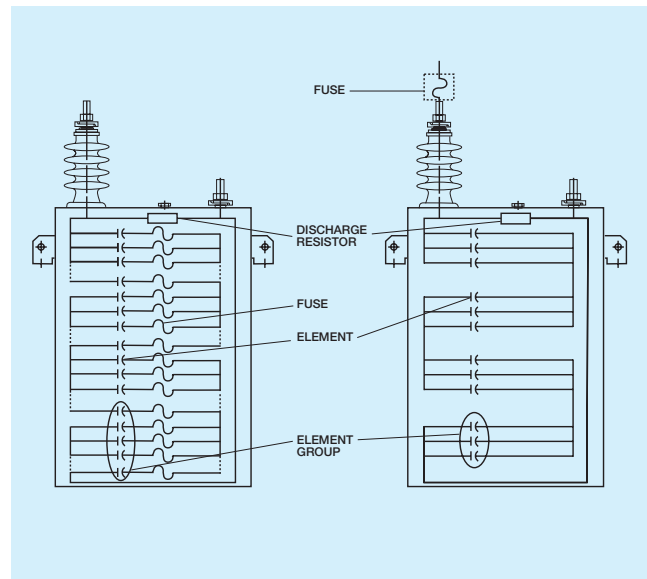


Fig. 1
Internally fused unit Externally fused unit

Fuse operation

In the element puncture the fuse blows very quickly with the energy discharge of the elements connected in parallel with them. The blowing time is some microseconds and the switch-off takes about 50-200 Joules energy. The operation of the fuse is quick and it does not demand much energy and does not form in the oil housing an open electric arc, neither gas. The fuse is in a closed room between the elements. When it burns it does not pollute the oil.

The open fuse distance can bear a higher voltage than the elements in parallel. This voltage solidity is tested in tests according to IEC standards.

It has also been experienced in practice that the possibility for the damage of the next element in a unit which already has one damaged internal fuse element is not higher than in a unit with no damaged elements. This answers all the questions with fuse operation speed of gas generation and arcing-by-product resulting in decreased performance in the dielectric properties of the fluid.

In external fuses the arcing-by-products can occur but they do not occur in the internal fuse because of the quick operation of the internal fuse (some microseconds).

Other failures

The internal fuse does not protect in the puncture between case and hot terminal. This insulation level is not an economical question and it is dimensioned over the demanded level. The routine tests prevent the production defects.

This type of failure is detected and tripped by the unbalance current protection.

Defects in the banks outside the capacitors can also be in the front side of the external fuse, the external fuse does not protect towards outcoming defects either.

Comparison of internal and external fuses

	Internal fuse	External fuse
Lost kvar in the case of a blown fuse	low	high
Possibility of spurious fuse operation	low	high
Possibility of a case rupture	low	high
Interruption in service cause by fuse operations	low	high
Difficulties in unbalance protection	low	high
Need of spare units	low	higher
Need of space of bank	low	higher
Influence of atmosphere (water, snow, ice)	none	yes
Servicing and maintenance costs	low	higher

Lost reactive power

If the capacitor unit is protected with internal fuses the lost reactive power in the case of a blown fuse is very low (approximately 2% of a unit). Because of the low percentage power loss there is no need to replace the entire capacitor unit; hence preserving continuity of operation and saving replacement costs.

If the unit is protected with external fuse the whole unit is lost and it is nearly always necessary to replace the faulty unit immediately. It is, therefore, obvious that by using internally fused units the need of spare units is much lower than by using external fuses.

Discharge current withstand

The discharge current of a capacitor unit is very high when a short circuit occurs between the terminals. The ratio of the discharge current to the rated current increases with higher capacitor voltage and with more internal series connections.

When in a 400-1000 kvar unit all the elements are in parallel, the theoretical current when discharging from the peak value of the rated voltage, is 200-300 times the rated current. For a similar unit with 4-8 internal series connections the corresponding value is 600-1000. The values depend on the internal connection of the unit.

The switching and other transient currents to the bank are less than the direct discharge currents but these, together with the harmonic currents, result in the fact that in the standard requirement the fuse shall be rated at least 1.5 x the rated current. Internal fuses are designed in a way that approximately four times the rated current can be used without any risk to the other operation requirements of the fuse. Equally rigid dimensioning with regard to the discharge current cannot be applied to an external fuse and, therefore,

its operation can cause unnecessary blowing of other fuses.

Operation after element breakdown

When a capacitor element breaks down, the discharge current from the elements connected directly in parallel with damaged element is even higher than in a direct external discharge. This is due to the lower discharge circuit inductance. With an internal fuse the energy of one element and some of the parallel connected elements discharges through the fault. The internal fuse detects a high discharge current from the parallel elements and operates well before the expected peak value current, within some tens of microseconds or milliseconds, depending on the voltage at the event of breakdown.

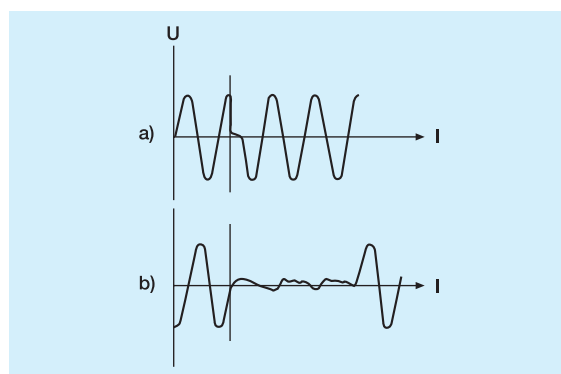


Fig. 2 Fuse operation when the fault occurs at
a) the peak value
b) the zero point of the voltage

The breakdown point in the parallel connected group also effects the operation time. A fuse which is correctly designed, limits the discharge current and breaks it very soon after the fault occurs.

An external fuse can never operate rapidly in units which have internal series connections as since most units have such connections, the external fuse is usually slow. When a fault occurs in a unit, not only does the energy of that group of elements discharge through the fault, but also some of the energy of parallel units and the energy caused by the increased power frequency current. In a unit where all the elements are in parallel the discharge current from the parallel units blows the fuse. If the fuse does not limit this current and break quickly, mechanical damage to the unit which has the breakdown may result.

With external fusing the rapid operation at the power frequency current is not easily arranged, because a fault in a group only slightly increases the unit current. If there are four groups in series in a unit and no parallel connected branches, the current increases to only 1.33 I_N . Therefore, some groups have 33% overvoltage and may eventually breakdown, even after some months. When this occurs, the current will be 2 I_N . The fuse still does not operate rapidly, as the rated current of the fuse is 1.5 x the rated current of the unit. At this time there may have been arcing in the unit and the possibility of the rupturing of the capacitor container is evident.

Unbalance protection

Unbalance protection on banks consisting of externally fused units is difficult since the situation immediately before fuse operation often corresponds to a higher operation itself. The unbalance protection may trip the bank before the fuse operation since an external fuse may withstand for hours from breakdown before it operates. Therefore, if the unbalance protection has caused the bank to be tripped, the visible indication of fuse operation is lost and the faulty unit must be detected by capacitance measuring.

In the internally fused capacitor banks the unbalance protection arrangements are simple and reliable. E.g. the star-star connection with the current transformer can be used and the line voltage compensation is not needed.

Losses of capacitor unit and bank

The losses of the unit with internal fuses are a bit bigger than they are without internal fuses. In the loss estimations of the internally fused capacitors which have been informed and dimensioned the fuse losses are included in them, in the externally fused they are not included. The rise of temperature in the internally fused capacitors can be some degrees higher than in the externally fused capacitors. It has no essential meaning in the operating life, because the losses in all-film capacitors are very low and the internal dielectric temperature is only 5-15°C higher than the ambient air temperature.

When noticing the losses of the complete capacitor bank (also the losses of external fuses and internal wiring), the losses of the capacitor bank internal and external fuses are the same.

Capacitor bank construction, unit size

If we assume the capacitor bank to be of 24 Mvar 143 kV and if external fuses are used, according to IEEE Std 1036-1992 page 19, table 15 recommendation, we will end at max. capacitor unit kvar.

$$24000 \text{ kvar} / 3 / 6 / 10 = 133 \text{ kvar (13.8 kV)}$$

3 = phases
6 = number of capacitor units
in series
10 = minimum recommended
number of units in parallels

The corresponding limitations do not exist when using the internally fused capacitor units. In that case e.g. 400 kvar (8280 V) or 800 kvar (16560 V) units can be used.

Maintenance

In order to find out the damaged unit, capacitors equipped with internal fuse must be measured. There are very easy-operated meters for this operation. The need for

measuring arises only when the unbalance protection trips or alarms. This is unusual because the internal fuse does not let separate punctures happen without the units getting less operating life.

In external fuses it is normally necessary to take the bank out of operation even if one fuse has been operating and change the unit and the fuse. This increases the servicing costs and also the time the bank is out of operation.

Capacitor banks are required to have a high degree of safety in operation and be easy to maintain. In particular series banks and direct voltage power transmission filter banks should be fit to be kept in operation all the year round. This calls for especially good fuse and relay protection. Satisfactory unbalance protection is usually very difficult to obtain with external fuses and it is nearly always necessary to replace the faulty unit immediately. Conversely, the burning of an internal fuse increases the unbalance only marginally, thus if an alarm occurs, a suitable time for the next maintenance inspection can then be chosen. If, for example, the bank is regularly inspected in connection with annual maintenance, it is not even necessary to inspect the bank when an unbalance alarm occurs if the annual inspection is near.

Since the location of some very large capacitor banks can entail a journey of some hundreds of kilometers for the service personnel, numerous visits to such a station would incur heavy expense. Even more difficult, of course, is that a very important transmission line has to be taken out of service, or operated on decreased capacity just because of the burning of one capacitor fuse. With internal fuses this can usually be avoided since damage element and the subsequent fuse burning have no effect on the operation of whole bank.

Summary

The following requirements can be stated for a capacitor fuse:

the fuse must operate rapidly and reliably with as small capacitance loss as possible, within an area protected by the fuses, with the discharge current from a parallel connected capacitor and with excessive power frequency current

the fuse must withstand reliably permissible overcurrents and voltages, transient currents when energizing or deenergizing the bank, test voltages and currents, shortcircuit currents when the breakdown is not within the area protected by the fuse and spark gap operations in series banks.

Fuse protection cannot often be satisfactorily obtained with external fuses because of the difficulties in discharge current withstand, power frequency current operation and unbalance protection. Also, the likelihood of rupturing the capacitor container is increased with present-day larger units. With internal fuses the protection and operation of units and banks are satisfactory in all these respects.

In line with our policy of on-going product development we reserve the right to alter specifications.