capacitor switching for power circuit breakers

isolated bank • paralell banks

general information

With the increase in number and size of capacitor banks used for voltage and power factor correction, there has been a corresponding increase in the demand for apparatus that will handle the switching duty. Considerable research development and testing have been done to determine the ability of standard power circuit breakers to handle this duty, and when necessary, the best modifications of these breakers to meet the requirements. This bulletin summarizes and interprets the results with respect to practical applications of the circuit breakers listed on page 4.

The type CA compressed air breakers are designed to have a maximum interrupting action under all conditions of current. They are very effective on capacitor switching and can operate essentially restrike free for most ratings.

The sulfur-hexafluoride (SF_6) breakers from 34.5 kv to 230 kv and higher are essentially restrike free and standard breakers can be applied to capacitor switching. The extremely high dielectric strength of the SF_6 gas enables short contact gaps to withstand high recovery voltage. If a restrike should occur, the gas absorbs the explosive effect of the energy released by the current surge and practically eliminates the possibility of any damage to the interrupter.

The type DH air breakers use magnetic blowout for arc interruption, and standard breakers can be applied to capacitor switching. They will not operate restrike free, but extensive tests indicate that the resulting transient voltages seldom exceed two times normal.

On the lower voltages and smaller banks the standard oil circuit breakers can be used, but on larger banks, higher voltages, and where parallel banks are being switched some modification of the oil circuit breaker is frequently necessary, or desirable to obtain the most satisfactory operation.

isolated bank

The switching of an isolated bank of capacitors on and off the line, while not particularly hard on the breaker, can produce serious transient overvoltages on the system. This overvoltage can result from the arc restriking during de-energizing operations. A clearer understanding may be obtained by examining the voltage and current conditions existing prior to and during the switching operations.

In figures 1-a and 1-b the top trace represents the system voltage, the second trace capacitor bank voltage, the third trace current through the breaker (bank current) and the fourth trace recovery voltage which appears across the breaker contacts in the situation where a large bank is being switched off the line. In figure 1-a the breaker contacts part at time T_0. Interruption will usually occur at the first current zero, time T_1, since very little recovery voltage (difference between bank and system voltage) appears across the breaker contacts. Since the current was leading the voltage by nearly 90° prior to interruption, the capacitor bank, on interruption of the current flow, is left charged at practically full line voltage. With no restrike, the change in system voltage is limited to a small transient oscillation which decreases to the slightly lower steady state level as dictated by the change in system reactance on removal of the capacitor bank from the system. The duty on a breaker under these conditions is extremely light. However, as shown in figure 1-b at time T_1 the capacitor bank is charged to practically full line voltage while the system voltage moves away from it thus increasing the recovery voltage across the breaker contacts. Since in this case interruption occurred early in the stroke, little contact separation exists, and it is quite likely that the gap will break down under the increasing voltage stress (in figure 1-b, see time T_2). When this occurs, the capacitor voltage immediately attempts to equalize with the system voltage, but the circuit is oscillatory and at the first peak of the transient the capacitor voltage has overshot by an amount nearly equal to the difference between the two voltages immediately prior to the time of the restrike. In this case figure 1-b shows the

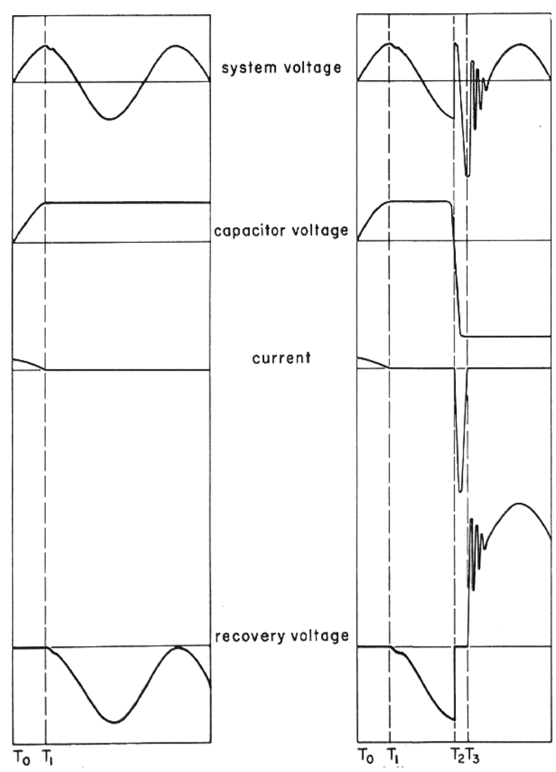


fig. 1-a: no restrike   **fig. 1-b:** restrike

Opening the circuit to a single phase capacitor in one step. On the left an opening without restrike. On the right, the maximum effect possible with one restrike.

October, 1961
supersedes technical data 33-063 dated May, 1957
mailed to: E/274-280/AD; D/811/DB; C/330-334/AD

isolated bank *continued*

current interrupted at its first high frequency current zero, time T_3 and the overshoot peak voltage is trapped on the capacitor bank.

The resulting recovery voltage reaches a value greater than that following the first interruption, but in this particular case there is no additional restrike because the contacts have moved further apart and the build up of dielectric strength exceeds the build up of recovery voltage.

If the gap breaks down less than a quarter cycle after a current zero, the amplitude of the voltage oscillation will not exceed the crest voltage, and no overvoltage is caused. This is defined as a re-ignition rather than a restrike.

In figure 1-b the restrike is shown to occur a full half cycle after current interruption. This is the worst possible condition for the first restrike because the recovery voltage has reached its maximum, and the resultant surge voltage can theoretically reach three times normal line-to-ground crest voltage. In actual practice it seldom exceeds two and one-half times normal. This should not be damaging to the system; however, additional restrikes can produce higher crest voltages and the sudden voltage changes and high frequency oscillations may produce other relatively higher voltages elsewhere on the system. Therefore, it is desirable to limit restrikes or the voltage phenomenon resulting from them to protect the entire system.

parallel banks

On breaker switching of a capacitor bank, the magnitude of voltage disturbances on the system is greatly reduced by the presence of one or more additional banks of comparable size close to the breaker and energized by the system. But, during a closing operation, or during a restrike, the transient inrush current through the breaker between the energized banks and the one being switched can be very large. With standard breakers these currents are oscillatory at very high frequencies. The peak current may exceed 100 times the normal peak of the capacitor bank current. Such a high instantaneous current will suddenly release a relatively large amount of energy which, particularly as an arc current in oil circuit breakers, can produce explosive like forces and possibly damage the interrupters.

Since the severity of parallel bank switching is caused by the very sudden high current which initially is limited only by the very low resistance and inductance of the usual circuit between the banks, it can be reduced by the addition of inductance to the circuit. An inductance which will have a 60 cycle reactance as little as ½ to 1% of the 60 cycle capacitive reactance of the banks and placed in series with them will greatly reduce both the rate of rise and the peak value of the inrush current which in turn greatly reduces the severity of the breaker duty.

modifications to oil breakers

. . . for capacitor switching

A circuit breaker which can be applied to either isolated banks or parallel banks must have two particular design features. First it must eliminate the harmful effects of the current surges to the breaker itself and secondly it must limit overvoltages on the system.

On the small outdoor oil breakers, 250 mva and below, and indoor oil breakers below 500 mva, because of the lower voltages involved, restrikes are infrequent and overvoltages are neither great nor much of a problem. By making the grids sufficiently strong, satisfactory results are obtained with these breakers.

In oil breakers for 115 kv and higher, extra strong multi-flow grids with pumps and shock-absorbing gas chambers near the arc spaces are used. The pumps make the grids essentially restrike free. The extra strong grids withstand the physical shock during those rare occasions when restriking does occur.

The higher currents associated with capacitor banks of comparable kvar at voltages below 115 kv make necessary such powerful pumps that the loads on the operating mechanisms are prohibitive. For this reason with breakers rated 69 kv and below, two-step switching where a resistance is inserted in the circuit is preferable to a design using pumps. The use of a resistor switched into a circuit during interruption to reduce switching surge overvoltage on a system has been common for many years; however, unless the interrupter is effective on the second step as well as the first, the resistor current must be very low and have a fairly high power factor. Consequently, the resistor must have an impedance about four times the single phase capacitive reactance. Tests show that such a relatively high value of resistance used with capacitor switching lowers the probability of restriking but does not reduce the overvoltage by much more than 15 to 25%. Lower values of resistance can be used with an interrupter that is effective on the arcs of both steps of the interruption and superior performance is obtained. Figure 2 shows schematically how well the "De-ion" grid is suited to this type of two-step switching.

how resistance switching works

The grid is separated into two sections by a probe which makes physical contact with the moving contact and is connected through a resistor, R, to the stationary contact. The arc drawn initially (at time T_0 in figure 3) in the upper portion of the grid figure 2-A is in parallel with the resistor. Its extinction, at time T_1 in figure 3, inserts the resistance into the circuit. By using a low value of resistance, in the neighborhood of only half the capacitive reactance, the step of inserting the resistance becomes easy. The current is changed very little from its normal magnitude, during time T_1 to T_2 in figure 3 and the voltage drop across the resistor, and consequently the first gap is small. The voltage across the first gap being small, restriking at this time is rare; however, should restriking occur as shown at time T_2, in figure 3, the current and voltage amplitude is low. The arc in the first gap is shown extinguished at time T_3 and the current path transferred through the resistor for the period T_3 to T_4 at which time the current is interrupted.

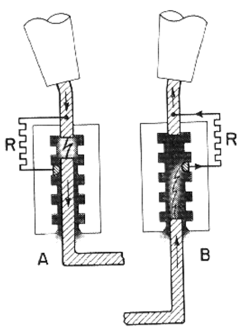


fig. 2:

Schematic drawing through breaker pole unit showing contacts, interrupters, and resistors (R) at:

A. 1st step of interruption; and B. 2nd step of interruption.

restrikes in lower half of grid: Should a restrike occur after the moving contact has withdrawn from the probe contact as shown in figure 2B and at time T_5 in figure 3, the resistor is in series with the bank and the transient current is hypercritically damped as shown from T_5 to T_6. The capacitor voltage equalizes with the system voltage. The transient voltage is not oscillatory and cannot rise above the normal rated frequency peak value.

design of the resistor: Analysis shows that in order to keep overvoltages to a minimum in the event of a restrike during the first step of interruption, the lower the resistance the better, because the bank voltage will then more nearly follow the system voltage, but in the event of a restrike (through the resistor) during the second step of interruption, the greater the resistance the better for minimizing the transient overvoltages.

The optimum condition to limit the transient overvoltage for restrikes in both steps is obtained when the resistance is about half the capacitive reactance, $R/X_C=0.5$. This does not, however, mean that a different resistor must be used for each size of bank. Tests have shown that excellent results are obtained by using one value of resistance for bank sizes from 2,000 to 8,000 kvar, and another for banks of 5,000 to 20,000 kvar. A third resistor size might be used for larger banks. This ratio R/X_C is maintained at a value less than one for best results.

When the ratio R/X_C is maintained at a value between ½ and 1, not only is the problem of system switching solved, but also the stress on the breaker itself is controlled because the impedance of the resistor, being independent of frequency, very effectively limits the surge current on closing the breaker to energize the capacitor bank, or on a restrike during an opening operation.

Thus a breaker designed for two-step switching using low values of resistance has a very low probability of restriking during the first step operation because the voltage on the gap is limited to the voltage across the resistor. If a restrike should occur the transient surge currents and overvoltages will be low. If a restrike occurs during the second step of operation the low value of resistance limits the surge currents and prevents any oscillation and any overvoltage.

two-step switching

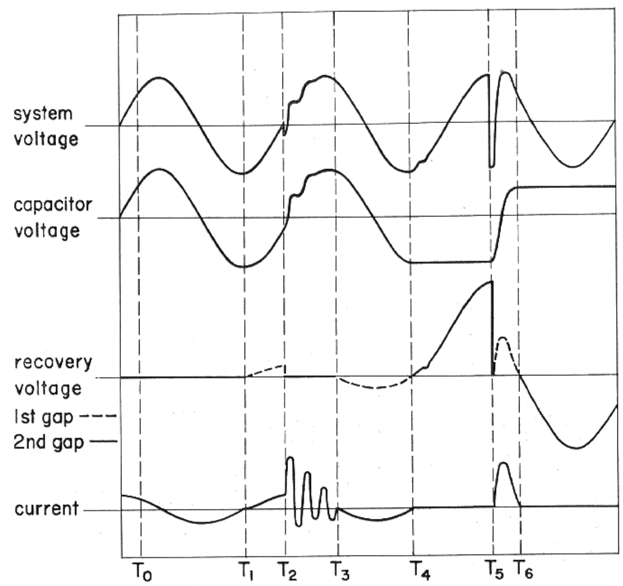


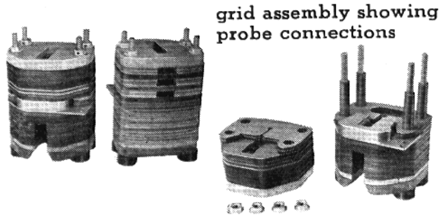
fig. 3: Opening the circuit to a capacitor in two steps. Approximately the maximum effects of one restrike while inserting the resistor and one restrike while opening the circuit through the resistor are shown. No overvoltages appear on the bus.

The resistor is also an aid to the interruption of fault currents which may occur within the capacitor bank. On insertion of the resistor, being in parallel with the first gap, only a very low rate of rise of transient recovery voltage appears across the first gap which in turn results in a low probability of restrike in the first gap. Consequently, insertion of the low value resistor into the circuit is facilitated by the resistor itself. The second gap then has only the resulting reduced fault current to interrupt. The interruption of fault current differs from the interruption of the capacitive circuit principally in the larger current drawn in the first gap and the greater amount of ionized gas which makes the insertion of the resistor more difficult.

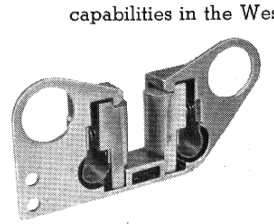
The resistance method of capacitor switching has been applied to the three tank outdoor oil breakers between 14.4 and 69 kv, inclusive, from 500 through 2500 mva interrupting capacity.

In all cases, resistor grid designs have been thoroughly tested and verified both as to capacitor switching and power interrupting capabilities in the Westinghouse High Power Laboratory.

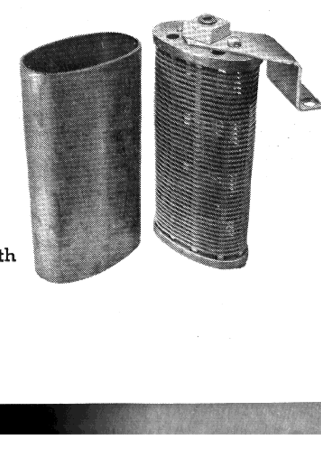
resistor switching grid details



grid assembly showing resistor probe connections



detail of finger box (probe)



typical resistor assembly with insulating sleeve removed

capacitor switching
for power circuit breakers

application

circuit breaker type	ratings: kv	amps	mva	maximum size of capacitor bank: kvar♦ isolated	parallel	recommended modification to breaker	literature reference
type CA compressed air circuit breakers							
150CA1000	14.4	1200	1000	22000	22000	none	
150CA1000	14.4	3000	1000	45000	45000	none	
150CA1500	14.4	2000	1500	37000	37000	none	
150CA1500	14.4	4000	1500	refer to Westinghouse			descriptive bulletin 33-450
150CA2500	14.4	5000	2500	refer to Westinghouse			
345CA1500	34.5	1200	1500	refer to Westinghouse			
345CA1500	34.5	3000	1500	refer to Westinghouse			
345CA2500	34.5	3000	2500	refer to Westinghouse			
type SF-6 sulfur-hexafluoride breakers							
345SF500	34.5	1200	500	50000	50000	none	descriptive bulletin 33-551
460SF500	46	1200	500	50000	50000	none	
	69 kv to 345 kv			refer to Westinghouse			
type DH De-ion® air circuit breakers							
				at 2400 v / at 4160 v	at 2400 v / at 4160 v		
50DH75	4.16	1200	75	3600 / 6400	‡3600 / ‡6400	none	
50DH150E	4.16	1200, 2000	150	3600 / 6400	‡3600 / ‡6400	none	
50DH250E	4.16	1200, 2000	250	3600 / 6400	‡3600 / ‡6400	none	
				at 13.8 kv	at 13.8 kv		descriptive bulletin 32-250
150DH150E	13.8	1200, 2000	150	21600	20000▲	none	
150DH250E	13.8	1200, 2000	250	21600	20000▲	none	
150DH500E	13.8	1200, 2000	500	21600	20000▲	none	
150DH750E	13.8	1200, 2000	750	21600	20000▲	none	
150DH1000E	13.8	1200, 3000	1000	21600	20000▲	none	
indoor oil circuit breakers+							
F-122	4.16	600	25	3200	not recommended		descriptive bulletin 33-150
F-124A	7.2	600	50	5400	not recommended		descriptive bulletin 33-151
		1200	50	6000□	not recommended		
F-100	7.2	600	100	5400	4800‡	reinforced grid	descriptive bulletin 33-152
		1200	100	6000□	4800‡△	reinforced grid	
138F150	13.8	600	150	6000	4800‡	reinforced grid	descriptive bulletin 33-152
		1200	150	6000□	4800‡△	reinforced grid	
138B250	13.8	1200	250	6000□	4800‡△	reinforced grid	descriptive bulletin 33-152
138B500	13.8	1200	500	6000□	4800‡△	reinforced grid	descriptive bulletin 33-152
outdoor oil circuit breakers+							
144GC100	14.4	600	100	6000	2700‡		descriptive bulletin 33-251
144GC250	14.4	600	250	6000	2700‡		descriptive bulletin 33-251
		1200	250	6000□	2700‡		
144GC500	14.4	600	500	6000	2700‡		descriptive bulletin 33-251
		1200	500	6000□	2700‡		
144G1000	14.4	1200	1000	22000*	22000*	resistor grid	descriptive bulletin 33-252
144G1500	14.4	3000, 4000	1500	30000*	30000*	resistor grid	descriptive bulletin 33-252
230GC250	23	600	250	6000	2700	reinforced grid	descriptive bulletin 33-251
230G500	23	1200	500	30000*	30000*	resistor grid	descriptive bulletin 33-252
345G500	34.5	1200	500	30000*	30000*	resistor grid	descriptive bulletin 33-252
345G1000	34.5	1200	1000	30000*	30000*	resistor grid	descriptive bulletin 33-252
345G1500	34.5	1200	1500	30000*	30000*	resistor grid	descriptive bulletin 33-252
345G2500	34.5	1200	2500	30000*	30000*	resistor grid	descriptive bulletin 33-252
460G500	46	1200	500	30000*	30000*	resistor grid	descriptive bulletin 33-252
460G1000	46	1200	1000	30000*	30000*	resistor grid	descriptive bulletin 33-252
690G1000	69	1200	1000	30000*	30000*	resistor grid	descriptive bulletin 33-252
690G1500	69	1200	1500	30000*	30000*	resistor grid	descriptive bulletin 33-252
690G2500	69	1200	2500	30000*	30000*	resistor grid	descriptive bulletin 33-252
GM	69 to 161 kv			refer to Westinghouse.			
GW	230 to 345 kv			refer to Westinghouse.			

♦ The continuous current rating of the breaker may further limit the capacitor bank size, particularly in applications at reduced voltage. Breaker current rating must exceed the nominal current of the capacitor load by 35%.

\+ Parallel banks equal in size to the isolated bank value may be employed in multiple provided they are effectively isolated with inductance to lower the amplitude and frequency of the interbank transient current. For such applications refer to Westinghouse.

□ When employed with an isolated bank at reduced voltage ($E < 7.2$ kv), the maximum bank size shall be determined by the following formula if not limited otherwise by the current rating (see note ♦):

$$KVAR = 6000 - 500\ (7.2 - E)$$

△ When employed with parallel banks at reduced voltage ($4.8 \text{ kv} < E < 7.2$ kv), the maximum size shall be determined by the following formula if not limited otherwise by the current rating (see note ♦):

$$KVAR = 4800 - 500\ (7.2 - E)$$

For voltages less than 4.8 kv the maximum bank size is 3600 kvar if not limited otherwise by the current rating.

‡ The total capacity of the load bank and all parallel banks on the source side is not to exceed two times the value listed.

* When used to switch isolated or parallel capacitor banks of 6000 kvar or less, these breakers do not require modification. If employed unmodified on parallel banks, see also note ‡.

▲ The total capacity of parallel banks not to exceed 40,000 kvar and the inductance between switched banks must be at least 25 micro-henries per phase.

further information: Refer to Westinghouse.

Westinghouse Electric Corporation
Power Circuit Breaker Dept: East Pittsburgh Divisions • East Pittsburgh, Pa.
printed in U.S.A.