Line-Charging Current Interruption by HV and EHV Circuit Breakers: Standard and Non-Standard Test Requirements as Determined by the Stresses Applied and by Breaker-Capability Considerations

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Abstract – This paper discusses the reasons that frequently lead electrical utilities to issue specifications with above-standard requirements relative to the interruption of line-charging currents by HV and EHV circuit breakers. It shows by means of examples, digital simulations and a discussion of the withstand capabilities of modern breakers that these special requirements are many times unjustified and often determine price increases of which proportions the buyers are generally unaware.

Keywords: Circuit breaker, capacitive switching, no-load line switching, IEC standards, recovery-voltage withstand capability, test requirements, digital simulations

1. INTRODUCTION

Circuit-breaker manufacturers often have to confront technical specifications with unusual requirements for the line-charging current switching test duties – sometimes significantly more severe than those defined in the existing standards, which on their turn have been prepared on the assumption of the maximum stresses that should reasonably be expected for the voltage levels involved. Whereas this frequently results in their having to offer the clients more expensive equipment to meet such requirements, it has been found many times that these had been determined either by an unjustified pessimism about the stress levels to be expected during the process of line-charging current breaking or by a simplified appraisal of the circuit-breaker capabilities assumed in the standards, and/or of the testing procedures defined thereby.

To address sensibly the above-referred problems one has to understand the concerns and difficulties of the planning engineers assigned by the utilities to define the electrical parameters of future switchgear with a view to preparing the technical specifications for their purchase. This topic deserves considerable more attention than it has so far received in the technical literature, particularly in view of the constant development of circuit-breaker technology and of the recent changes introduced by the IEC on the testing methods defined in standard 60056 [1] for the capacitive-current interrupting duty of circuit breakers.

2. MAIN STRESSES FOLLOWING CURRENT INTERRUPTION

After a transmission line is left unloaded by the opening of its remote end by a circuit breaker, the breaker at its other end (which will be referred to from now on as the sending end) may be called upon by an operator command or by a trip order to interrupt the line's charging current. In typical cases the phenomena involved in this second interruption are very similar to those associated with the opening of a capacitor bank. Different patterns appear, additionally, when the transmission line is shunt compensated and / or when there is a phase-to-ground or phase-to-phase fault on the line. Of course in the latter case only the current on the sound phase(s) may be properly classified as "charging current".

Line-charging currents are quite small in comparison with the short-circuit currents the breakers are required to cope with, being therefore easy to interrupt. The interruption may thus take place even when the distance between breaker contacts is still very small – a circumstance that inevitably increases the risk of restrikes, which may have rather undesirable effects, such as voltage escalation [2]. The major concern of buyers and manufacturers as far as this duty is concerned is, therefore, to make sure that circuit breakers withstand the high recovery voltages that arise after current interruption without restriking – or, to use the new IEC terminology, with "a very low probability of restriking".

The maximum values reached by recovery voltages in this type of operation are affected by the magnitude of the voltage rises that may take place on one or both sides of the circuit breaker before or after current interruption. These rises are caused by a few factors such as phase-to-phase capacitive coupling, the possible presence of a line fault, Ferranti effects on the open line and the load-rejection effects that may be associated with the opening of the breaker at the remote end. For a non-compensated line the maximum value of the recovery voltage (U_c) may be calculated with the aid of the following formula:

$$U_c = k_b U_0 \,.\, k_{as} + k_b U_0 \,.\, k_{a\square} = k_b U_0 \; (k_{as} + k_{a\square}) \qquad (1)$$

where U_0 is the crest value to ground of the steady-state voltage that prevailed on both sides of the circuit breaker at the sending end before the line is opened at its remote end; $k_b = 1 + r_b$, r_b being the voltage rise (relatively to U_0) that takes place on both sides of the breaker at the sending end after the line is opened at the remote end (as a result of this opening and of any subsequent event such as a fault), but before the interruption of the charging current by this breaker; $k_{a\square} = 1 + r_{a\square}$ and $k_{as} = 1 + r_{as}$, $r_{a\square}$ and r_{as} being the voltage variations (relatively to $k_b U_0$) that may take place, respectively, on the line side and/or the source side of the breaker after this interruption.

Sometimes no important variation of the peak voltages takes place on any side of the source-side breaker after the interruption of the charging current, and in this case $k_{a\square} + k_{as} = 2.0$. More frequently it is only the voltage variation at the source side that may be neglected, and in this case $k_{as} = 1.0$.

When the line is compensated by shunt reactors the voltages on its phases are oscillatory after the interruption of the charging currents by each circuit-breaker pole and the peaks of the oscillations taking place on the two sides of each pole will hardly be coincident. Due to this fact the maximum recovery voltage will generally be lower than the value determined by (1).

2.1. Capacitive coupling between phases

Fig. 1 (centre) shows a general representation of all types of capacitive loads, where C_1 and C_0 are respectively the positive-sequence and zero-sequence components of the equivalent capacitance seen from the supply side.

The influence of the of the ratio C_1/C_0 of the capacitive load on the voltage that may evolve on the line side of the circuit breaker after current interruption – and, therefore, on the recovery voltage – has been explained in [2]. Fig. 1 shows the variation of the voltage on the line side of the first breaker pole to interrupt as a function of the ratio C_1/C_0 . For transmission lines, C_1/C_0 normally lies between 1.6 and 2.0, thus the line voltages after current interruption tend to lie between 1.2 pu and 1.4 pu and the recovery-voltage peaks between 2.2 and 2.4 pu.

A fact that is frequently forgotten is the reduction of the line-side voltage that takes place on the phase connected to this pole when current is interrupted by the other circuit-breaker poles. Fig. 2 shows the effect of the current interruption by the second and third poles of a circuit breaker for a 220 kV ungrounded capacitor bank. Current interruption takes place first at phase A at peak voltage, and the voltage on this phase starts to increase. This growth (which would proceed until the level of 2.0 pu was reached) is reverted when the charging current is interrupted simultaneously on phases B and C.

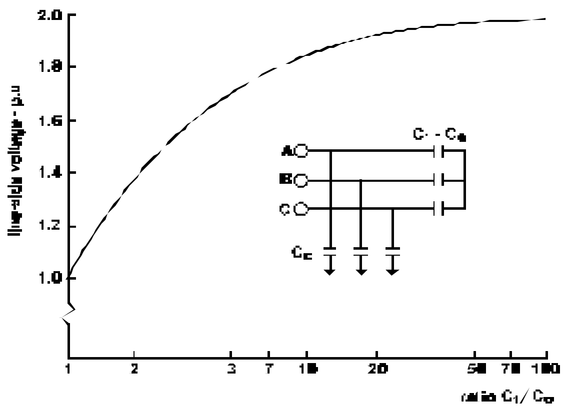

Fig. 1 – Line-side voltage after first current interruption as a function of the ratio C_1/C_0 (pu of the previous voltage).

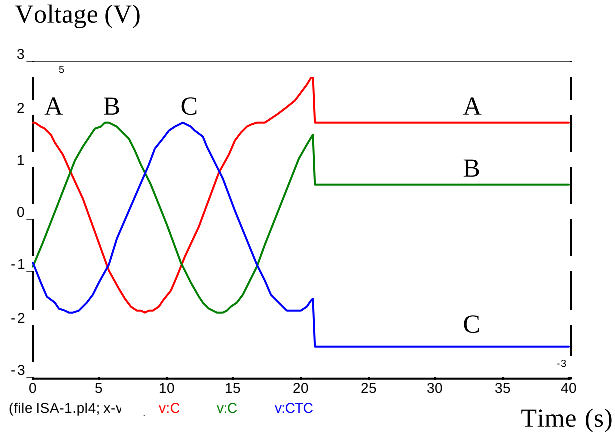

Fig. 2 – Voltages to ground during capacitor switching.

2.2. Ferranti effects

When a transmission line is left unloaded, the Ferranti effect will cause a rise in voltage from the sending end towards the remote end. This effect will be more pronounced the longer is the line and the higher is the voltage applied. The voltage at the sending end, although lower than that at the remote end, will still be higher than the one that prevailed when the line was loaded. This voltage rise at the sending end, caused by the flow of the leading current drawn by the open line through the inductances of the system on the source side of the breaker is called “Ferranti Rise”.

When the open line is dropped at its sending end the voltages on each side of the circuit breaker will change in opposite ways: the source-side voltage will adjust itself to a lower level by way of a transient oscillation (voltage jump), whereas on the line side the voltage will rise (also by way of an oscillation) in the process of redistribution of the electrostatic charge that takes place along the line length as a result of the break of the line-charging current.

2.3. Line faults

When an unloaded transmission line is exposed to a single or two-phase fault the circuit-breaker at its sending end may limit its action to the interruption of the current on the faulted phase(s) if single-pole opening is possible. However, even in this case current interruption may take place on the sound phase(s) as well. The interruption of current on the sound phase(s) is a typical case of capacitive switching. Circuit unbalances introduced by the fault will affect the voltage(s) on the sound phase(s) prior to current interruption, causing in most cases a voltage rise on the sound phase(s) which is mainly a function of the ratio X_0/X_1 of the circuit seen from the point of fault. Besides this ratio, other factors will affect the recovery voltage across the circuit-breaker poles after current interruption on the sound phases, such as the type of fault, the fault location, the sequence of current interruption by the poles, the ratio C_1/C_0 of the line etc.

2.4. Load Rejection

In many occasions in which a transmission line is dropped by the opening of a circuit breaker (say, breaker 1 in Fig. 3), following a trip order determined by a fault or by protection maloperation, the system connected to the other end of the line (shunt-compensated in the figure) will see this event as a loss of load. This type of event is called load rejection and may have a significant impact, particularly in radial systems and when large loads are involved. The line is left unloaded and remains connected to the system at the sending end, but shortly after the first opening the circuit breaker at this extremity (breaker 2 in Fig. 3) may also be called upon to open. This second operation may be motivated by the remanence of the fault, by transfer trip from the remote line end or by the voltage rise that takes place on the supply system and on the line as a result of the voltage increase at the terminals of nearby generators, caused on its turn by the change of their internal voltages and excitation conditions. A speeding up of the generator rotors and a consequent frequency increase are also caused by the load drop.

In a load rejection the overvoltages normally have a transient component that lasts from 0.5 cycles to 2 cycles and a temporary component that may last several cycles, until voltage and frequency at the generator terminals are brought back to their normal values by the system controls. On weak radial systems the temporary overvoltages may reach 1.4 pu. A value lower than 1.1 pu should be expected, however, on meshed networks with strong generation and not very long lines [3].

The opening of sound phases during the second operation is normally seen as a case of capacitive switching. The recovery voltage across any pole of the circuit breaker at the line's sending end may be particularly severe if a high temporary overvoltage has occasion to develop on the respective phase after load rejection.

2.5 Combination of effects

An unrealistic combination of all the factors mentioned in sections 2.1 to 2.4 may lead to the definition of extreme values / shapes of the recovery voltage which, if specified, would probably determine the supply of unnecessarily overrated and expensive circuit breakers.

Of course the occurrence of a fault, a load rejection or a stuck circuit breaker before or during the interruption of a line's charging current are perfectly possible events to which some probability may be associated. The question remains, however, of defining the reasonable degree of pessimism which should be taken into consideration for establishing the combination of events to be assumed for a specification.

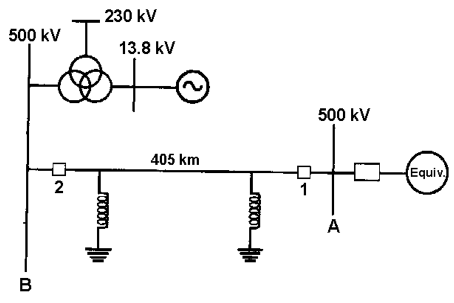

Fig. 3 – Load rejection (opening of breaker 1) affects the system on its left-hand side and may lead breaker 2 to open.

For 230 kV, 345 kV, 500 kV and 750 kV transmission lines an average figure of 0.0148 failures/km/year may be assumed on the base of records kept by FURNAS – Centrais Elétricas (a Brazilian utility) between the years of 1970 and 1986. If an average length of 400 km is (pessimistically) assumed for these lines, we come to the figure of 5.9 failures per line (37.2% of which caused by lightning discharges on one or two phases) . These failures will cause circuit-breaker operation at one of the line extremities (at least). Considering other possibilities, including operations due to human failure, accidents, equipment maintenance, testing etc it can be estimated that a line circuit breaker opens tipically between 10 – 20 times per year. In view of the above-mentioned possibilities, the number of operations involving the interruption of line-charging currents can be roughly estimated as 20% of all interrupting operations (i. e. between 2 and 4 times per year). This estimate already includes the cases in which a load rejection can be characterized.

In a recent CIGRÉ report [4] the rates of major failures are informed for single-pressure SF_6 circuit breakers with rated voltages within the following ranges:

- 200 / 300 kV: 0.814 failures / 100 breaker years
- 300 / 500 kV: 1.210 failures / 100 breaker years
- 500 / 700 kV 1.847 failures / 100 breaker years

Further, the document gives information on the various reasons, or characteristics of the major failures. The characteristic "does not open on command" makes up 8,3% of all major failures. Our reasoning may proceed like this: A typical SF_6 line breaker interrupts 20 times per year, and fails once in 100 years, i.e. once in 2000 operations. These failures are caused by stuck breaker (complete breaker or a pole) in around 10% of the cases, i.e. once in 20000 operations. And in only 20% of these operations the interruption of a line-charging current would be involved. It can be concluded, therefore, that the "stuck breaker" condition is extremely rare for no-load line switching operations and can be disregarded for the definition of the recovery voltage under this duty.

3. TESTING PRESCRIPTIONS OF IEC 60056

3.1. Probability of Restrike

The IEC Standard 60056 is currently undergoing a full revision by IEC Commission 17-A [1]. The testing prescriptions for the capacitive-current switching duty has been deeply modified under this process, and the most visible change introduced is the definition of two different test series, designed to demonstrate that the test objects have a "low" (class C1) or a "very low" (class C2) probability of restriking when interrupting capacitive loads.

The above-mentioned change reflects the recognition that restrikes are statistical phenomena. This stance underlines the incorrectness of the former procedure of classifying as "restrike-free" circuit breakers that would pass the previously-defined test series without any restrike. It is important, for the purposes of this paper, to draw the reader's attention to the restriking probabilities assumed in the new IEC classification. These figures are not stated in the standard, but can be roughly estimated considering that two test series are to be performed for each type of circuit breaker, each series comprising 48 opening operations (class C2 breakers) or 24 operations (class C1 breakers) (single-phase tests are assumed). Although the testing conditions are different for each test series, these roughly estimated probabilities will be defined here as inferior to 1/96 (class C2) or 1/48 (class C1), which would be the restrike frequencies if one restrike had taken place for each breaker class. These probabilities are, therefore:

- Breakers of low probability of restrike: < 2,08%;
- Breakers of very low probability of restrike: < 1,04%.

The test series defined in [1] for breakers of Classes C1 and C2 involve a large number of operations at minimum arcing time (a condition that maximizes the probability of restrikes): for Class C2, 12 out of 48 operations for each test series; for Class C1, 6 out of 24 operations. This means that in normal service, with arcing times randomly distributed, the restrike probability will be well below 1% and 2% respectively.

3.2. Overvoltages assumed

The above-estimated probabilities of course refer to the application of specific values of recovery voltage following current interruption. To model the maximum recovery voltage due to be found in each application the IEC establishes that in single-phase tests of line breakers of rated voltage 52 kV and above the rms test voltage measured at the circuit-breaker location before the opening shall not be less than the product of $U_r / \sqrt{3}$ and the following factors (U_r is the rated voltage of the circuit breaker):

a) Line-charging current switching in earthed-neutral systems:

- For tests corresponding to normal service conditions: 1.2;
- For tests corresponding to breaking in the presence of single or two-phase faults: 1.4.

b) Line-charging current switching in other-than-earthed neutral systems:

- For tests corresponding to normal service conditions: 1.4;
- For tests corresponding to breaking in the presence of single or two-phase faults: 1.7.

In single-phase tests the recovery voltages applied to the breakers will reach peak values twice as high as the above-indicated voltage factors, i.e. 2.4 , 2.8 and 3.4 pu of $U_r \sqrt{2} / \sqrt{3}$.

The values of these voltage factors indicate that IEC considers it necessary to reproduce, in the single-phase tests, the voltage-raising effects of the C_1/C_0 ratio and of a possible line fault, but does not make provision for any increase of the applied voltage due to a previous load rejection.

4. TYPICAL REQUIREMENTS OF SOME BRAZILIAN UTILITIES

Brazilian utilities usually specify test requirements for the line-charging interrupting duty of HV and EHV circuit breakers consisting of a crest value of the recovery voltage found after current interruption. Sometimes a two-parameter (u_c , t_3) or a four-parameter recovery voltage (u_1, t_1, u_c, t_2) is specified and, rather often, an overfrequency of 66 Hz. At least a utility uses to specify, additionally, an overvoltage factor relative to the conditions assumed before current interruption (k_b in formula 1). The rated line-charging switching current informed is presumably calculated on the assumption of this overfrequency, of the (over)voltage applied and of length of a standard section of line, which sometimes exceeds the length of the actual line section to be switched by the breaker (some utilities usually assume two successive line sections). The Table at the bottom of this column contains examples of typical specifications issued recently by four Brazilian utilities (A, B, C, D) for 550 kV circuit breakers.

The 550 kV systems of all the four utilities considered have earthed neutrals. It is worth noting that in the case of utility (A), the overvoltage factor specified is not given in pu of $U_r \sqrt{2} / \sqrt{3}$ (like the overvoltage factors specified by the IEC) but in pu of the peak value (phase to earth) of the normal operating voltage (525 kV rms, in the case). Therefore, the 1.5 pu factor actually corresponds to 1.43 pu of the base 550 $\sqrt{2} / \sqrt{3}$ kV.

5. DEFINING THE RECOVERY VOLTAGE FOR SPECIFICATIONS

When digital simulations of the line opening are performed with a suitable modelling of the line, of the system components and of the initial operating conditions, including or not events such as a fault or a load rejection, the voltage-raising factors present in each case influence the calculation results and the maximum recovery voltage may be reliably determined. The specifier may, therefore, proceed to specify directly this maximum recovery voltage without having to mention an overvoltage factor. If he wants to refer to this factor, its value should be defined as one half of the value of the maximum recovery voltage in pu of $U_r \sqrt{2} / \sqrt{3}$, or the immediately superior overvoltage factor defined in the IEC standard 60056 (see section 3.2 of this paper). The definition, in the specification, of the "actual" overvoltage applied to the circuit breaker before the opening (k_b) would not lead to the reproduction of the full recovery voltage in the laboratory, because some of the factors that may have caused voltage raises in the calculations (such as the Ferranti effect, capacitive and inductive interphase coupling and possible faults) are not represented in single-phase laboratory tests, which are normally used for EHV breakers.

Sometimes the lack of time to perform digital simulations leads the specifier to determine the maximum

	A	B	C (1)	C (2)	D
Line-charging switching current (A)	850	1100	500	1100	710
Frequency (Hz)	66	66	60	60	60
Overvoltage factor k_b (pu)	1.5	–	–	–	–
Peak value (u_c) of the recovery voltage (kV)	1460 (*)	1300	1078	1257	1030

(*) Four-parameter recovery voltage, consisting of:
u_1 = 1347 kV
t_1 = 7.5 ms (time to peak)

u_c = 1460 kV

t_2 = 60 ms (time to peak)

recovery voltage by means of hand calculation using formula (1), assembling together a few available pieces of information on the effect of the voltage-raising factors (sometimes assessed by studies performed for other system configurations) to determine the overvoltage factors $k_{a\square}$, k_{as} and k_b. This course is easily misleading, since many important influences / effects are frequently forgotten, e.g:

a) The voltage-raising effects of the capacitive coupling (the C_1/C_0 ratio) take place, essentially, on the line side of the circuit breaker only **after** current interruption and hardly affect the source-side voltage. And, as explained in section 2.1, even these effects on the line side will be limited following current interruption on the second and third poles to break. On the other hand, in what concerns the Ferranti effect, after the open line is dropped the voltage on the source side of the circuit breaker will actually revert to a lower value by way of the so-called "voltage jump" (section 2.2).

b) The reports on load-rejection studies generally inform the maximum values of the overvoltages calculated for each line considered. Although these maxima frequently differ significantly from line to line, it is not uncommon to find specifications issued on the assumption of the maximum of all values calculated, even when this value is higher than the ones expected on the lines that are actually going to be switched by the breakers under purchase. Another factor that is easily forgotten is that due to the Ferranti effect and other factors the maximum overvoltages to which lines are submitted normally occur close to the points of load rejection. These points are remote relatively to the position of the circuit breakers that may be called upon to interrupt the line-charging current. At these breakers' sites the overvoltages applied may be significantly lower, but their values are frequently omitted in the study reports, as a result of the planner's tendency to refer exclusively to the most severe values. Moreover, as the concern of the load-rejection studies is to assess the dielectric stresses on the equipment of the adjacent substations and the energy absorbed by the line surge arresters, the maximum values reported normally include the effect of the transients that follow the opening of the circuit-breaker at the remote end – which will probably be significantly or completely damped by the time the breaker at the sending end interrupts the no-load current.

c) In what concerns the overfrequency sometimes determined by a load rejection, it is worth noting that in hydroelectric power stations the speeding-up process of hydrogenerators may last up to 10s before the maximum speed allowed by their regulators is reached. Although a maximum frequency change between 30% and 40% of the rated value may be reached by the end of this period, the opening of a circuit breaker at the sending end of the line following the load rejection will most certainly happen well before the first second elapses. A proper determination of the overfrequency reached as a result of this acceleration at the moment the circuit breaker opens requires the use of a dynamic model of the synchronous machines in the digital calculating program. The frequency change determined by a load rejection at a point far away from any power station is normally quite smaller than that involving the opening of lines directly connected to a generating station. Some users tend, however, to overlook this fact and specify the same maximum overfrequency regardless of the circuit-breaker location.

6. SIMULATIONS AND RESULTS

Two recent papers [5, 6] have published results of digital simulations involving the calculation of the recovery voltages after the opening of the sound phases of no-load lines in the presence of load rejections followed by line faults in the Brazilian 500 kV system. In both cases the no-load lines considered are compensated by shunt reactors. In [5] the maximum value reported (1259 kV) corresponds to 2.8 pu of $550\sqrt{2} / \sqrt{3}$ kV, which is exactly twice the overvoltage factor of 1.4 recommended by IEC 60056 for systems with earthed neutrals. In reference [6] the maximum recovery voltage reported has a peak value of 880 kV, which corresponds to only 1.96 pu of $550\sqrt{2} / \sqrt{3}$ kV. This small value is determined by the fact that the no-load line considered is also compensated by series capacitors. The results reported in the same paper show that when the load rejections were properly simulated the recovery voltages were lower than in the cases in which a temporary overvoltage of 1.4 pu (base 429 kV, i.e. $525\sqrt{2} / \sqrt{3}$ kV) resulting from a previous (and unsimulated) load rejection was assumed.

The second paper [6] goes on to inform that for the particular breakers considered in the study a recovery-voltage withstand of 1300 kV for the charging-current interruption duty was specified (47.7% higher than the maximum value calculated), on the assumption that this was the standard value defined by IEC 60056 for earthed-neutral systems. Actually, for 550 kV circuit breakers the calculation of U_c (crest value of the recovery voltage) per the IEC rule, assuming a line fault), yields 1257 kV (= 2 x 1.4 x $550\sqrt{2} / \sqrt{3}$ kV).

Extensive load-rejection simulations involving the 500 kV system that extends from Serra da Mesa power station to the substations of Governador Mangabeira, Imperatriz and Samambaia, covering a large portion of the Brazilian territory, were performed in 1999 / 2000 by a Consortium of consulting companies for ELETROBRÁS, the major holder of generation and transmission utilities in the country [7]. Four different pessimistic load-flow conditions were selected and the input of the transients program (ATP) was adjusted so as to produce the same flows before the switchings were actually simulated. A total of 76 cases was processed, and the results indicated that except in a couple of situations involving very unrealistic assumptions the overvoltages determined by the load rejections were safe for the equipment insulation and for the surge arresters. In most of the cases a single-phase fault at the substation busbar was assumed before the opening of the circuit breaker that determined the load rejection. During the transient period, overvoltages as high as 1.9 pu of 500 $\sqrt{2} / \sqrt{3}$ kV (i. e. 1.41 pu of 550 $\sqrt{2} / \sqrt{3}$ kV) were obtained at the opposite line extremities. An assessment of the temporary overvoltages verified that their value was substantially stabilized around 150ms after the first current interruption, and that 300ms after the opening their peak values, in the great majority of the cases, were lower than 1.2 pu of 550 $\sqrt{2}$ / $\sqrt{3}$ kV.

7. CONSIDERATIONS ON BREAKER CAPABILITY

Due to the comparatively low currents and short arcing times, the stresses on a circuit breaker when switching line-charging currents are almost purely dielectric. After interruption of the current the contact system of the breaker poles will be stressed by the recovery voltages, and the breaker has to withstand these voltages in order to prevent restrikes. As shown in Fig. 2, the recovery voltage in the first pole to clear will have a (1-cos) shape, with some modifications due to interruption in the two other poles. The risk of getting restrikes is normally highest when the current is interrupted at minimum arcing time. In this case the peak value of the recovery voltage will occur at a relatively small contact separation, well before the breaker has reached the fully open position.

A number of factors influence the dielectric withstand capability of HV or EHV circuit breakers during the separation of their pole contacts. For breakers of SF_6 type, the main influencing factors are:

Geometry of the arcing contacts and the blast nozzles: In order to have a good dielectric withstand the contacts should be well rounded; the interaction between gas, metal and the insulating nozzle material should be controlled, and the electrical field along the surfaces of the insulating nozzles should be optimized.

Opening speed of the breaker: A high opening speed enhances the line-charging current interrupting behaviour, since the contacts will then be well separated at the time the peak value of recovery voltage is reached. There are, however, limits to how high the opening speed can be. A high speed requires higher operating energy in the mechanism, and also leads to high mechanical stresses in the mechanism and the linkage systems. A high opening speed also limits the time interval during which the circuit breaker will give full gas blast and have full extinguishing capability for short-circuit current.

Gas density and gas flow: In principle a high SF_6 gas density gives a higher dielectric withstand capability than that possible with a lower density. An upper limit for the density that can be used is determined by the onset of gas liquefaction at low ambient temperatures. Depending on the climate, the SF_6 gas density may be in the range of 0.5-0.8 MPa (abs) at 20^o C ambient temperature. The gas flow in the breaker during an opening operation also affects the dielectric withstand capability. There will normally be a dynamic pressure rise between the contacts due to compression of the gas, which is beneficial, but this effect may be offset by local areas with low pressure, or even eddies, caused by the the gas flow.

Wear of the contacts and nozzles: This factor will in general decrease the dielectric capability. For this reason, type tests to verify the line-charging current switching properties of a certain circuit breaker are more and more often made after some electrical wear of the breaker.

With proper design, a modern SF_6 breaker will be able to handle normal line-charging current switching stresses as specified by IEC, with one breaking chamber at 245 kV rated voltage, and two chambers at 550 kV rated voltage.

8. CONCLUSIONS

There are indications that many Brazilian specifications for the line-charging current switching capability of HV and EHV breakers are based on the addition of several more or less improbable events. The resulting requirements on recovery voltage are high, and often well in excess of the standard values specified by IEC. Such non-standard requirements may result in the installation of overrated circuit breakers which are more complicated, and considerably more expensive than those of standard designs.

Instead of specifying extreme recovery-voltage values, which will rarely be reached, it is more important to use a type-test procedure conceived to ensure that the circuit breaker will have a very low probability of restriking at the specified test voltage. In this respect the new fifth edition of IEC Standard 60056, which is soon to be published, introduces new more stringent test procedures.

Modern SF_6 circuit breakers are able to handle normal line-charging current switching stresses as specified by the IEC, with one breaking chamber at 245 kV rated voltage, and two chambers at 550 kV.

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