OVERALL BENEFITS OF CONTROLLED SWITCHING

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Summary

A general overview of the benefits offered by the use controlled switching of switchgear in HV and EHV electric power systems is presented. These benefits include enhancements of circuit breaker performance, reduction and control of switching transients, improvement of power quality and the extension of equipment life.

Keywords: controlled switching, circuit breakers, switching transients, switchgear.

1. Introduction

The benefits of applying controlled switching are technical and economical. Technical benefits include the reduction of the severity of switching transients and their effect on equipment and system life cycle and performance. Economic benefit assessment may be qualitative or quantitative.

2. Benefits for the Circuit Breaker

The main benefits of controlled switching for the circuit breaker are:

- Extension of circuit breaker life and increase in time intervals between interrupter maintenance or retrofit,
- Added value associated with circuit breaker performance enhancement during current interruption in the thermal or in the dielectric region.

2.1 Interrupter Wear and Life Extension

The main impact of controlled switching for the purposes of circuit breaker life is to reduce the magnitude of energization currents and the associated interrupter wear and to reduce the probability of occurrence of damaging restrikes.

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For SF_6 gas-insulated single pressure circuit breakers, interrupter wear refers to arcing contact erosion and nozzle ablation.

The source of arcing contact wear is the presence of a burning electrical arc across the contact gap, combined with mechanical abrasion due to breaker operation. Arcing contact erosion implies loss of material caused by vaporization, melting and burnoff. The main consequences are contact shape distortion and increase in surface roughness. Both of these effects influence the dielectric withstand characteristics of the gap.

Contact erosion is a complex phenomenon that depends on the following:

- contact material composition and micro-structure (manufacturing process),
- contact surface hardness and porosity,
- initial contact shape,
- arc current duration, amplitude, frequency and shape, and
- mechanical forces between the surfaces of the stationary and moving contact

Nozzle ablation generates an increase in the internal diameter of the nozzle throat. The inside wall surface experiences flaking, burnoff and vaporization. The main effect of nozzle ablation is that it causes changes to the dynamic gas flow during interruption. In turn, this leads to reduced gas density across smaller contact gaps resulting in degradation of circuit breaker performance in the thermal region (short line fault, ITRV duties).

Assessment of the benefits for the circuit breaker involves an estimation of life extension or of the increase maintenance intervals. During its useful life, the breaker will interrupt a wide range of current magnitudes, with different waveshapes, frequencies and arcing times. Most manufacturers provide information about the maximum allowable number of interruptions that a circuit breaker can perform for each current magnitude before scheduled maintenance or interrupter retrofit. These curves are based on a simple relation between the interrupted current and a maximum number of operations. They are calculated based

on a limit given by summation of integrals over arcing time of a series of current interruption duties defining the electrical life of the breaker. In most cases, this limit is defined as certain number of full short-circuit interruptions, v.g. 10, 15, 20. These curves cover the range from the rated symmetrical short-circuit current down to the continuous current rating of the circuit breaker. The maximum number of operations below the continuous current is equal to the value tested for mechanical endurance. An example of such a curve is included in Figure 1.

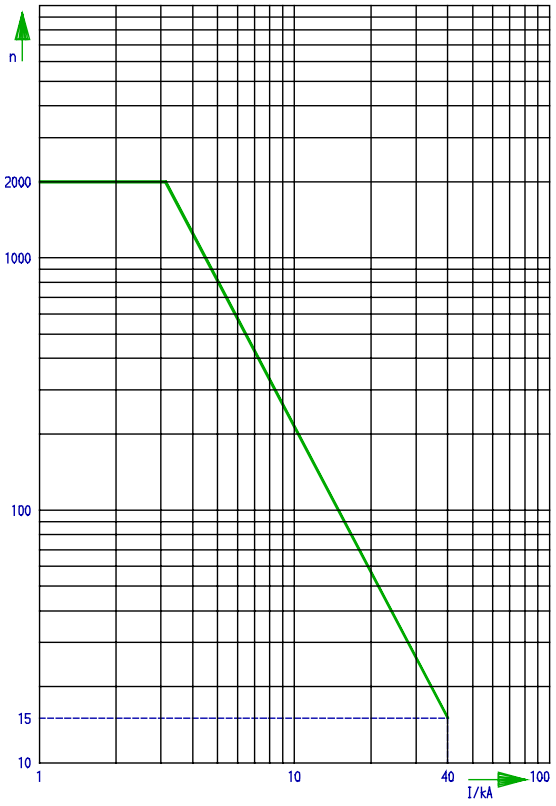

Figure 1. Maximum allowable number of interruptions with respect to the interrupted current.

The use of such charts implies a linear cummulative effect of the interrupter wear. Furthermore, it does not consider the effect of the interrupted current frequency. Nevertheless, it can be used to estimate the benefits of the increase of maintenance intervals as a result of reduced current magnitudes obtained by controlled switching.

Two cases are compared in Figure 2. The first case assumes maintenance intervals of 2000 operations, the second case assumes 2500 operations. Benefits can be calculated by comparing the present value (P_1 vs P_2) of maintenance costs during the useful life of the circuit breaker (M_i where i = 1, 2, ..5), which is assumed to be 10000 operations. Maintenance cash flows may be indexed according to estimations of future cost increases.

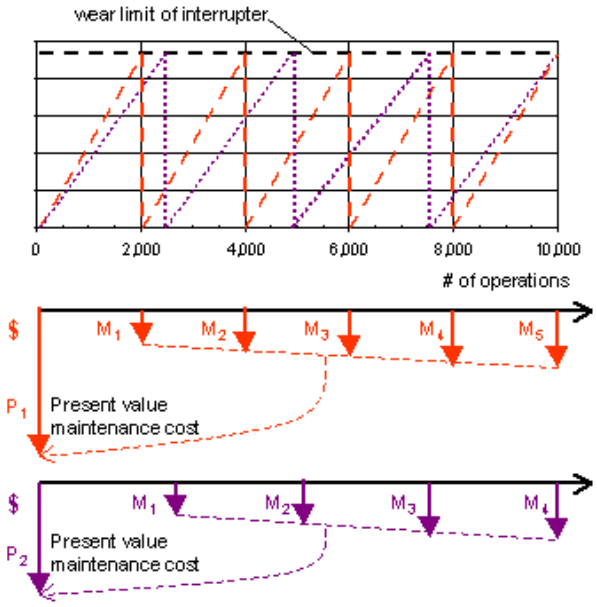

Figure 2. Comparison between the present value of the circuit breaker maintenance cost for maintenance intervals of 2000 and 2500 operations.

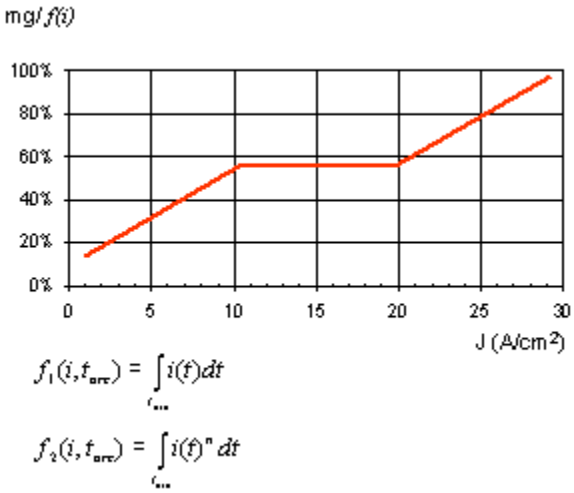

Figure 3. Arcing contact erosion rate in milligrams with respect to arc current density.

The definition of the interval between maintenance can also be expressed in terms of separate limits for arcing contact wear and for nozzle ablation. Arcing contact wear rates can be expressed in units of weight as a function of the current density in the arc as shown in Figure 3. Similarly, an ablation rate and limit in the increase of the throat inside diameter can be established. In the past, the latter dimension has been checked by inserting a gauge into the nozzle during routine inspection of some circuit breaker. As a result, maintenance may be necessary as soon as one of these limits is reached. Modern electronic circuit breaker monitors allow automatic tracking of the switching duty of the circuit breaker and enable the implementation of such methods.

2.2 Circuit Breaker Performance

Circuit breaker performance can be enhanced by improving the conditions during interruption. Improvements can be associated with the thermal or the dielectric regions of interruption. Controlled opening can be applied to reduce or increase the arcing time by targeting the instant of contact break by a determined period of time before the subsequent current zero crossing.

Consistent, lower arcing times during fault interruption can extend circuit breaker life. Control over the arcing time can also allow the application of circuit breakers for non-standard power systems. For example, it can be used to avoid long arcing times when interrupting fault currents in rail systems operating at 25 Hz. Controlled opening can also offer an alternative in cases where the asymmetrical short-circuit fault requirements are increasing. In the latter case, an additional time delay in contact part allows interruption of asymmetrical currents with higher X/R ratios (slower decay of the exponential component). The disadavantage of this alternative is the increase in the interrupting time.

In contrast, the use of controlled opening to permit longer arcing times results in greater contact gaps after current interruption. This may be applied to reduce the probability of a restrike, thereby enhancing circuit breaker performance in the dielectric region. Restrikes can rapidly degrade circuit breaker capabilities, e.g. leading to a nozzle puncture. The aim is to maximize the transient recovery voltage capabilities for the most severe duties like capacitive switching, out-of-phase switching.

3. Benefits for the Power System and Equipment

Transient control is probabilistic in nature. The transient magnitudes obtained follow a probability distribution. In this sense, controlled switching is similar to other methods such as pre-insertion resistors, pre-insertion inductors and permanent inductors. Other methods are stochastic due to changes in pole spread, random closing instants and associated initial conditions imposed on the transients. Controlled switching yields a probability distribution of operations affected by breaker characteristics such as mechanical scatter, electrical scatter and deviations of timing due to interval between subsequent operations. Deviations in the adjustments made for control voltage and temperature compensation also come into play. The result is a distribution of controlled operations around a target point on the voltage or current wave. Refer to Figure 4. Such characteristic can be translated into a probability distribution of currents and/or overvoltages.

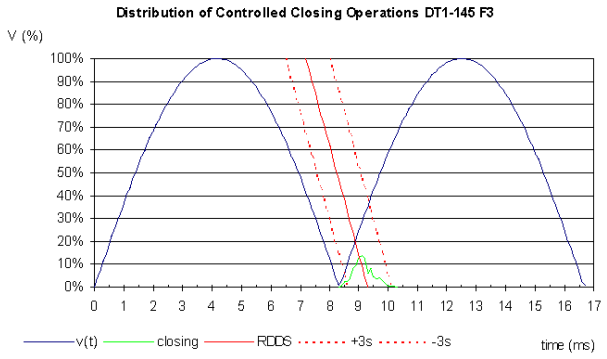

Figure 4. Probability distribution of controlled closing operations around the target for a shunt capacitor bank application.

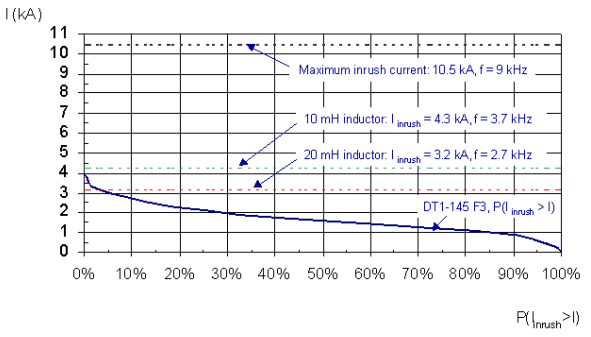

Figure 5. Probability of exceeding an inrush current value during back to back shunt capacitor closing.

In terms of electromagnetic compatibility, the suceptibility level of a system to switching transients can be compared to the magnitude of these transients and to their frequency content. This relationship in depicted in Figure 6. A similar relationship is used to describe insulation coordination when comparing dielectric withstand levels with temporary, slow transient, fast and very-fast overvoltage transients.

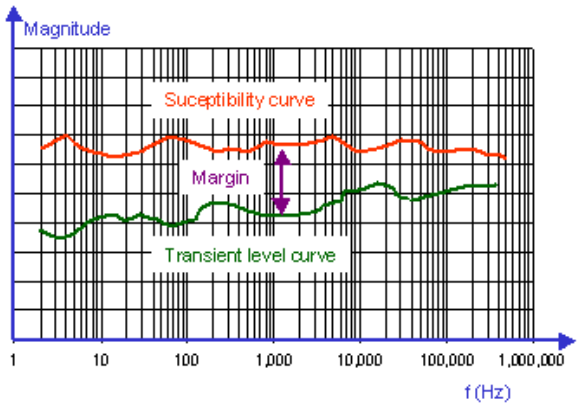

Figure 6. Comparison between the suceptibility of a system, equipment or electronic equipment and the transient level with respect to frequency.

The switching transient level curve is described by a probability distribution of transient currents and overvoltages. A line can defined with a certain associated probability of being exceeded (a common value is 2%) and then compared with levels of suceptibility of equipment or systems (local or remote effects) and of loads connected to the system (power quality).

The frequency dependance of the suceptibility curve derives from effects such as uneven voltage distributions in windings during the transient phase due to stray capacitances, increase in voltage drops across a grounding system at higher frequencies, among others.

Some technical benefits for the power system and equipment are:

- reduction of stresses on switched equipment leading to life extension,
- control of local transients in the substation,
- local surge supression, reducing possible coupling to the control and protection scheme.
- decrease in the severity of remote transients and their effects on sensitive loads.

Coupling of transients to control circuits in the substation occurs mostly through conduction. High currents flowing through conductors can cause inductive coupling. For very-high frequency transients, radiative coupling is present. Coupling effects are complex and specific to each location. They depend on the trajectories chosen for wiring and on the shielding efficiency of conduits and trenches. Conditions do not remain constant in time, for example, due to seasonal variations in the characteristics of the soil affecting the grounding system.

Coupling modes may be common or differential. In common mode surges couple to several conductors in the same trajectory. Differential mode coupling may be present in multiple ground connections where transient differences in the potential appear between points thought to be grounded.

Examples of effects on sensitive loads at the far end of transmission lines connected to the substation include power electronic devices such as motor drives used in manufacturing processes. Benefits from transient control on loads may be obtained by computing in economical terms the cost associated with loss of load or from the economic impact of process interruption.

4. Conclusions

Controlled switching offers an effective means of transient control and an attractive alternative to other traditional means of achieving this purpose. It may be applied as the sole solution or may be combined with other means, such as surge arrestors, to increase reliability.

Assessment of the benefits of controlled switching may be qualitative or quantitative. An example of the first case is the desire to acquire technical experience with this solution. Costs and alternatives vary depending on the situation. The effects of system growth in the severity of transients may be overlooked during the planning stage. An example is the installation of a shunt capacitor bank in one location leading to power quality problems. In existing installations, controlled switching may offer an advantage over other means of transient control, provided that the circuit breaker is suitable for this purpose. A typical example of life extension and reduction of maintenance costs is the use of controlled operation of circuit breakers performing reactor switching.