Reduction of Switching Over Voltages in H.V. Transmission Line

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Abstract — This synopsis presents the development of a knowledge base for reduction of switching transient over voltages in HV Transmission Lines. From this knowledge base, we can derive some practical rules for switching surge transients. These practical rules will be used in the proposed intelligent support system. These rules will be extracted by studying the switching transient phenomena in more detail. The knowledge base for switching surge studies solves the problem of selecting the proper models for representing power system components in the Electromagnetic transient program. It helps in checking the validity of the data used to represent the simulated transient phenomena, and gives some suggestions to the user to correct his case data before simulation.

Index Terms— Transmission Line, Over Voltage, Controlled Switching, Power Frequeny, Energization, Simulation.

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1 INTRODUCTION

Till the time when the transmission voltages were about 220 kV and below, over voltages due to lightning were of very high order and over voltages generated inside the system were not of much consequence. In later years, with increase in transmission voltages from 400 kV and above, the over voltages generated inside the system reached the same order of magnitude as those of lightning over voltages or higher. Secondly, the over voltages thus generated last for longer durations and therefore are severe and more dangerous to the system. The switching over voltages depends on the normal voltage of the system and hence increases with increased system voltage. The insulation level and the cost of the equipment depend on the magnitudes of these over voltages. In the EHV range, it is the switching surge and other types of over voltages that determine the insulation level of the lines and other equipment and consequently, they also determine their dimensions and costs.

A transient occurs in the power system when the network changes from one steady state into another. This can be, for instance, the case when lightning strikes a substation directly. The majority of power system transients are, however, the result of a switching action. Load break switches and disconnectors switch off and switch on parts of the network under load and no- load conditions.

Switching events and system disturbances the energy exchanges subject the circuit components to higher stresses, resulting from excessive currents or voltage variations, the prediction of which is the main objective of power system transient simulation. The long transmission line energization can cause high over voltage stresses mainly along the transmission line but also in the supply network. A traditional method of limiting switching over voltages to acceptable levels is to use circuit breakers equipped with pre- insertion resistors.

The switching transient in a transmission system cannot be prevented as well as its total suppression is extremely difficult. However, its magnitudes have to be limited to become compatible with insulation level of the system equipment. Consequently, over voltage control measures have to be adopted providing suitable protection for the network.

The level of transient over voltage has a strong effect to power system reliability. The main operations that can produce switching over voltages are line energization and re- energization, capacitor and reactor switching, occurrences of faults and breaker openings.

Transmission line switching transient and its severity depend on the difference between the supply and the line voltages at the instant of energization. If energization occurs at an instant when the difference between supply voltage and the line voltage is high, a large traveling wave would be injected on the transmission line. IEC specifies one, two, or three BIL levels for each system voltage, thus giving the customer some room for adapting the BIL to the actual switching over voltage conditions.

The manufacturer is simply required to produce cables that satisfy the switching test voltages. To avoid cable failures due to Switching Over voltages, it is essential to keep the protective level provided by arresters within a safe margin.

For long transmission lines, traditionally the switching transient over voltages are limited through the adoption of pre-insertion resistors in the line circuit breakers but it presents a decreasing acceptance due to the high cost of implementation and maintenance.

The first alternative analyzed to replace closing resistors is the installation of metal oxide surge arresters (MOSA) at both line terminals. Another method to reduce the switching transient is synchronous switching. It is a method for eliminating transient over voltages trough time controlled switching operations. Closing commands to circuit breaker are delayed in such a way that contact separation will occur at the optimum time instant related to the phase angle.

Several solution methods have been proposed and applied to reduce switching over voltages, namely, pre-insertion resistors, pre-insertion inductances, permanent inductances, surge arrestors and controlled switching. Among these, controlled switching of circuit breakers has become an increasingly useful method for reducing switching over voltage.

CONTROLLED SWITCHING

Controlled switching is the term which is commonly used to describe the use of an electronic control equipment to facilitate operation of the contacts of a switching device at a predetermined point in relation to an electrical reference signal. There are also some other terminologies used for this technique such as "Synchronized switching" or "Point-on-wave switching".

In controlled switching technique, there are mainly two critical stages. Firstly, an optimum operation point on the reference voltage or current wave should be determined such that the resulting transient over voltage after operation is minimum. This task needs considerable attention, since the optimum operation point differs according to the type of the load to be switched.

Secondly, the instant to apply the related operation command to the circuit breaker should be determined such that the circuit breaker operates at the pre-determined point. In order to accomplish this task, operation times of the circuit breaker should be known. Even though circuit breaker operation times can be measured but environmental and operational parameters substantially effect operation times. Hence any controlled switching application should take these variations into account.

As a result, it can be said that operational details of controlled switching applications depends mainly on two factors; the type of the load to be switched and the operational characteristics of the particular circuit breaker to be used.

Power Frequency Over voltages in Power Systems

The power frequency over voltages occurs in large power systems and they are of much concern in EHV systems, i.e. systems of 400 kV and above. The main causes for power frequency and its harmonic over voltages are

(a) Sudden loss of loads,
(b) Disconnection of inductive loads or connection of capacitive loads,
(c) Ferranti effect, unsymmetrical faults, and
(d) Saturation in transformers, etc.

Control of Over voltages due to Switching

The over voltages due to switching and power frequency may be controlled by

a) Energization of transmission lines in one or more steps by inserting resistances and withdrawing them afterwards,
b) Phase controlled closing of circuit breakers,
c) Drainage of trapped charges before reclosing,
d) Use of shunt reactors, and
e) Limiting switching surges by suitable surge arresters.

(a) Insertion of Resistors

It is normal and a common practice to insert resistances R in series with circuit breaker contacts when switching on but short circuiting them after a few cycles. This will reduce the transients occurring due to switching. The pre-insertion of suitable value resistors in practice is done to limit the over voltage to less than 2.0 to 2.5 p.u. normal time of insertion is 6 to 10 ms.

(b) Phase Controlled Switching

Over voltages can be avoided by controlling the exact instances of the closing of the three phases separately. But this necessitates the use of complicated controlling equipment and therefore is not adopted.

(c) Drainage of Trapped Charge

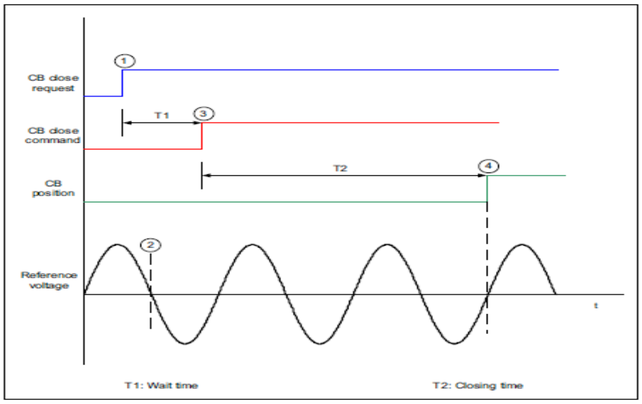
When lines are suddenly switching off, "electric charge" may be left on capacitors and line conductors. This charge will normally leak through the leakage path of the insulators, *etc*. Conventional potential transformers (magnetic) may also help the drainage of the charge. An effective way to reduce the trapped charges during the lead time before reclosing is by temporary insertion of resistors to ground or in series with shunt reactors and removing before the closure of the switches.

(d) Shunt Reactors

Normally all EHV lines will have shunt reactors to limit the voltage rise due to the Ferranti effect. They also help in reducing surges caused due to sudden energizing. However, shunt reactors cannot drain the trapped charge but will give rise to oscillations with the capacitance of the system. Since the compensation given by the reactors will be less than 100%, the frequency of oscillation will be less than the power frequency and over voltages produced may be as high as 1.2 p.u. Resistors in series with these reactors will suppress the oscillations and limit the over voltages.

Controlled Switching Applications - General Phenomena of Controlled Switching

Controlled switching is a method used to eliminate harmful transients generated by switching operations. In this technique opening or closing commands to the circuit breaker are delayed in such a way that current interruption or initation occurs at a pre-determined point on an electrical reference signal, i.e. voltage or current waveform.



Sequence of events for controlled switching in this example is as follows;

a) Circuit breaker close request is received at point 1
b) In order to determine the target point, next voltage zero is detected at point 2
c) Knowing the circuit breaker closing time and power system frequency, target voltage zero is identified
d) Time to give close command to the circuit breaker is estimated, and the close command is applied at point 3
e) Contacts of the circuit breaker touches at target voltage zero at point 4

Controlled switching of overhead lines

Reduction of switching over voltages associated with unloaded line switching is one of the earliest proposed applications of controlled switching. Transient over voltages are encountered in both opening and closing operations in overhead line switching, and controlled switching methods can be applied to both operations. Controlled switching can also be used to eliminate restikes by increasing the arcing time.

Benefits of controlled switching

Application of controlled switching provides benefits in both technical and economical aspects.

1. **Circuit Breaker Lifetime Extension -** Controlled switching methods can be used to minimize interrupter wear by controlling arcing and pre-arcing time. Minimizing interrupter wear proposes extension of circuit breaker life, longer maintenance periods and thus lower maintenance costs. Also controlling arcing and pre-arcing times provides a Possibility of using more compact and cheaper circuit breaker designs.

2. **Elimination of costly auxiliary equipments such as closing resistors.** Elimination of these auxiliary equipments provides reduction not only in circuit breaker cost but also in maintenance costs. Limitation of switching over voltages proposes reduction in insulation level and thus cost of power system equipment. This is especially important for overhead lines, where insulation cost is considerable. With the use of controlled switching, it is possible to use more compact tower designs and less string insulators in overhead line construction.

SIMULATIONS AND RESULTS

In this section actual simulations performed and results are shown. The Transmission line used is 400 km long. This Line is divided in four equal parts of 100km to observe the values of voltage at different distances on the transmission line.

Over voltages at time of Energization of transmission line:

At the time of energization of transmission line over voltages occurs due to the switching operation of circuit breakers. There are several techniques to reduce these over voltages to acceptable level methods like Surge arresters and controlled switching of circuit breakers are used in the simulations performed. Following are the simulation results for different condition considered.

Without using any techniques for Over voltage reduction:

At the both ends Transmission line connected with 400V Voltage source and two circuit breakers used t the both the ends to isolate the line from source. Circuit Breaker is closed at time 0.2sec and behavior of line is observed for energization. Graphs for Sending and Receiving end voltages are observed as follow. These are the voltages at the time of energization of the transmission line maximum voltage is around 536 kV.

Applying Controlled switching for C.B. for Over voltage reduction:

Now to apply controlled switching three different C.B poles are switched individually. Three poles of C.B. are switched separately when the voltage across the contacts of pole is zero. Following graph can show the moment of switching of each pole.

Over voltages at time of Re-energization of transmission line:

More sever values of voltages along transmission line can be occurred at the time of re-energization of transmission line. Following are the results and methods to reduce those over voltages.

With using surge arrester and controlled switching for Over voltage reduction:

Now for the given line both the techniques surge arresters and controlled switching techniques applied and results are observed.

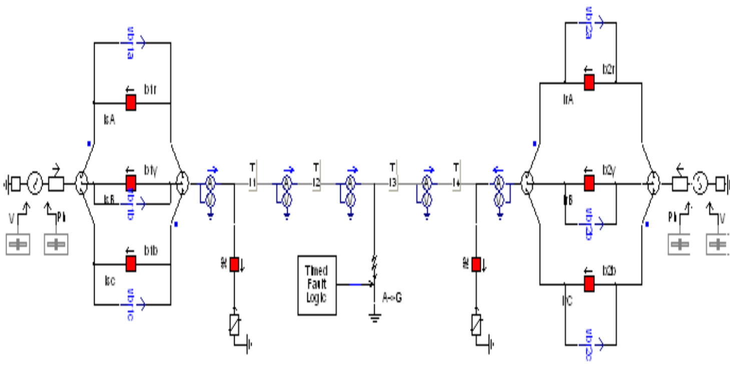


Figure 4.17: Model to apply controlled switching at time of re-energization

Graph showing the switching instant of each pole of circuit breaker for both side circuit breakers. Below is the comparison of maximum over voltage appearing at different distances in line with applying different over voltage reduction techniques

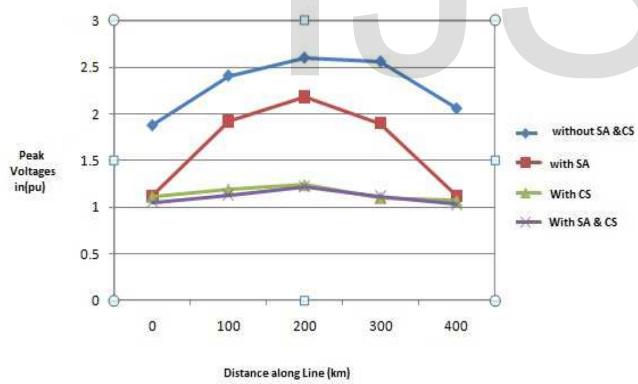
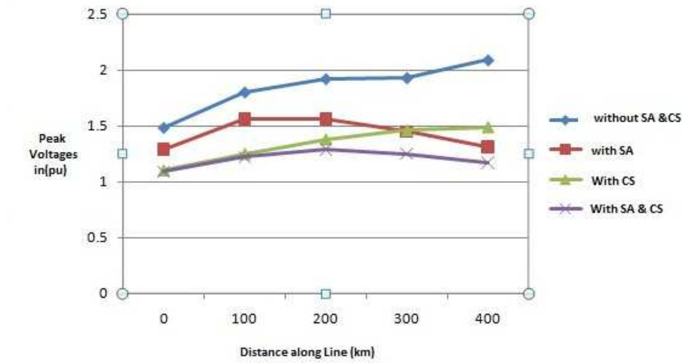


Figure 4.22: Comparison of over voltages for different conditions at time of re-energization

Above graph shows that switching over voltages can be reduced to acceptable level by using surge arresters and controlled switching method at the time of re-energization of the transmission line.

Figure 4.29: comparison of over voltages for energization of line fed at one end for different conditions



For re-energization of transmission line given above result can be given as below.

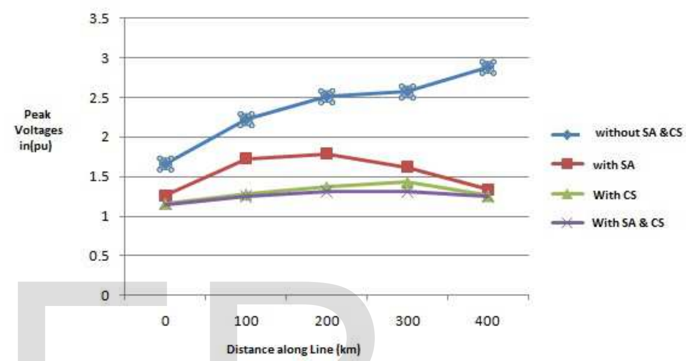


Figure 4.30: comparison of over voltages for re-energization of line fed at one end for different conditions

CONCLUSION

From above simulation we can conclude that controlled switching of circuit breaker is the best technique to reduce switching over voltages than any other method. Without using surge arrester or controlled switching peak over voltages can reach to 2.12 p.u. and even up to near 3.0 p.u. These voltages are very dangerous to the whole power system. If surge arresters are used at the both ends of the line these over voltages can suppressed by some level, peak value of voltage observed with surge arrester is 1.8p.u. By using controlled switching we can reduce these peak voltages to very low and sustainable level.

Using controlled switching peak value of over voltages is 1.31 p.u. Controlled switching provides several benefits in both technical and economical aspects like extended lifetime of circuit breakers and lower insulation cost of the power system equipments. Reliability of controlled switching applications cannot be assesses for the time being, because of the fact that the wide usage of this method does not reach more than last 10-15 years. The protection and control schemes including both controlled switching method and surge arresters provide a better result for transient over voltage reduction.

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Future Scope

Today controlled switching method is applied using an external control device (controller), which takes system voltage and current signals as inputs. Such external applications decrease the reliability of the method, since the cabling and the environmental conditions affect the operation of the controller. In the future it is expected that these controllers will be internal equipment provided as a standard feature of circuit breakers. Furthermore it also seems possible in the future that, controlling algorithms will be integrated in the substation protection and control systems, which leads to a result that the controlled switching will become a matter of software only.

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