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OVERVIEW OF SWITCHING OVERVOLTAGES AND THEIR MITAGATION

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ABSTRACT
Economy of most countries is growing every year, for which large sized resource based generating stations are required which are generally far away from load centres. To keep pace with the increase in generation, transmission system capacity had to be increased for transfer of this bulk power. To meet this requirement majority of the countries have adopted UHV AC transmission systems. In the UHV range, switching overvoltages decides the insulation level rather than lightning overvoltages. Therefore, in the insulation design of UHVAC transmission systems it is important to know the magnitude of switching overvoltages that affect the cost of a transmission system. Hence, in this paper the origin of switching overvoltages and types of switching overvoltages and different methods to reduce the magnitude of switching overvoltages are clearly discussed.
Keywords
- UHVAC transmission
- Switching Overvoltages
- Line Energization overvoltages
- Line Re-Energization Overvoltages
- Fault Initiation and Fault Clearing overvoltages

INTRODUCTION:
Economy of most countries is growing every year, for which electrical energy is one of the most important input. In order to achieve sustained development in any country, electricity growth should match the pace of economic growth.
The electricity dependent development causes an increase in power demand which necessitates additional power generating stations. In most countries, to meet the ever-increasing power demand and to ensure optimal utilization of unevenly distributed energy resources, development of large sized resource based generating stations in resource rich regions that are generally far away from load centres are required.
To keep pace with this increase in generation, transmission system capacity had to be increased for transfer of this bulk power over longer distances from remote generating stations to far-off load centres which necessitates large number of transmission corridors between generating stations and load centres. However, considering serious difficulties in the availability of Right-of-Way (ROW), phased development of transmission corridors, power losses in transmission corridors, increase in short circuit level and stability of the power system with large number of transmission corridors, majority of the countries have adopted UHV AC transmission systems between generating stations and load centres.
W. H. Croft et al. [1] and A. J. McElroy et al. [2,3] performed field tests on 345 kV transmission lines in the late 1950s which gave the first quantitative information on Switching Overvoltages (SOVs). Later, I.S. Stekolinikov et al. [4] and G.N. Alexandrov et al. [5] surprised the engineering

fraternity when they proved that the insulation strength of air (generally used as transmission line insulation) for switching overvoltages was lower than that of Lightning Overvoltages (LOVs) when the operating voltage exceeded 345 kV. Hence, their research encouraged other engineers to consider switching overvoltages for insulation design of Extra High Voltage (EHV) and UHV AC power transmission systems.

The magnitude of switching overvoltages depends on the system voltage and as the system voltage increases the magnitude of these switching overvoltages increase and hence cause a greater stress on the line insulation in EHV and UHV AC systems. Also, air insulation used for the transmission systems have relatively low withstand strength for these switching overvoltages [4-7] in EHV and UHV range. Therefore, switching overvoltages became the controlling factor in the insulation design of EHV and UHV AC power transmission systems rather than lightning overvoltages. Therefore, this paper presents the overview of switching overvoltages.

CHARACTERISTICS OF SWITCHING OVERVOLTAGES:

An electrical transient is the outward manifestation of the sudden change in circuit conditions, as when a switch opens or closes or a fault occurs on a system. Generally, a switching operation in a power system changes the state of the system from those conditions existing prior to switching to those conditions existing after the switching, this generates transient phenomena.

Switching transients usually exhibit complex waveforms for which the fundamental frequency usually lies in the range 100 Hz to 10,000 Hz but in some cases a very steep voltage rise or collapse can occur.

According to IEC 60071-1 [8] a standard phase to ground switching overvoltage waveform is shown in Fig: 1 and its wave front (time to crest) and wave tail (time to half value) are 250 µs and 2500 µs respectively. Switching overvoltage waveforms have a wide range of wave fronts from 20 µs to 5000 µs and wave tails of less than 20,000 µs.

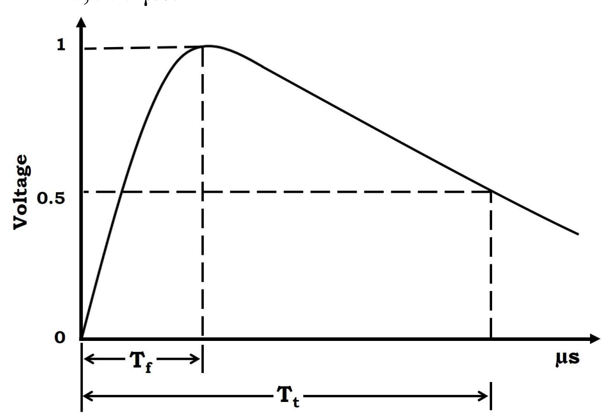

Fig: 1. Standard Switching Overvoltage Waveform

Switching overvoltages are also called as slow front overvoltages and are customarily expressed in per unit (p.u.) of the phase to ground peak steady state voltage. For example, for a 1200 kV transmission line 1 p.u. is 980 kV $\left(\frac{1200\times\sqrt{2}}{\sqrt{3}}\right)$.

TYPES OF SWITCHING OVERVOLTAGES:

In UHV AC power transmission system, the important switching operations which produce switching overvoltages are as follows:

- Line Energization (LE)
- Line Re-Energization (LRE)
- Fault Initiation (FI) and Fault Clearing (FC)
- Switching of EHV reactors

- Transformer switching with no load on the secondary
- Transformer switching with a load of shunt reactors on the secondary
- Switching of capacitor banks
- Load rejection
- Line dropping

However, the overvoltages produced during the switching of reactors and transformers may be limited by surge diverters and overvoltages produced by switching of capacitor banks, load rejection and line dropping are relatively small therefore, generally these switching overvoltages are not considered for the insulation design [9]. But, other switching operations like LE and LRE generally produce larger overvoltages. When the overvoltages produced by LE and LRE switching operations are controlled to values below 2 p.u., then the overvoltages produced by FI and FC switching operations require careful examination if they are not controlled to the same degree [6,9,10]. Hence, in this paper the overvoltages produced by these four types of switching operations are presented.

LINE ENERGIZATION OVERVOLTAGES :

Line Energization (LE) overvoltages are generated by the initial closing of a Circuit Breaker (CB) to energize an unloaded transmission line.

When the line is connected to the source, due to the voltage difference between both the ends of the transmission line, a voltage surge propagates along the line towards the receiving end and reflects at receiving end (open end) of the transmission line and causes an overvoltage.

LINE RE-ENERGIZATION OVERVOLTAGES:

Line Re-Energization (LRE) overvoltages may occur after a normal breaker opening or after a fault on the line, here, the former situation is used for representing LRE switching operation.

If the CB at the energizing end of a no-load line is opened then a charge will be trapped on the line due to the line capacitance. If the line is re-energized in the presence of the trapped charge, a higher overvoltage is seen because on re-energizing the power frequency voltage on the feeding point side superimposes on the residual voltage corresponding to the trapped charge across the CB gap.

The discharge of this trapped charge depends on the remaining equipment connected to the line after opening the CB at the energizing end of the line such as insulators and shunt reactors because they would drain off the trapped charge.

FAULT INITIATION OVERVOLTAGES :

The most commonly occurring fault on an overhead transmission line is phase to ground fault. Hence, this paper considered the Single Line to Ground (SLG) faults for Fault Initiation (FI) overvoltages because 90% or more of the faults experienced by a transmission line are SLG faults [7,11-17].

If a fault occurs on any one phase, then the CB operates to de-energize the transmission line and clear the fault, then at that instant there may be significant voltage swings, particularly on the un-faulted phases and these overvoltages are called as Single Line to Ground Fault Initiation (SLG FI) overvoltages.

When a single phase to ground fault occurs, then the faulted phase voltage changes to zero potential instantaneously which is the equivalent of injecting a voltage surge which is equal and opposite to the faulted phase voltage immediately before the ground fault. This surge voltage is induced to other healthy phases of the line and multiple reflections generated in the lines are superimposed on the AC waveform, leading to overvoltages.

FAULT CLEARING OVERVOLTAGES:

Fault Clearing (FC) overvoltages are the overvoltages that occur on the healthy phases or on the faulted phase while clearing a short circuit fault with a CB on the faulted phase.

These FC overvoltages are generated due to the change in voltage from operating voltage to temporary overvoltage on the healthy phases and the return from a value close to zero back to the operating voltage on the faulted phase.
FC overvoltages are the most severe overvoltages compared to all other overvoltages considered in this paper. These overvoltage magnitudes significantly depend on the type of fault. The fault clearing overvoltage magnitudes increase in the order of Single Line to Ground (SLG) fault, Double Line to Ground (DLG) fault, and Three phase Line to Ground (TLG) fault [11,18-20]. The TLG fault clearing overvoltage is higher because the recovery voltage is high.
Other important faults that occur on the transmission line are Three phase Short Circuit (TSC) faults. These faults to a large extent are caused by bush fires or other fires under the line.

REDUCTION OF SWITCHING OVER VOLTAGES:
Generally, the following methods are used to reduce the magnitude of switching over voltages.

- Use of Pre-insertion resistors (PIRs)
- Phase controlled closing of circuit breakers
- Use of shunt reactors

PRE-INSERTION RESISTORS:
It is normal practice to insert resistance R in series with circuit breaker contacts when switching on but short circuiting it after a few cycles. This will reduce the magnitude of switching overvoltage. In general, the value of resistance is equals to the surge impedance of the transmission line and its insertion time is 6 to 10 ms.

PHASE CONTROLLED SWITCHING :
The magnitude of switching overvoltages can be reduced by controlling the exact instant of the closing of the three poles of circuit breaker. But this requires complex controlling circuit to control the closing instant of the three poles of circuit breaker. Therefore, most of the power transmission systems are not adopted this method.

SHUNT REACTORS :
The primary reason for applying Shunt Reactors (SRs) to UHV AC power systems is to absorb line charging MVAR and consequently reduce the Ferranti effect and secondary reason is to reduce the magnitude of SOVs.

CONCLUSION:
In this paper, why switching overvoltages decides the insulation level rather than lightning overvoltages is clearly explained. This paper also clearly discussed the characteristics of switching overvoltages, the switching operations which generates the switching overvoltages on the transmission system and the important types of switching overvoltages which should be considered while deciding the insulation level of transmission system and different methods to reduce the switching overvoltages.

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