Executive Summary

Of

the thesis entitled

ANALYZING OVER VOLTAGES BY FREQUENCY DEPENDENT LINE MODELING FOR DESIGNING INSULATION COORDINATION OF ULTRA HIGH VOLTAGE AC SYSTEM

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INTRODUCTION

Insulation coordination, as defined by the International Electrotechnical Commission, "involves selecting the electric strength of equipment and its application in relation to the voltages which can appear on the system for which the equipment is intended, taking into account the characteristics of available protective devices in order to reduce to an economically and operationally acceptable level the probability that the resulting voltage stresses will cause equipment failure." A good coordination of insulation requires two stages of research: an analysis of the many overvoltage situations the power system faces and a broad evaluation of insulation performance under those circumstances. In light of the findings of those research, the coordinating effort for insulation intends to specify the following:

1. The electrical strength of all system components' insulation
2. The clearances from phase to phase and phase to ground
3. The external insulators' leakage distance
4. The ratings, kind, quantity, and positioning of surge arresters as well as any other potential protective spark gaps.

It is helpful to categorise a power network's insulation according to location and dielectric performance when using insulation coordination. Insulation is categorised as either internal or external depending on where it is used. Insulation can be self-restoring or Non-self-restoring, which describes its dielectric performance. International standards have been developed for calculating acceptable insulation levels in relation to operational voltages to help with the planning and coordination of insulation for a power system. These limits are based on the anticipated overvoltages that could be caused by lightning and switching surges, as well as the occasional power-frequency malfunction. These disturbances must be estimated during the power system's comprehensive design. This is an extremely intricate procedure that depends on numerous variables like Temporary overvoltages brought on by faults, load rejection, line energizing, resonant circumstances, ferroresonant frequencies, Switching (slow-front) overvoltages that are caused by switching operations, fault initiation, or remote lightning strokes, Lightning (fast-front) overvoltages that are caused primarily by lightning strikes but can also be caused by some switching operations or fault initiation, Very fast-front overvoltages that are the result of switching operations or faults and are usually associated with high voltage disconnect switch operation, GIS, and cable connected motors.

The insulation's dielectric strength is influenced by many elements. Such elements consist of:

- the magnitude, shape, duration, and polarity of the applied voltage;
- the distribution of the electric field in the insulation, such as whether it is homogeneous or non-homogeneous,
- the electrodes next to the gap under consideration, and their potential;
- the type of insulation, such as whether it is gaseous, liquid, solid, or a combination of these.

- Quantity of impurities and existence of regional inhomogeneities;
- the physical condition of the insulation, including its state in relation to temperature, pressure, and other external conditions, mechanical stress, etc. The insulation's history may also be significant:
- surface effects of the conductor, chemical effects, and stress-induced deformation of the insulation.

The gap arrangement, as well as the polarity and waveshape of the applied voltage stress, have a significant impact on breakdown in air. In addition, regardless of the shape and polarity of the applied stress, relative air conditions have an impact on the breakdown strength.

For Designing Insulation Coordination of UHV Transmission system using frequency dependent line modelling, It is necessary to understand the physical geometry of the line in order to get the surge impedance (or admittance) and line propagation matrix. Convolution, which is analogous to multiplication in the frequency domain, is needed to obtain the time domain response. The use of recursive convolutions makes this possible in a time-effective manner. This is accomplished by minimising the square of the frequency-domain function formed by the propagation constant and the frequency-dependent surge impedance.

The necessary equations should first be examined in the frequency domain because the line parameters are functions of frequency. Curve fitting should be heavily utilised to incorporate the frequency-dependent parameters into the model. The characteristic impedance Zc and propagation constant are two crucial frequency-dependent factors that affect wave propagation and are expressed as frequency-dependent continuous functions that must be fitted with a rational function, as opposed to being observed in the frequency domain and considered separately for each frequency.

Therefore, travelling wave transmission line models are preferred for all except very short transmission lines. A frequency transmission line dependent model will be employed if frequency dependence is significant. To precisely determine the frequency-dependent electrical properties of the line, information about the geometry of the transmission line and conductor data are then needed. The line's quickest reaction time must serve as the foundation for the simulation time step. Various models of frequency-dependent multiconductor transmission lines exist. On the assumption that the transformation matrix between the phase and mode domains is frequency independent, a typical model is constructed.

Problem Description and Research Gap

For Designing Insulation Coordination of UHV Transmission system using frequency dependent line modelling in terms of computation needs, a full representation of the entire power system is not a workable idea. In most cases, just a small portion of the system needs to be accurately modelled, with the remainder being represented by an acceptable equivalent. However, due to the presence of other frequency components, for transient simulation, it is not adequate to utilize an analogous circuit based on the short-circuit level at the fundamental frequency. The link between the time and frequency domains provides the basis for building a practical frequency-dependent model. When looking at the time domain, the input excitation is combined with the impulse response of the system. To ensure an exact time domain solution, the frequency response must be accurately represented; otherwise, the convolution reduces to a multiplication in the frequency domain.

The behaviour of the external network across a variety of frequencies must be represented by an effective equivalent. The phenomenon being studied, and consequently the expected frequencies involved, determine the necessary frequency range. The original models used a suitable network of R, L, and C components to represent the external system, with values for these components chosen to produce a frequency response that was identical to that of the external system. The frequency response that can be expressed is constrained by these methods, but they can be implemented in transient programmes that are already in use with little modification. To replace it, we prefer a more general alternative based on rational functions (in the s or z domains). The following processing processes are involved in the development of a Frequency Dependent Network Equivalent (FDNE):

- The impedance or admittance response of the system can be derived from this equivalent.
- Parameter fitting for a model (identification process).
- Transient simulation software with FDNE implementation.

Since the FDNE is incapable of representing non-linearities, any component displaying significantly non-linear behaviour must be omitted from the processing. As a result of every non-linear component being linked to a new port, the equivalent will have more ports. The models of individual components can use the same identification approaches, despite the focus being on frequency dependent network counterparts. For instance, the equivalent of a frequency-dependent transmission line can be derived by fitting a suitable model to the frequency response of the admittance and propagation constant of a characteristic transmission line (or cable).

Motivation

For Designing Insulation Coordination of UHV Transmission system using frequency dependent line modelling, primary factors in deciding how far from the disturbance the equivalent should be situated are as follows:

- locations throughout the system where it is needed
- reliability of the synthetic FDNE
- the reliability of the transient simulation's frequency response to the model's components
- topology of power distribution system
- explanation of where the disturbance is coming from.

Any assumptions based on the assumption of a remote FDNE location must contain detailed models of the intervening components, and these approximations must be separated by several busbars. Here, it helps if the FDNE is located somewhat close to the point of disturbance. Additionally, the features of the transient simulation software will play a role in determining the precise location of the FDNE. The power system is divided into two regions: the first is the region that requires detailed modelling, or the area immediately surrounding the disturbance's source and other regions of focus; the second is the territory now occupied by the FDNE. The entire system ought to be scanned for frequencies during the reduction process. How to determine whether a suitable system representation has been included is the challenge at hand. To do this, one must assess how closely the response of the system entered corresponds to the response of the entire system. An analysis of the frequency response's sensitivity to changes in component count, ending when the resulting shift is significant, minor are two potential methods for making a choice. Due to standing wave effects, the combined harmonic impedances of small loads fed by transmission lines might be low, which can have a considerable impact.

Problem Statement

For Designing Insulation Coordination of UHV Transmission system using frequency dependent line modelling, the frequency scan and FDNE synthesis range will be determined by the problem under investigation. The frequency scan range, however, should always be larger than the highest frequency of the phenomenon under investigation. In addition, the first resonance above the maximum frequency being examined should be included in the scan range as it impacts the frequency response in the upper portion of the necessary frequency range. To ensure that all the peaks and troughs are precisely identified, choosing the gap between frequency points is another crucial consideration. If optimization techniques are used, this will also influence the number and placement of frequency points utilized in LSE computations (least square error). Interpolation can be used to determine the system reaction at intermediate points; this is computationally more effective than directly determining the response using smaller intervals. The system response produced at intervals of 5Hz and cubic spline interpolation is nearly identical to that obtained at intervals of 1Hz, which is more than sufficient for most designs. However, both the real and hypothetical components of the system response require the use of cubic spline interpolation. The foundation of the FDNE is the calculation of the transfer impedance (or admittance) matrices at the boundary busbars for the desired frequency range, based on the external system's driving point. This can be done with experimental data if it is available; but, in most cases, time or frequency domain identification procedures are necessary. Frequency domain identification can use data from either time or frequency domain simulation to determine model parameters & model parameters finalise the optimised design of insulation coordination.

Objectives

The objectives of the research work are as follows:

- To study the overvoltages for ultra high voltage AC transmission system with their details regarding causes of their origin & their effects on transmission system performance, along with justified solution for them.
- To determine the transmission system parameters by using frequency dependent transmission line model, the simulation of Transients are utilised, which are valid for a frequency range from DC to

several MHz & the results from transient simulation are used for suggesting design for Insulation Coordination of UHV Transmission system.

- To estimate the design parameters for insulation coordination of ultra high voltage AC transmission system using statistical & deterministic approach.
- To estimate the design parameters for insulation coordination of ultra high voltage AC transmission system using ElectroMagnetic Transient Program (EMTP).
- To estimate the design parameters for insulation coordination of ultra high voltage AC transmission system using suggested novel approach.

Scope

For Designing Insulation Coordination of UHV Transmission system using frequency dependent line modelling, it is required to perform a transient analysis on the system & it is necessary to first use steady-state time domain signals, and then it is necessary to use the discrete Fourier transform in order to generate the Frequency Dependent Network Equivalent (FDNE). The ability to easily define the arbitrary frequency response of any given power system component is an advantage that can be gained by producing the system nodal admittance matrix at each frequency. It is generally agreed that the transmission line is the component that is most sensitive to changes in frequency, and this sensitivity can be determined with a high degree of accuracy. Because there is a shortage of exact data, other components of the power system are not currently represented with the same level of accuracy.

In three-phase mutually linked systems, the admittance matrix must be fitted as a function of frequency rather than a scalar admittance. Even if the fit of each matrix element may be stable, fit errors might cause the entire system to be unstable at certain frequencies. As a result, the solution is to make sure that the system of fitted terms is stable rather than fitting each member separately. The fitting error has a tendency to spread out over the frequency range when using least squares fitting. Although this produces a strong transient response, the steady-state inaccuracy is modest but distinct. weighting the fundamental frequency is possible. The steady-state error is eliminated by giving the fundamental frequency a larger weighting (usually 100), but the transient response is significantly worse as a result of higher errors at other frequencies. An effective analytical tool for circuit phenomena in power systems is the Electromagnetic Transients Program (EMTP). With the use of EMTP, surge problems in a high-frequency region and steady state voltage and current distribution at the fundamental frequency can both be solved. To obtain accurate results, relevant models and adequate parameters must be used. Numerous comparisons between the output of calculations and the actual data that was captured are made, and the accuracy of EMTP is reviewed.

Research Methodology For Work Done

The UHV system requires affordable, dependable transmission lines and substations. Overvoltages generated in the system, ranging from lightning to power frequency voltage, should be suppressed to a tolerable level for rational insulation design of equipment. On the other hand, the extra expense needed to suppress overvoltages should be optimised for cheap power system design, and costs should be decreased by equipment downsizing. Transmission lines and substations are fully optimised for the UHV system both technically and economically. The UHV system requires affordable, extremely dependable transmission lines and substations that take environmental concerns into account. A acceptable standard for the insulation design of UHV systems should be established based on these system requirements particular to UHV systems. Complex methods are required to reduce system overvoltages to a manageable level. The type and length of insulator string are determined by factors such as switching or lightning surges, as well as continuous power frequency voltage and pollution. Type A contamination is distinguished from Type B contamination by a few key characteristics. IEC/TS 60815-1-2008 details the process of identifying different forms of pollution.

Outcome of Research Work

The suggested novel approach is described for determining various parameters for Designing Insulation Coordination of Ultra High Voltage AC System & Based on the obtained designed parameter mainly Surge Arrester Current (kA) and Residual Voltage (kVp), the design optimization has been done. A generalized approach has been presented for optimizing the design of insulation coordination for ultra high voltage AC transmission system. The standard withstand voltages for UHV equipment of 1100 KV are attempted and the range of withstand voltages that can be used for a particular maximum system voltage, upto 1200 KV are proposed based on the insulation coordination process & High Performance Surge Arrester and other Measures for Overvoltage Suppression are also proposed for system voltages of 1100 KV & 1200 KV. As a result, all five research objectives are solidly based on the gaps identified from the literature studies.

Objective 1:

To study the overvoltages for ultra high voltage AC transmission system with their details regarding causes of their origin & their effects on transmission system performance, alongwith justified solution for them.

Achievement:

The literature survey highlights that Ultra High Voltage Transmission system is affected by power frequency temporary overvoltages, slow front overvoltages like switching overvoltages, fast front overvoltages like lightning overvoltages on transmission lines, Substations & very fast front ovrervoltages, on gas insulated substations & proper selection of surge arrester with opening & closing resistor will provide solution regarding protection of power system.

Thus, the first objective is justified because existing methods do not provide a unified, optimized insulation coordination for UHV transmission system of 1100 KV & 1200 KV level.

Objective 2:

To determine the transmission system parameters by using frequency dependent transmission line model, the simulation of Transients are utilised, which are valid for a frequency range from DC to several MHz & the results from transient simulation are used for suggesting design for Insulation Coordination of UHV Transmission system.

Achievement:

According to the literature survey,, A frequency transmission line dependent model can be employed if frequency dependence is significant. To precisely determine the frequency-dependent electrical properties of the line, information about the geometry of the transmission line and conductor data are then needed. The line's quickest reaction time must serve as the foundation for the simulation time step. The frequency scan range, from DC to several MHz, however, should always be larger than the highest frequency of the phenomenon under investigation. In addition, the first resonance above the maximum frequency being examined should be included in the scan range as it impacts the frequency response in the upper portion of the necessary frequency range.

This objective directly aligns with the need for frequency dependent line modelling for designing Insulation coordination for ultra high voltage transmission lines.

Objective 3:

To estimate the design parameters for insulation coordination of ultra high voltage AC transmission system using statistical & deterministic approach.

Achievement:

The literature survey indicates that for modern UHV power system, the co-ordination withstand voltages are determined by calculating the lowest values of the withstand voltages of the insulation meeting the performance criterion when subjected to the representative overvoltages under service conditions. Statistical and deterministic techniques are both used to coordinate insulation against transient overvoltages. But many of the actually used procedures combine the two approaches. For instance, certain deterministic method elements were generated from statistical considerations, while certain statistical variances were ignored in statistical methods.The three types of insulation coordination techniques are deterministic, statistical, and reduced statistical techniques.The rated withstand voltage of devices is calculated using the deterministic technique, which multiplies the representative overvoltage and the arrester protection level by the necessary factors. According to the statistical method, the insulation coordination fulfils a statistically permitted failure rate when the overvoltage, insulation strength, or other elements are treated as random variables.

This objective is directly justified by the insulation coordination technique is needed which fulfils a statistically permitted failure rate when both the statistical overvoltage and the insulation strength are treated as normally distributed random variables, according to a simplified statistical technique. Simplified statistical approach is another approach for the procedure that conducts coordination using random variables such as insulation strength and arrester protection level.

Objective 4:

To estimate the design parameters for insulation coordination of ultra high voltage AC transmission system using ElectroMagnetic Transient Program (EMTP).

Achievement:

An effective analytical tool for designing insulation coordination for UHV power system is the Electromagnetic Transients Program (EMTP). With the use of EMTP, surge problems in a high-frequency region and steady state voltage and current distribution at the fundamental frequency can both be solved. To obtain accurate results, relevant models and adequate parameters must be used. Numerous comparisons between the output of calculations and the actual data that was captured are made, and the accuracy of EMTP is reviewed. [78] EMTP is utilised globally through such applications. Control functions can also be treated by EMTP in addition to main equipment.

So, objective of ElectroMagnetic Transient Program (EMTP) for Designing Insulation Coordination for Ultra High Voltage AC Transmission System is justified by ATPEMTP, programme that evolved from EMTP. ATPEMTP is able to increase its user capability with ATPDraw (which offers an intuitive, simple, and powerful graphical user interface) established.

Objective 5:

To estimate the design parameters for insulation coordination of ultra high voltage AC transmission system using suggested novel approach.

Achievement:

Mathematical Analysis & software outcome are evaluated, and it is concluded that It is crucial to lower the lightning flashover rate and assure the dependability of power transmission for UHV systems. Based on the equipment's estimated lifespan and the consequences of failure, lightning flashover rate is calculated. The allowable lightning flashover rate for UHV transmission lines is between 0.1 and 0.5 flashovers per 100 km-year, which is lower than for EHV systems. The allowable switching flashover rate for UHV systems is normally 0.1 flashovers per 100 switching operations, which is significantly less than the rate for EHV systems, which is 1 flashover per 100 switching operations. The mean time between failures—a measure of substation reliability—is typically used to specify the desired level of lightning protection (MTBF). The MTBF for EHV gas-insulated substations has been set as high as 800 years in IEEE Std 1313.2TM-1999 in order to reduce large outages and repair delays of substations. Given the significance of UHV systems, it is advised that the MTBF for UHV substations damaged by lightning be greater than 1000 years for GIS and MTS substations.

Thus, objective is satisfied by a unified, optimized insulation coordination approach for UHV transmission system of 1100 KV & 1200 KV level.

Research Contribution

The research primarily contributes that Ultra High Voltage Transmission system is affected by power frequency temporary overvoltages, slow front overvoltages like switching overvoltages, fast front overvoltages like lightning overvoltages on transmission lines, Substations & very fast front ovrervoltages, on gas insulated substations & proper selection of surge arrester with opening & closing resistor will provide solution regarding protection of power system.

To support the primary contribution, strategies are employed to develop frequency dependent line modelling for design of insulation coordination for UHV transmission system for which It is necessary to understand the physical geometry of the line in order to get the surge impedance (or admittance) and line propagation matrix. Convolution, which is analogous to multiplication in the frequency domain, is needed to obtain the time domain response.

The use of recursive convolutions makes this possible in a time-effective manner. This is accomplished by minimising the square of the frequency-domain function formed by the propagation constant and the frequency-dependent surge impedance. The necessary equations should first be examined in the frequency domain because the line parameters are functions of frequency. Curve fitting should be heavily utilised to incorporate the frequency-dependent parameters into the model. The characteristic impedance Zc and propagation constant are two crucial frequency-dependent factors that affect wave propagation. Zc and are expressed as frequency-dependent continuous functions that must be fitted with a rational function, as opposed to being observed in the frequency domain and taken into account separately for each frequency.

For designing insulation coordination of UHV transmission system, statistical & deterministic approach is utilised for determining various parameters described as above.

Finally novel approach is described for determining various parameters for Designing Insulation Coordination of Ultra High Voltage AC System & Based on the obtained designed parameter mainly Surge Arrester Current (kA) and Residual Voltage (kVp), the design optimization has been done. A generalized approach has been presented for optimizing the design of insulation coordination for ultra high voltage AC transmission system.

FUTURE WORK

1. Due to the existence of calcium sulfate in natural contamination, insulation can be significantly enhanced. However, salt deposit density (SSD) measured in field is not exactly the effective salt deposit density (ESDD) which leads to flashover. Consequently, influence of calcium sulfate should be considered in this study to determine the ESDD, which corresponds to the SSD in an artificial pollution test, named test salt deposit density.

2. According to the results of artificial pollution tests, the pollution flashover test curves of various profile insulators can be obtained in different SDD, i.e., the relationship between insulator flashover voltage and SDD.

3. Flashover voltage will be affected by factors such as the types of soluble and non-soluble salts, the adhesion density, as well as non-uniform distribution of contamination on insulator surface, etc. Therefore, those factors should be considered in determining the Critical Flashover Voltage, which is not considered in this study.

4. At various pollution levels, unified specific creepage distance (USCD) of insulators including post insulators should be determined and be testified by withstand test in fog according to design pollution requirements, which is not covered in this study.

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