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SYSTEM RESPONSE TO ELECTRICAL TRANSIENTS THROUGH FREQUENCY DOMAIN TRANSFER FUNCTION APPROACH

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Abstract----Using scaled down model of actual system the response of the parent system can be predicted. The transfer function is obtained by conducting laboratory experiment on scaled down model. It can then be used to estimate the response to any standard switching surge. The transfer function is in frequency domain so that unique response can be obtained for all frequency components of the desired pulse which can be then transformed to time domain.

Key words: transient, modeling, scaling, NEC-2, transfer-function

I. Introduction

Electrical transients are caused due to redistribution of stored energy in electrical and magnetic fields in the power system, or may get induced due to external phenomenon such as Lightning strike. In order to select the right rating of the device and also to build a reliable protection system it is necessary to have an optimistic estimate of the magnitude of the stress developed when a system device or apparatus is subjected to these transients. This paper discusses an transfer function approach in frequency domain to estimate the level of stress induced at desired measurement point in the system lighted by electrical surge either internally developed or external surge.

II. Methodology

The method is based on getting the transfer function of the system at the point of interest by measuring the system response at that point by conducting an experiment. The experiment is performed on scaled down model of the device or system such that all the electromagnetic parameters of the actual system are preserved. This is done by

Table 1 Scaling Factor for the Electromagnetic model [1]

Name of Quantity	Ratio in terms of k, Geometric scale factor
Length	l = k
Time	t = k
Conductivity	σ = 1/k
Dielectric constant	ε = 1
Permeability	μ = 1
Frequency	f = 1/ k
Wavelength	λ = k
Phase velocity	V_0 = k
Resistance	R = 1
Reactance	X = 1
Impedance	Z = 1
Capacitance	C = k
Inductance	L = k

The response of the actual system will be identical provided the time and frequency are correspondingly scaled. Further, upon measuring the response the transfer function is obtained by converting the data into the frequency domain. Now response of the system to any standard surge wave can be conveniently obtained by multiplying the frequency domain transfer function to the constituent frequency spectrum of the time domain standard waveform

The experimental set up using principal of electromagnetic modelling. Anderson et al. [1] have provided in detail the principle of electromagnetic modelling. Accordingly, for an electromagnetic model with a geometric scaling factor k, various quantities involved should be scaled accordingly. The principle of electromagnetic modeling states that using obtained FFT. The time domain response of the system then can be easily obtained by taking the inverse FFT.

III. Validation of the method.

In order to ascertain how far the frequency domain transfer function obtained by measured experimental data is successful in predicting the response to any desired input, results from validated public domain software are used. The software called NEC-2 [2, 3, 4] is successfully used to get the response of the systems struck by lightning. Electromagnetic Code (NEC-2) is widely used computer code in analyzing three dimensional electromagnetic field around antenna and scatterers in the frequency domain. NEC-2 solves integral equations at boundary numerically with Method of Moments (MoM). It has been employed for evaluation of the lightning surge response of tower and accuracy of the computed result was verified through comparison with experiments [5]. The Numerical Electromagnetic codes (NEC-2) have also been successfully employed for the studies on lightning interaction with elevated strike objects [6, 7]. Thus its effectiveness in the application to time domain analysis of lightning transients of a conductor system has been proved. The literature survey reveals that the results predicted by NEC agree with actual field measurements. It is a frequency domain code and requires geometric model of the system by using thin wire mesh. The geometric model is subjected to excitation and NEC predicts the the frequency domain response The flow of procedure of transient analysis in time domain using NEC-2 and FFT is shown in Fig1 [4] and all the transformation is carried out in MATLAB.

Thus if NEC predicted response, matches satisfactorily with that predicted by scaled down experimental setup response then it can be concluded that scaled down models depicts the actual system and response obtained can be used to predict the behavior of the system to any desired input in frequency domain.

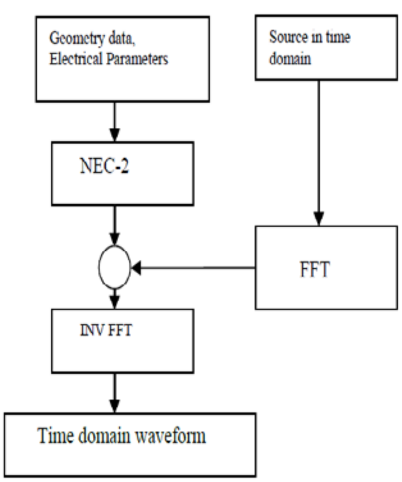

Fig. 1. Flow of procedure of transient analysis in time domain using NEC-2 and FFT [3, 4]

IV. Detail Explanation of the Method.

As earlier stated the first and most important step is to build the scaled down model of the system which very nearly imitates the actual system in the field [8]. All the crucial geometrical nodes in the parent system should feature in the scaled down model. This will to ensure that once the model is excited by the pulse in the laboratory the electromagnetic field structured is set up which will resemble the field structure at actual site, of course to a scaled down magnitude. Once this is accomplished the system response is measured at desired location using storage digital oscilloscope which is set to eliminate the noise and record the data faithfully. One of the methods is to set the measurement mode to the averaging mode so that the ambient noise is minimized or eliminated. The measurement of the source pulse and the response at the desired location thus measured is now processed.

First the data is converted to frequency domain using frequency analysis tools. The transfer function is then the response of the system to any set of constituent frequencies of response to any desired signal or surge. The flow is as shown in fig.2. The method is further illustrated by an experimental example.

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Since the transfer function is in frequency domain, it is an absolute response and it will predict

V. Experimental setup

In this experiment a conductor of 3.6 m length terminated with 350 Ω resistances is employed. The setup is in fig.3b. This termination impedance would almost eliminate the ground end reflection which makes the validation easier. It is excited by pulse as shown in fig.3a.

The Pearson make Model 2877 current to voltage converters, with 2 ns rise time, 200 MHz bandwidth with an output impedance of 50Ω, are used for the non-invasive measurement of various currents. These current monitors are connected to the oscilloscope with one-meter long Tektronix probes. The Tektronix Model TPS2024, 4-channel digital storage oscilloscope is employed for the measurements.

It has floating channels with 200 MHz bandwidth, 2 GS/s sampling rate and 8-bit resolution. The system is excited through a co-axial cable (Zo = 50Ω) connected to the function generator. Using the waveform generator a repetitive pulse excitation was imposed on the current lead wire. The resulting current had a time to peak of 5 - 10 ns and a pulse width of 200 ns. A repetitive pulse with 1 kHz repetition frequency is employed to arrive at best possible bandwidth and to eliminate noise in the measurement originating from extraneous sources.

VI. Result and discussion

It is evident from fig.3 that the agreement between simulated and experimental results is quite reliable. The measured ground end down conductor currents is as shown in the figure 3a. The system is also modeled in NEC-2 and response obtained. The response obtained using transfer function which is then transformed to time domain is also shown as simulation in fig 3a.

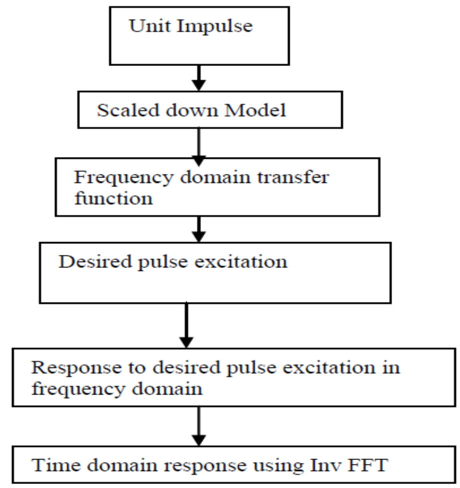
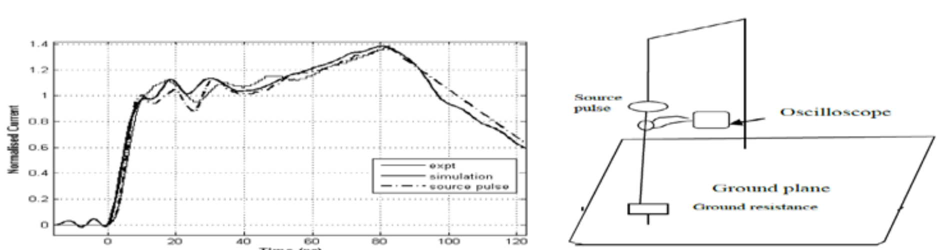


Figure 2. Flow chart to predict system response.

Thus method can be employed for getting response due to any standard excitation like switching surge, lightning surge etc notified by IEEE and IEC and by suitably using the scale factor corresponding to the geometry of the actual model.

VII. Conclusion.

The paper describes the method to estimate the response of the electrical system by using the experimental results on an scaled down model of actual system in frequency domain. The transfer function in frequency domain is obtained at measurement point. This then can be used to predict the response of the actual system to any desired standard surge at the same measurement point. Thus method successfully can be employed to predict the response in actual field scenario.



(a) Simulation and experimental results (b) Experimental Setup

Fig 3. Isolated down conductor excited at the top

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