Fault Transient Signal through Underground Cables: Analysis of Cable Components Effect on Transient Pulse

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Abstract

The behavior of electric power transient signal, in the high-voltage (HV) cables, is a significant problematic of real-world issues to the utility. Modeling this behavior with appropriate software is attractive attitude for most researchers, particularly in case of matching the calculated results with the real behavior. This paper introduces modeling and analysis of behavior of transient signal getting from treated and un-loaded underground cables via PSCAD simulating. A valuation of suitability of Bergeron and frequency dependent (FD) model (FD-mode model and FD-phase model) during transient within transmission cables is given. The fault transient signal and switching transient signal on the cable system are simulated and then presented. Through cable modeling, system parameters should be modeled in an accurate mode, like main core-conductor, main insulations, semiconductors, and cable sheaths. The transient signal sources are applied to 132kV underground XLPE cable system to examine the effects of cable parameters and external factors due to the transient signal behavior. Effect of each main component studied and its effect on the transient signal analyzed.

Index Terms Fault analysis, High Voltage Transmission Line, PSCAD/EMTDC, Transient Signal, Underground Cables.

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INTRODUCTION

Underground cables have become main prime in the transmission line systems, and now playing a vital role in the power distribution and transmission systems, both. However, due to a constant enlarge in opening underground cables have become widespread in the extended urban areas. Their permeation in civilized cities particularly, has compact visual impact comparing to the large overhead transmission lines.

In some cases, the enlargement in the overhead-lines becomes incredible because of the effect of political situation and environmental [1]. Subsequently, such advancements lead to make the underground transmission in a position of competitive with the overhead ones, based on each of the technical, environmental and economic levels.

Nonetheless, implementing underground cables has enormous impact on the power quality. Therefore, it became one of the most important topic that researchers and engineers dealing with its. The main reason of current transient and higher frequency of voltage is the energisation of an underground cable [2]. Behavior of such transient is determined by different structures. For instant, the transient extents and peak are estimated via closing of CB contacts and the value of angle on power signal of voltage frequency [3]. Also, voltage transient signal initiated significant anxiety on the cable insulation, and the system insulation of close by components. These anxieties might be resulted due to either extra transient and its big values or increasing incidences of small magnitude of over voltage. Therefore, it has become important to mitigate transient and unwanted phenomena effect[4].

The peak value assessment and transmission time of transient signal and waveforms are vital in the valuation of cable insulation and examination for fixing protection patterns. In this sense, to assure precise and reliable results via simulation model, it's decisive to employ dependable model of underground cable systems establishing an accurate frequency dependent cable model. Particularly, assessing of the transient behavior in the switching transient and transient fault source is an essential task in designing and developing of the underground-cable systems [5].

In general, effect of transient signals is mitigated through some defensive methods, like such protective device and technique [6]. In this case, a specific factors of these devices, like circuit breakers and other protective equipment's and techniques should be integrated through assessing the transient signal of some transient faults in the voltage signal within underground cables and networks [7].

Also, it is important to underline that electromagnetic transient signal should be study precisely due to it’s the most important event in the modeling and predicting faults in transmission lines. Subsequently, the main topic of the current study are modeling and electromagnetic transient signal simulation in order to examine its behavior.

The Electromagnetic Transients Program (EMTP) is one of the best widespread software methods implemented in the electromagnetic transient signal analysis. Base on the EMTP algorithm, the Electromagnetic Transients including (EMTDC) program was presented [8]. The computer aided design software, like the Power-Systems Computer Aided-Design (PSCAD) insures the simplicity of implementation to access and structure such software. The PSCAD /EMTDC software group nowadays is one of the best tools employed in transmission power systems, in particular in transient behavior of over-head and under-ground cables transmission systems [9].

EMTP-type suites have a lot of faithful models which could be employed in underground cables. The models that have been chosen in this paper are frequency dependent model. Furthermore, this has been devised, to model transient analysis. Minimal precise action on exists model on underground cable has elevated queries related to their usefulness and dependability, while implementing this model in underground cables. Nevertheless, the implemented method, only offers and applied within single phase energisation. Of late, Nichols *et al*[10] have conducted a realistic assessment by investigating a lot of pictures of frequency dependent model, like, Semlyen [3] methods which implemented with the 3-phase case. In this study, both, 3-phase and single-phase can be implemented.

The main aim of this study is to perform and analysis the transient signal behavior within underground cable system. So, to investigate the effects of various factors influences the transient's amplitude and propagation time of 132kV underground XLPE cable.

FREQUENCY DEPENDENT MODEL

Frequency dependent model is considered as distributed traveling wave model. Nonetheless, the distribution of the model resistances R is distributed along the line extension (lengthways of L and C) rather than being gathered in the end points. What is further important is that the solution of the FD model which transpires at a different frequency plugs. There are two available models in PSCAD in terms of frequency dependent model. The frequency dependent (phase) model is considered as the precise and exist model because it takes into consideration the frequency dependent of interior transformations matrix (in so doing perfectly demonstrating un balanced, and balanced system). According to the traditional frequency dependent (mode) model, a fixed transforming is assumed and consequently, the accuracy is achieved in case of balance system model acquired. The frequency dependence models attempt hard to achieve representation of the complete frequency dependent of underground cable model. In like case, the time consumed by the frequency dependent models in solving is longer than that consumed by the Bergeron model [11], however they are required for tracking and demanding a deep details that represent the transmission system along wide frequency ranges. These models differ from the Bergeron model since they reflect the representation of the value of total resistance "R" as a distributed constraint, thus, achieving better outcomes in terms of accuracy. As mentioned above, PSCAD introduces two modes of frequency dependent model:

A. The Frequency Dependent (Phase) model.
B. The Frequency Dependent (Mode) model.

However, frequency dependent Phase model is the most precise one, due to its presented fit results as compare to frequency dependent mode model.

A. The Frequency Dependent (Phase) model.

In the last three decades, the requisite for developing or designing a model represents underground cable and at the same time capable of carrying out or performing accurate simulation was first time performed. This design focusing on all of unattractive interfaces concerning DC and AC line and the extensively unpredictable modal time-delay in underground cable was of great significance. Previous studies showed that the frequency dependent mode depends on the fixed transformation matrices based on PSCAD was concern in dealing with time-delay modal's tricky in transmission system. However, they hadn't been apparent of existence consistent in accuracy of simulating system with un balanced geometrical shape (like AC and DC system). At the end of 90th, a new model called the Universal Line-Model (ULM) was based on theory claimed the originality suggested in [12], which integrated in PSCAD for the purpose of addressing these shortcomings. In this regards, it was presented a common and precise FD phase-model to represent any underground cable model from any geometry, besides to the overhead lines. The operation of FD phase-model is based on the principles proposed that the representation of the full frequency dependent of transmission systems could be performed via two matrices called transfer-function; propagation-function H', and the characteristics of admittance Y'C.

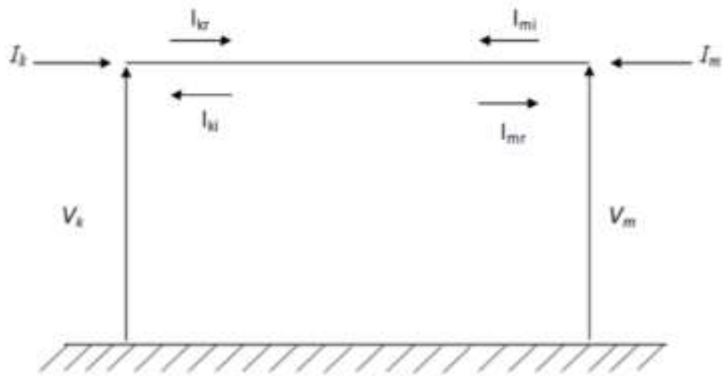

Figure 1 Voltage and Current propagation in No. of Conductors in Transmission Lines

As shown in Figure 1, subsequent equations driven straight from equations 1 and 2:

$d'v/d'x = - Z'. I'$ (1)

$d'i/d'x = - Y'.V'$ (2)

$Y'_C \cdot V_k - I_k = 4 \cdot H'^T \cdot I_{mr} = 4 \cdot I_{ki}$ (3)

$Y'_C \cdot V_m - I_m = 4 \cdot H'^T \cdot I_{kr} = 4 \cdot I_{mi}$ (4)

Where,

H' = $e^{-\sqrt{Z'.Y'.li}}$ represents broadcast function-matrices

YC=$Z'^{-1}\sqrt{Z'.Y'}$represents characteristics admittance -matrices

And,

V_k,V_m represment the end point for voltages vector at the end point of *k* and at the end point of *m*.

I_k,I_m represent the injected currents vector at the end point of *k* and at the end point of *m*.

I_{ki},I_{mi} represent the incident currents vector at the end point of *k* and at the end point of *m*.

I_{kr},I_{mr} represent the reflected currents vector at the end point of *k* and at the end point of *m*.

H' and *Y'C* are considered as calculated numerous time by the LCP at separate point in the FD domains, also they are estimated and substituted by correspondent squat order of rational-function. Thus, such a technique permits or assists in the recovering the complication procedures in EMTDC for relocation in the time-domain, which have confirmed that it is much further computational effectiveness than execution complication integral in straight [13].

TIME DOMAIN IMPLEMENTATION

Following expression illustrates the interface of the FD phase-model in EMTDC electric-network countenance via means values in the Norton representation and equivalent circuit:

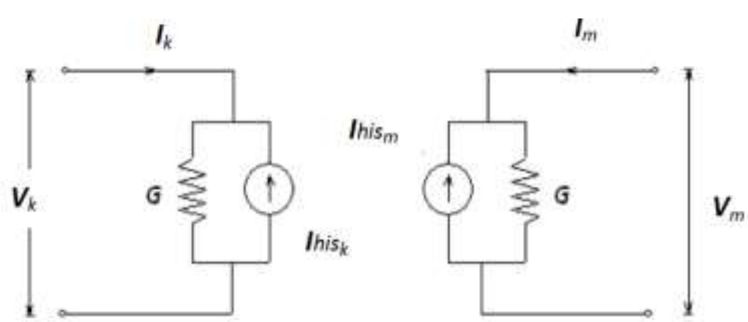

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Figure 2 EMTDC FD Phase-Model in the Time-Domain Interface.

Given the nodes voltage of V_k and V_m, based on calculation with EMTDC, it is important to update the antiquity current sources injection $I\text{-}his_k$ and $I\text{-}his_m$ every time footstep. The steps followed in accomplishing this update by the FD-phase model time domain interface routine is as provided below are explained in [14]:

$$I\text{-}_k(n) = G \cdot V\text{-}_k(n) - I\text{-}his_k(n) \quad (5)$$

$$I\text{-}_{kr}(n) = I\text{-}_k(n) - I\text{-}_{ki}(n) \quad (6)$$

$$I\text{-}_{ki}(n+1) = H'* I\text{-}mr(n-\tau) \quad (7)$$

$$I\text{-}his_k(n+1) = yC'*V_k(n) - 2 \cdot I\text{-}_{ki}(n+1) \quad (8)$$

Where,

i refers to the incident wave.

r refers to the reflected wave.

* Indicates a convolutions of the integral.

SWITCHING TRANSIENT MODEL

Transient analysis for underground cable is presented in the below Figure 3, which represents the cable (132 kv) model and parameters performance during the transient source for two voltage and current waveforms. The purpose of the model that is developing in this report is to get best emulate their results and study which value for each parameter effect more and which effect less on the amplitude and time cycle of the voltage and current transient waveforms.

The circuit is shown in the Figure below is described by PSCAD/EMTDC® program. The diagram simulates a 132 kV single-core cable hereinafter in a form of PSCAD program.

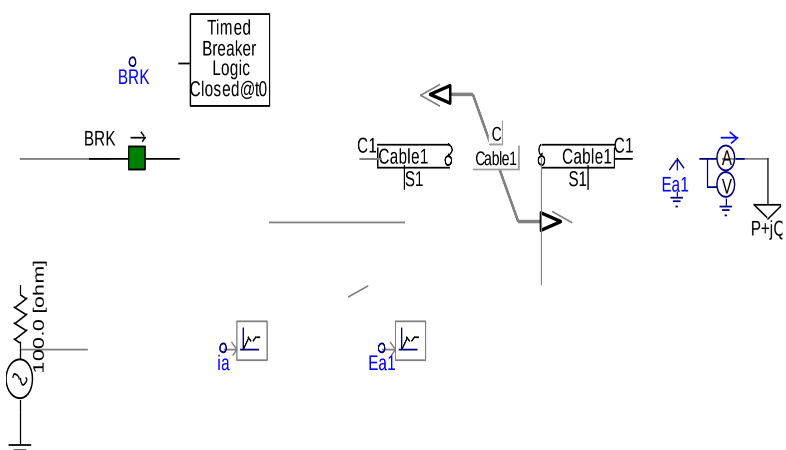

Figure 3 show the model of underground cable during switching transient study by PSCAD program.

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This simulation has been studied the parameters that effects on the transient current and voltage waveforms during PSCAD® /EMTDCTM under the two frequency dependent model, FD-phase model and FD-Mode model for switching transient(circuit breaker) and seeing the amplitude and the time scaling of the transient waveform that affected by the values of each parameter alone to analyze the values of that parameter choice to apply as a suitable value can be selected after that finally for considering value.

Consequently, this study has been taken the main four parameter are the main conductor resistivity, the main insulation thickness, the semiconductor permittivity and finally the sheath thickness or sheath resistivity.

FREQUENCY-DEPENDENT (PHASE) MODEL BASE ON FAULT TRANSIENT SIGNAL

FD Phase-model denotes express the frequency-dependence of each parameter like the ones in the Mode-models. Nevertheless, FD Phase-model avoids implementing a technique depends on constant transformations problem while depends straight formulations by phase-domain. It's consequently precise in most of transmissions and configuration, include unbalance line-geometries.

The FD Phase-model has to continuously be the selected model when looking to accurate and precise model, except in some cases when FD Mode-model is chosen for particular reasons. Therefore, it can be concluding that FD Phase-model is the most progressive and precise time-domain in underground cable model.

Figure 4 shows Transient fault waveform at 100m cable length for all the types of models.

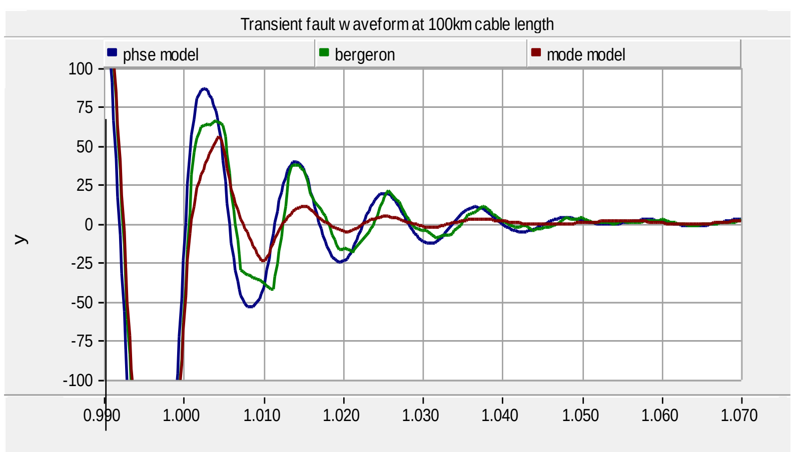

Figure 5 shows Transient fault waveform at 100km cable length for all the types of models.

It does can include from two Figures above 5.5 and 5.6 that the more accurate to represent transient in the short lines is Bergeron from other two types of FD Mode-model and FD Phase-model. Thus, because of the shorten length in the transmission lines the traveling waves model is cannot be implemented and the suitable model is Bergeron. While in the long distance it's the more suites and perfect is the FD Mode-model from the other two models. As the reality of underground cable is long and complicated, so this study will focus on the FD Mode-model as a reference [15].

CONCLUSION

The paper presented fault transient signal through underground cables, through analysis of cable components effect on the signal amplitude and transient time. This represented by modeling 132 KV underground cables in PSCAD/EMTDC. A detailed analysis of each parameter effects for the cable system was also performed. Firstly showing that three type of PSCAD model (frequency dependent phase model) can used in this study and because of the cable system build as 100 km cable length, concluded that frequency dependent phase model was the appropriate one.

The main purpose of this study also exists in the last steps of these paper, which is study of effect the internal and external parameters on the transient behavior. Most of these parameters effect on time of transient signal and the value of the wave amplitude unless the depth of buried was independent, but at the same time effect on the impedance. This modeling is crucial to the proper model of the cables used in the industrial system.

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