Simulation Analysis of Switching Transient in a Short Transmission Line System

Ravinderpal Singh, Azrul Mohd Ariffin and Shahram Bakhmanrokh
College Of Engineering, Universiti Tenaga Nasional (UNITEN) 43000 Kajang, Selangor, Malaysia.

Abstract: Overvoltage transients due to fault, switching, and lightning can cause severe damages on electrical power system. In addition, these transients can also propagate along the length of the cable; causing significant voltage build-up at the junctions which if not controlled, can lead to total disruption of power transmission. This paper attempts to analyze transient behaviour occurring in a power transmission system; namely an underground cable system. The first part of the work would be on the understanding of the most common transient surges and classify the likelihood of occurrence within the power system. The knowledge on this will be the basis for the work to theoretically simulate the transient signals based the concept of circuit equivalence. In addition, the parameters representing the cable will also be studied as part of the work since they will directly affect the response of the transient signals. For this study, the transient behaviour will be analyzed using PSCAD simulation tools. The simulation work will allow a more conclusive understanding on how a transient signal may propagate within the power system.

1. Introduction

There are two types of transient which are classified as impulsive and oscillatory. These terms mirror the waveshape of a voltage or current transient. An impulsive transient is a sudden, non-power frequency change in the steady-state condition of voltage, current, or both that is unidirectional in polarity (either positive or negative). [1]

Impulsive transients are typically portrayed by their rise and decay times, which can likewise be shown by their spectral content. The most common cause of impulsive transients is lightning.

An oscillatory transient is a sudden, non-power frequency change in the steady-state condition of voltage, current, or both, that includes both positive and negative polarity values. [1] An oscillatory transient comprises of a voltage or current whose instantaneous value changes polarity rapidly. It is described by its spectral content (predominate frequency), duration, and magnitude. The most common cause of oscillatory transients is switching.

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The main focus of this paper is to study on the event of transients caused by switching.

In a transmission system, transient occurs due to abrupt change in the operating condition or design of the system framework. Transient is a quick event where the duration of the event is very significant and the disturbance caused by the transient cannot be ignored. The main action that can contribute to switching overvoltage generation are line energization and re-energization, reactor and capacitor switching, breaker openings and occurrences of faults [2].

Switching operation which causes in electrical power system is another vital risk as it can lead to insulation failure of high voltage equipment. The severity of damage depends on the magnitude and duration of such switching overvoltage, as well as derating of insulation strength of high voltage equipment. The magnitude of overvoltage is determined by the parameters of system and the instance when the switched is closed [3]. Switching overvoltage amplitude varies with respect to the complications of the power system circuit representation, different parameters of network, circuit breaker various performances, and different closing and opening times caused by phase angle and phase sequence of circuit breaker [3].

Oscillatory transients is introduced by closing of a circuit breaker to energize a high voltage underground cable system which are characterized by their magnitude, duration and spectral content. The frequency can increase up to the range of tens of kilohertz and last several milliseconds before settling down to the steady state condition [4].

In power system planning and design, evaluation of switching overvoltage is an important task as it has a direct effect on insulation characteristic and coordination, project cost and system reliability.

2. PSCAD/EMDTC

One method to emulate any transmission line is by using frequency dependent modelling [4-7],

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however according to the author, this method is not appropriate to use to simulate in real-time and implement it in hardware. Modelling the line in time domain is another popular method [8-12], in which the electromagnetic transient program is usually used [10-12]. One of the main difficulties when dealing with transient simulation studies in a time domain digital simulator program, such as electromagnetic transient program (EMTP), is the correct representation of transmission lines. In his paper, the author used time domain method to emulate the transmission line in the hardware.

PSCAD/EMTDC is a consistent power system simulator to study transient within a cable system. This simulator lets the operator to configure the cable system according to the area of interest [5]. PSCAD (Power Systems Computer Aided Design) is an effective and adaptable graphical UI to the world-renowned EMTDC (electromagnetic transient simulation engine). PSCAD have aspects that allows the operator to develop a schematic circuit, run a simulation, break down the outcomes, and deal with the information in a totally incorporated, graphical environment. Operator is allowed to adjust the framework parameters during a simulation run with the presence of Web-based plotting capacities, controls and meters which are additionally included in the simulator. [5].

PSCAD comes with a pre-programmed library and includes tested simulation models, which consist from control capacities and simple passive elements, to more complex models, for example, all UI FACTS gadgets, electric machines, transmission lines and links. As it turned out that a required model does not exist, PSCAD allows the operator to build their own custom models. For instance, custom models may be built by sorting out existing models to frame a module, or by building simple models starting from scratch to an adaptable plan environment. [5-6]

3. Simple Pi Model

A cable or a short transmission line can be described as a lumped pi model with arrangement of inductance, resistance, and capacitance (RLC) parameters of the mutually coupled phases calculated at the steady state frequency [13]. R and L represent the series impedances where shunt losses are ignored and the total admittance is divided into two sections lumped at the sending and receiving ends. Such a model can be used to perform accurate steady-state system calculations and is also suitable for studies which assume constant parameters. Cascading many Pi sections can, in general, represent a long line. [13]. However, for predicting a wide range of frequency variations upon cable energization, such implementations may not be adequate. Furthermore, cross-bonding of cable sheaths is neglected in this approach.

A simple Pi section does not simulate reflections in cables at all, and it is thus usually only used for steady state studies and to see low frequency harmonics. For this, a more complicated cable model is required such as the one provided in PSCAD.[13-14]

Since the simple Pi model that makes use of the electrical information above cannot be used at high frequencies, it is thus imperative that the correct geometric data is entered into the simulation program. It will be shown in the following sections how the geometry affects the electrical parameters (capacitance, inductance, and resistance) and how it is possible to match the specified electrical information of the system at low frequencies while also treating high-frequency effects with good accuracy.[14] A simple Pi model transmission line consists of passive elements such as resistor, capacitor, and inductor and is simulated in the PSCAD as shown in figure 1.

![Figure 1 Transmission Line representation in Simple PI Model](image)

4. Methodology

In order to design and simulate the switching transient in PSCAD software, firstly the theoretical study on transient is performed. After understanding the theories, background, and types of transient, an equivalent circuit is designed. In this case a simple PI model is designed using PSCAD software and is used to study the effect of transient due to switching.

The simple Pi model as per figure 2 is designed in PSCAD software to analyze the output of model during its initial condition before switching. The simulation is designed based on an actual transmission power system where a load is connected and the measurement of the output is conducted at the load. The supply injected to the system is 132kV AC, 50Hz and the load is set to be at 10MW. The resistor, $R_1$, is a generator resistance and it is set to a minimum value, (in this simulation $R_1 = 1\Omega$). Assuming the length of transmission line is 100 km, the model simulated in PSCAD is as in figure 2.

The parameters of the passive elements is then calculated using a full cable model. The values obtained are per meter, therefore by assuming the length of cable as 100 km, the resistor, inductor and the capacitor values for 100km of cable will be:
Figure 2 shows 3 Phase Simple PI Model simulation in PSCAD

5. Result Analysis

Switching transient can be simulated in PSCAD using the same simple Pi model. In order to cause transient due to switching, a 3 phase breaker is added in the circuit. The breaker is initially set to be in “CLOSE” mode at t=0 second. The breaker is then set to “OPEN” mode at t=0.1 second. The circuit is then set to “CLOSE” mode at t=0.2 second. This setting is done to breaker to imitate the switching process in power system. The model to observe transient caused by switching is simulated below as

The simulation results from PSCAD is then analyze with the actual result which is obtained from a disturbance recorder. this recorder is one of the vital equipment installed in many TNB high voltage substations. This device helps the control engineers at National Load Dispatch Centre (NLDC) to analyze a faulted line fast and energize it in case of emergency. Other than that, the protection unit also uses the disturbance recorder to analyze tripping. The maintenance of this equipment falls under regional protection unit. This recorder is equipped with remote communication facility. In NLDC the recorders are monitored by software every hour. This process is called auto polling. So all the recordings obtained will be polled into a dedicated server in NLDC. The latest disturbance recorder approved in TNB is BEN 6000. BEN32 application is used to communicate with BEN recorders to download the event records. It can also perform the fault location calculation and indicate fault distance. The recorder used have the ability to measure the voltage, current and other digital inputs and can also record disturbance at t=0.1 sec before the fault to t=4 sec max during tripping.

Initial conditions of the model show a constant current and voltage waveforms for all 3 phases throughout the simulation as shown in figure 5 and figure 6 respectively.

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waveform is distorted for all 3 phases. Initially during \( t = 0 \) s both capacitor \( C_1 \) and \( C_2 \) were being charged and when the breaker is set to “OPEN” the capacitors start discharging. Thus as seen from the result the current is decaying until the circuit is close at \( t = 0.2 \) s.

At \( t = 0.2 \) s when the circuit breaker is set to “CLOSE”, a slight increment of current is observed at \( t = 0.2 \) s.

The result obtained as in figure 7 is then compared with the actual result as in figure 8 which is obtained from the disturbance recorder.

Figure 8 shows a recording of inrush current. It shows increase in current during switching and the system trips due to current inrush condition.

6. Conclusion

Switching problems have been a general concern among utilities in ensuring a consistent quality of supply, reliability as well as continuous prevention from transients and protection of system components in any network. In this paper, the effect of switching is simulated and analyzed by using PSCAD software. A simple Pi model transmission system was design is PSCAD software. This switching simulation was used to investigate the effect and impact of transient due to switching.

Results obtained from this study is then compared with the actual results obtained from a disturbance recorder and the simulations shows that switching can cause tripping in the power system due to over current even though it lasts for a few cycles. The settings of the circuit breaker and relay should be designed such that these instruments will not cause tripping in the circuit breaker.

7. References