Network Modeling for Digital Simulation of Switching Transients

Farzan Rashidi, Mehran Rashidi, Masoud Bahadori

Abstract-- **Power Systems Switching Transients are initiated by the action of circuit breakers and switches and by faults. These actions include energization, de-energization, reclosing and fault clearing. The range of frequencies of primary interest in a switching transients study vary from the fundamental power frequency up to about 10 kHz. Therefore the proper and good representation must be chosen for the various components such as Transmission lines and cables, transformers, source equivalents, loads and circuit breakers. Equipment modeling aspects for the analysis of switching transients are the principal subject of this paper. The electromagnetic simulation program PSCAD/EMTDC is employed to simulate line energization.**

Index Terms-- - Switching Transients, Line Energization, Pre-Strike.

I. INTRODUCTION

One of the major concerns in power system restoration is the occurrence of overvoltages as a result of switching procedure. These can be classified as transient overvoltages, sustained overvoltages, harmonic resonance overvoltages and overvoltages resulting from ferro-resonance. Steady state overvoltages occur at the reciving end of lightly loaded transmission lines as a consequence of line charging currents (reactive power balance). Excessive sustained overvoltages may lead to damage of transformers and other power system equipment. Ferro resonance is a non harmonic resonance characterized by overvoltages whose waveforms are highly distorted and which can cause catastrophic equipment damages [1]. Switching transients are caused by the operation of breakers and switches in a power system. The switching operations represent two main categories: i) energization phenomena and ii) de-energization of the system elements. The former category includes energization of transmission lines or cables, transformers, reactors, capacitor banks etc. The latter category includes fault clearing and load rejections and so on. Traditional method of representing a circuit breaker for energizing transmission lines, transformers, capacitor banks etc. in transient's studies is to assume that the contacts can close on any part of the cycle. In reality, there is a closing time between when the contacts start to close and when they finally make. Somewhere in between, an arc may strike across the contacts as they close. This is known as "pre-strike." The pre-strike effect in closing circuit breakers with a finite closing time is shown in figure 1 [2]. The vertical axis in this figure is a measure of the withstand voltage across the circuit breaker contacts. In the open position, the withstand voltage of the circuit breaker will be a per unit value of rated voltage. The time varying value of voltage across the open contacts is depicted as an absolute function of the alternating voltage across the contacts. As the contacts close, the withstand voltage reduces as the separation distance between the contacts reduces. When the voltage across the contacts exceeds the reducing withstand voltage of the insulating medium between them, pre-strike occurs. As a result of the prestrike, there will be a greater tendency for effective closing to occur with rising or maximum voltage across the contacts. For slow contact closing, there will even be a shadow effect where it will not be possible any effective closing to occur over a portion of the cycle [3].

II. MODELING ISSUES

This section discusses general and specific modeling requirements. General requirements include a discussion of the extent of the system to be modeled. Specific requirements include the equipment models typically used for switching transients simulation [2].

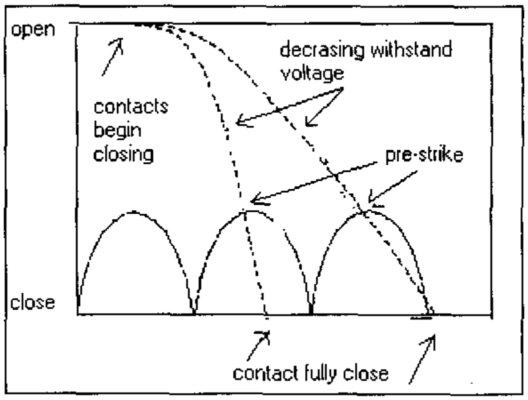

Fig. 1. Pre-strike effect in closing circuit breaker with a finite closing time.

Farzan Rashidi is with the Engineering Research Institute, Tehran, Iran.
Mehran Rashidi is with the Hormozgan Regional Electric Co., Bandar-Abbas, Iran.
Masoud Bahadori is with the Engineering Research Institute, Tehran, Iran.

A. System Equivalents

A reduced network diagram must be developed which should include detailed transmission line and transformer data for at least two busbars away from the substation busbars under study. For the network representation beyond the two busbars, a three phase equivalent source with positive and zero sequence impedances can be applied at the second busbar removed from the busbar under study which serves as an interface busbar. The value of the source impedances will be based on the short circuit impedances. The network example shown in figure 2 is to have the portion in thicker lines modeled in detail for study of the transmission line between Station A and Station B. The network portion shown by thin lines is to be reduced. The short circuit impedances X1, X2 and X3 shown in this example should be more than just a simple inductance. At the very least, the sources should represent a resistive portion modeled with the series R-L impedance configuration of the Three Phase Voltage Source component. The zero sequence portions of the short circuit impedances should also be modeled with the sources. It is preferable that X1, X2 and X3 should be frequency dependent network equivalents. The short circuit impedances X1, X2 and X3 as described above for each of the Three Phase Voltage Source components are required, both for maximum expected short circuit capacity over the life of the station equipment, and for minimum expected short circuit capacity.

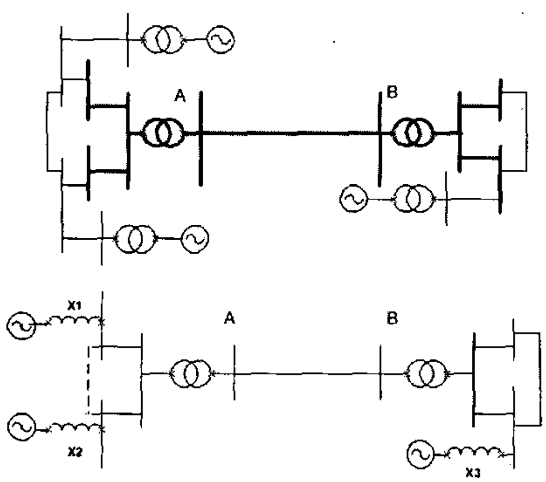

Fig. 2. Network example for transient studies

B. Power Flow

The power flow for maximum expected power flow through the study system network diagram at maximum and minimum short circuit capacity is needed. So too is the light power flow conditions for maximum and minimum short circuit capacity. The power flow should include fundamental frequency voltage angles and magnitudes so that the source voltages and angles can be determined.

C. Transmission Line Data

For each transmission line represented in the network diagram, dimensions and data are required. This can be given at the tower, and should include conductor sag. Shield wire dimensions and resistance should also be provided. The transmission line data required includes:

- Transmission line conductor diameter and resistance per unit length.
- Total length of each transmission line.
- Phase transformation data and distances between phase transformations.
- Spacing between conductors in a phase bundle.
- Spacing between phases.
- Shield wire diameter and resistance per unit length.
- Height of each conductor and shield wire at the tower and sag to midspan, or average height of each conductor and shield wire above ground.
- Tower dimensions
- Ground conductivity.

D. Transformer Data

For each transformer to be represented in detail, the following information is required:

- Transformer MVA rating.
- Winding configuration and winding voltage.
- Transformer tap change ranges and normal setting.
- Leakage reactance's between windings.
- Knee point of transformer core saturation characteristic in per unit of rated flux or voltage.
- Estimated saturated air core reactance of transformer and the winding it is based on.

E. Circuit Breakers

The locations of the circuit breakers that will be switched must be identified on the study system network diagram. Other parameters of the circuit breakers should be determined:

- Protection delay or clearing times.
- Maximum fundamental frequency switching voltage.
- Maximum capacitive switching capability.
- Reclosing sequences and whether they will be used.
- Rated transient recovery voltage and maximum rate of rise of transient recovery voltage.
- Mechanical closing time and variation in pole closing times. This is of particular importance if point-on-wave closing is to be investigated.
- Half cycle closing resistor range of values and the additional cost for such.

F. Surge Arresters

The expected location and rating of surge arresters should be provided. The minimum ratings, and in particular the energy absorption capability will be determined with the studies [5].

G. Shunt Reactors

The location of shunt reactors should be identified. This will include whether they are line connected (located on the line side of the energizing circuit breakers) or bus connected (located on the station side of the line energizing circuit breakers). Information on whether the shunt reactors are switched and if so, the time it takes to close its switch to connect it into service and the time delay to switch it out of service. The reactor rating should be supplied along with its characteristic if it is a saturating reactor. If single pole switching is required for the transmission line, line connected shunt reactors connected to a neutral reactor may be necessary on long lines to assist in the reduction of secondary arc current.

H. Shunt and Series Capacitors

It is important to include shunt and series capacitor data and the associated equipment such as switches, circuit breakers, surge arresters etc. to ensure their effects are included in the transients study.

I. Load

In general, the power system load is represented using an equivalent circuit with parallel connected resistive and inductive elements. The power factor of the load determines the relative impedance of the resistive and inductive elements. Shunt capacitance is represented with the resistive and inductive elements of the load if power-factor correction capacitors are used [3].

J. Generator

In general, generator is modeled by generalized Park's model that both electrical and mechanical part are thoroughly considered, but it has been shown the dynamic behavior of generators does not major influence the line energization. Thus in this work, generators are represented by a sinusoidal voltage source behind their subtransient reactances. Phase of voltage sources are determined by the load flow results.

III. SIMULATION

The energization of overhead transmission lines by closing the circuit breaker produces significant transients. The source, transformer, overhead lines, circuit breaker and the trapped charges (if any) on the line are to be modeled in order to study the line energization transients.

In this study a portion of 39 bus New England test system, which its parameters are listed in [6], is used to demonstrate the simulation results (figure 3). This simulation results is based on PSCAD/EMTDC program [7]. A statistical overvoltage study is conducted in order to evaluate the switching time at which maximum transients are produced. The results of the statistical energization study were presented in Table 1. From Table 1 it can be seen that the overvoltage is 2.334 P.U. The end of line energization waveforms and dielectric strength of switch are shown in Fig. 4 and 5 respectively.

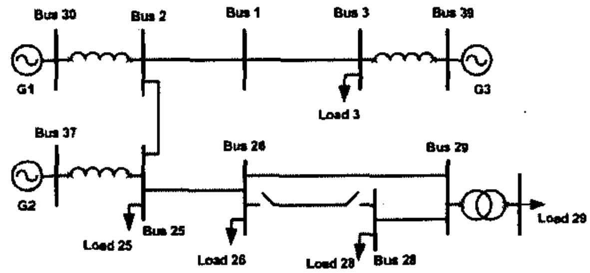

Fig. 3 single Line Diagram for case studies of switching transient

Table 1: Overvoltage in the end of line

Phase A (p.u)	Phase B (p.u)	Phase C (p.u)
2.04	2.334	1.65

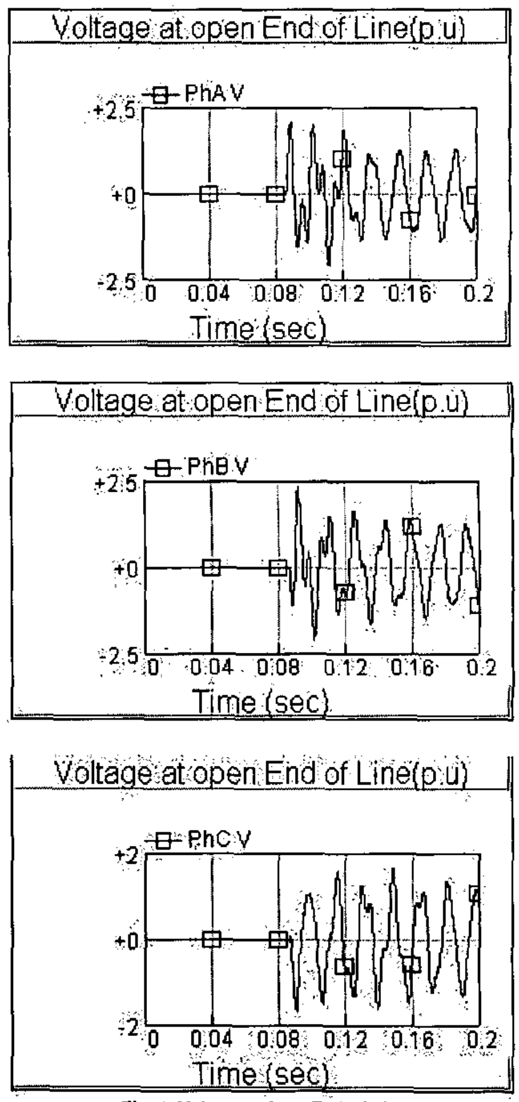

Fig. 4. Voltage at Open End of Line

IV. CONCLUSIONS

The paper presented general rules for the study of switching surges using electromagnetic transients simulation. The main goal is to have as simple a model as possible without a significant loss in accuracy. In addition to the modeling representations, general concerns such as the extent of the system to be studied were also addressed.

V. REFERENCE

[1] M. M. Adibi, R. W. Alexander, and B. Avramovic, "Overvoltage Control during Restoration", IEEE Trans. Power System, vol. 7, pp.1464-1470, Nov 1992.

[2] Dennis Woodford, "Introduction to Pscad", Manitoba HVDC Research Center Inc., 2001.

[3] "Modeling and Analysis of System Transients", IEEE publication No. 99TP133-0, 1998.

[4] D.A. Woodford, L.M. Wedepohl, "Impact of Circuit Breaker . Pre-Strike on Transmission Line Energization Transients", IPST'97, Seattle, 1997, pp250-253.

[5] IEEE WG 3.4.11, "Modeling of Metal Oxide Surge Arresters", IEEE Transaction of Power Delivery, Vol. 7, No. 1, January 1992, pp 302-307.

[6] S. Wunderlich, M. M. Adibi, R. Fischl, and C. O. D. Nwankpa, "An approach to Standing Phase Angle Reduction", IEEE Trans. Power Systems, vol. 9, no. 1, pp.470-478, February 1994.

[7] Manitoba HVDC Research Center inc."PSCAD/EMTDC User Manual".

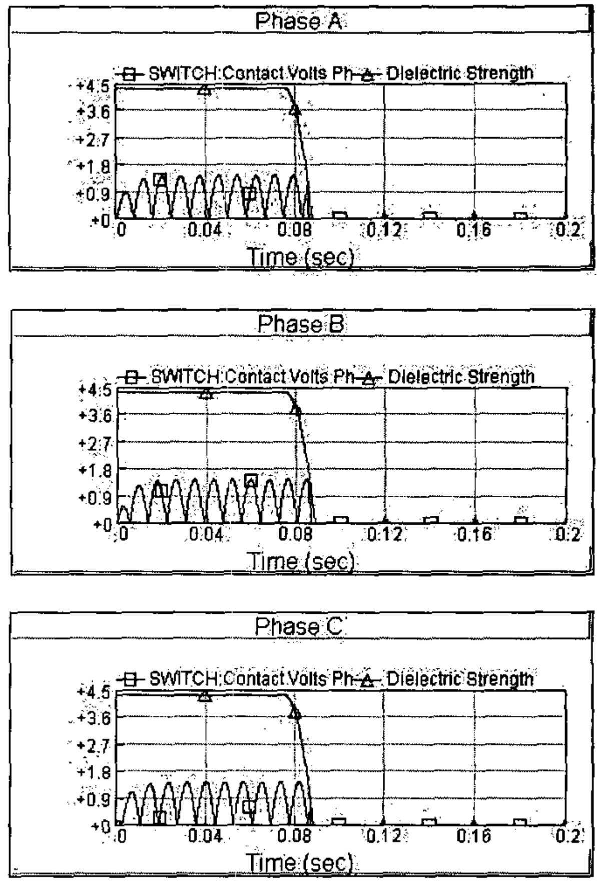

Fig. 5. Contact Voltage and Dielectric Strength of Switch