Switching Transient Overvoltage Study Simulation Comparison Using PSCAD/EMTDC and EMTP-RV

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***Abstract*—Switching transients are an important factor on the equipment selection, protection and tower air clearances. Lightning and switching are two primary causes of transient overvoltage in power systems. This paper focuses on a comparative study of the modeling and simulation of a switching transient overvoltage study using two widely used simulation tools: PSCAD/EMTDC and EMTP-RV. The overvoltage modeling and statistical analysis method have been carefully described in both simulations. The comparative overvoltage results for switching transient study are also provided.**

Keywords-switching transient overvoltage; simulation; modeling.

I. INTRODUCTION

The objective of this paper is to report a detailed comparison between PSCAD/EMTDC and EMTP-RV for the modeling and simulation of a switching transient study. Both programs are widely used power system transient simulation tools. The most important part in this study is the modeling of breaker contacts and statistical implementation in the simulation. The comparison is based on the complexity of implementation of the modeling requirements for each component and statistical study, simulation results and simulation time. The comparative study will be helpful in identifying the pros and cons that the programs inherit.

EMTDC is a powerful time-domain power system transient simulator [1]-[3]. PSCAD is its Graphical User Interface (GUI) simulator. PSCAD/EMTDC has a powerful library for power system simulation, especially for different kinds of control systems, from source control to load control and any other controls for almost all the components in the network. Different types of faults can also be modeled using the components from its library. The nodal analysis technique together with the trapezoidal integration rule with fixed integration time-step is employed in PSCAD/EMTDC to solve the differential equations of the entire power system in the time domain.

EMTP-RV is a high-performance computational engine for advanced transient analysis of various phenomena in different areas of power system operation and protection [4]. Both time-domain and frequency-domain simulations can be performed in EMTP-RV. The GUI for EMTP-RV is EMTPWorks. It is a simulation environment designed to efficiently create networks. A large library of electrical and electronic circuit and power system devices can be found in the EMTP-RV library. The network equations are assembled based on sparse modified-augmented-nodal analysis in EMTP-RV. EMTP has its built-in waveform visualization function MPLOT which can be used for plotting and analysis tasks. ScopeView is an advanced data programming tool which can also be used to process data from EMTP-RV.

[5] describes the simulation requirements for different system components in the switching transient overvoltage study. This paper will follow the recommendations provided in [5]. Section II of this paper gives a brief introduction about the system and its components for use in a switching transient study. Section III and IV introduce the modeling of each component and statistical implementation in PSCAD and EMTP-RV. Section V provides an example system along with the comparison switching transient results for both energization and re-energization studies in different cases.

II. SWITCHING TRANSIENT OVERVOLTAGE STUDY

A. System Description

An example system used for a switching transient overvoltage study is shown in Fig. 1. The fault is only considered in the fault clearing study. System impedance is a parallel circuit of source impedance and network equivalent of the power network not under study (the two remote systems) [5]. The transformer model is not central to the transient

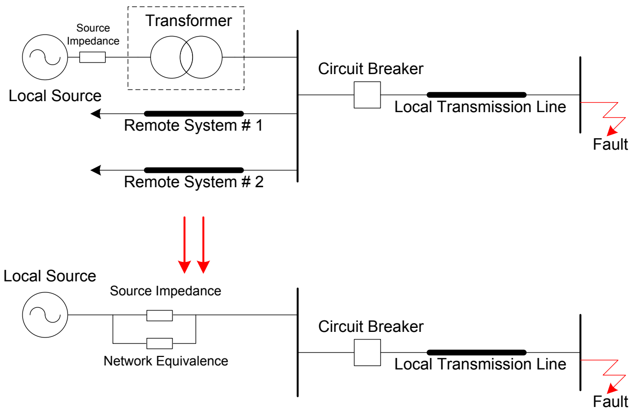

Figure 1. One-line diagram of a system under study.

overvoltage study, so transformer modeling is not considered in this paper.

Since the transient frequency can be up to 10 kHz for switching transients, the model for a transmission line should be frequency dependent. Statistical switching times need to be considered for the operation of breaker contacts since the overvoltage level is dependent upon the source voltage waveform at the instant the circuit breaker contacts close electronically. The value to be measured for comparison is the receiving-end voltage of the transmission line.

B. Breaker Settings

The random data law for the distribution of the breaker contacts can be represented by a uniform distribution for the master contact which is usually set as phase a as shown in Fig. 2(a), and Gaussian distributions for the slave contacts in phase b and phase c as shown in Fig. 2(b). According to the characteristic of uniform and Gaussian distributions as shown in Fig. 2, the standard deviation value for each distribution, which is the parameter needed to be input in EMTP-RV for the statistical function can be calculated using (1) and (2). The calculated random data for the main contacts are provided in Table I.

$$\frac{T}{2} = \sqrt{3}\sigma_m \qquad \sigma_m = \frac{1}{2\sqrt{3}f} = 4.811ms \tag{1}$$

$$\frac{T}{4} = 3\sigma_s \qquad \sigma_s = \frac{1}{12f} = 1.389ms \tag{2}$$

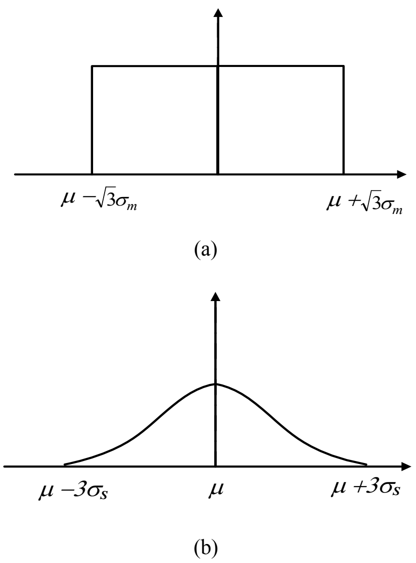

Figure 2. (a) Uniform distribution; (b) Gaussian distrubution.

TABLE I. MAIN CONTACTS RANDOM DATA

	Phase a	Phase b	Phase c
Switch Dependency	Master	Slave	Slave
Random Data Law	Uniform	Gaussian	Gaussian
Random Coverage	One cycle 16.67 ms	Half cycle 8.33 ms	Half cycle 8.33 ms
Standard Deviation	4.811 ms	1.389 ms	1.389 ms

where,

- f is 60 Hz power frequency;
- T is a power frequency cycle;
- σ_m is standard deviation for master contact;
- σ_s is standard deviation for slave contacts.

C. Overvoltage Reduction Methods

1) Pre-insertion resistors

The switching overvoltage level can be reduced by pre-insertion resistors as shown in Fig. 3. In this case, the auxiliary contacts are supposed to be slave switches related to their corresponding main contact, e.g. phase c auxiliary contact is a slave contact to its master switch phase c main contact. The distribution for the auxiliary switches is Gaussian distribution, with the coverage of quarter cycle. The calculated standard deviation for the auxiliary contacts is 0.6945 ms.

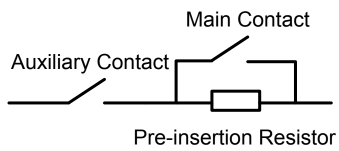

Figure 3. Breaker with pre-insertion resistor in one phase.

2) Surge arresters

Another method commonly used to mitigate overvoltage levels is the installation of surge arresters. The objective of a surge arrester is to protect the insulation of other equipment without putting itself at risk. The arrester must spark over at a given level and carry the impulse current to ground. The arrester is able to reseal when the applied voltage returns to normal. Metal oxide arresters are most popular used arresters. It is needed to place the arrester as close as possible to the protected device.

D. Simulation Scenarios

1) Energization

For an energization study, simulation starts from steady state of the system. The transient occurs when the circuit breaker operates from open to close. A surge is applied to the transmission line when the breaker is closed and travels to the end of the line. Reflection of the surge from the end of the transmission line is a complex function decided by the surge impedance, line length, terminating impedance, system impedance and closing time of the circuit breaker. As a result, the overvoltage level can be up to 2.0 p.u. by the combination of these factors.

2) Re-energization

The difference between a re-energization and energization study are the initial conditions of the system, especially for the transmission line. The trapped charge left on the transmission line will add to the overvoltage level. The excessive overvoltage can be limited to a certain level by applying overvoltage mitigation methods such as pre-insertion resistors for circuit breakers and applying surge arresters along the system.

3) Fault Clearing

A fault clearing study in this paper is for the purpose of generating initial conditions for a re-energization study. A single phase-to-ground fault is applied at the end of the line. The receiving-end voltage of the transmission line is recorded after one-half cycle of breaker operation.

III. Switching Transient Overvoltage Study in PSCAD/EMTDC

A. Transmission Line Modeling and SnapShot

A frequency dependent transmission line can be modeled in PSCAD by following the steps in the transmission library. PSCAD has a complete library for various kinds of line configurations. After selecting the certain type of line configuration, the parameters can be modified.

There is no initial condition set up function for transmission lines or other system components in PSCAD. The snapshot feature can be used to record system data at a certain time and restart the system from the recorded snapshot file. As a result, the snapshot method can be used to model the system for re-energization simulation. The snapshot file can be created after one-half to one cycle of breaker operation for the fault.

B. Multiple Run Component and Circuit Breaker Modeling

The statistical setting for the breaker contacts in PSCAD is a complex process. The Multiple Run component is used to implement the statistical variables and record the output parameters for each run. Additional logic circuits need to be added to relate the statistical variables to the actual breaker contact operation times. The number of statistical runs is split into each individual statistical variable generated from the Multiple Run function.

The advantage of using the Multiple Run function is that the optimal run can be set to record the worst case during the statistical simulation. The switching times of the worst case as well as the statistical results such as the maximum value, 2% statistical value, mean value and standard deviation can be found in the output file after the statistical simulation. But the overvoltage values for each run should be exported to get the CDF plot.

The breaker model in PSCAD has the built-in option of using pre-insertion resistors. In this case, additional Multiple Run output variables need to be added to include the time logic of the auxiliary contacts. And the bypass time of the pre-insertion resistor for each phase need to be set for the breaker.

C. Surge Arrester

PSCAD provides default I-V characteristic for the MO arrester. In this case, the arrester voltage rating is the most important factor in arrester modeling. Note that arresters are installed phase to ground; so, the voltage rating for the arrester needs to be the single phase-to-ground voltage. Also provided for arrester modeling are user defined and external data file I-V characteristic. It applies to the case when the manufacturer data for the specific arrester model is given.

IV. Switching Transient Overvoltage Study in EMTP-RV

A. Transmission Line Modeling

A frequency dependent (FD) transmission line device is provided in the EMTP-RV transmission line model library. The data for this device is obtained from another separate "Line Data" device, where the basic line parameters such as horizontal and vertical distances, DC resistance, line length and ground return resistivity are entered to calculate the line parameter matrices at different frequencies.

An individual tab in the FD line device is provided for the initial condition set up. The trapped charge voltages generated from a fault clearing case can be input in this tab to initialize the transmission line for a re-energization simulation.

B. Statistical Implentation and Circuit Breaker Modeling

A statistical analysis operation function is used to implement a statistical representation of the breaker contacts in EMTP-RV. The overall statistical parameters such as the number of runs and maximum multiple of standard deviation for the output variables are decided in the statistical analysis operation. The random parameters such as distribution type, mean value and standard deviation can be set directly in each switch. For the output file, a CDF plot as well as the statistical parameters can be generated from the MPLOT function of EMTP-RV. However, the worst-case details can only be found out by retracing output parameters.

The pre-insertion resistor and auxiliary switch circuits need to be built in parallel with the original switches for the modeling of a breaker with pre-insertion resistors. The random setting of the auxiliary switches is similar to the main contacts.

C. Surge Arrester

EMTP-RV offers a complete customized surge arrester model. Complete arrester characteristics can be defined using its data calculation function. Options also provided for selection of gap or gapless arresters.

V. Example Simulation Comparison

A. Example System Settings

Generator:

- 525-kV voltage rating (L-L RMS);
- System inductance: 1 mH;
- Two remote system connected to bus, each with surge impedance of 300 ohms;

Transmission line:

- Horizontal configuration with two shield wires as shown in Fig. x;
- Phase conductor diameter: 70 mm;
- Shield wire diameter: 20 mm;
- Line length: 100 km.

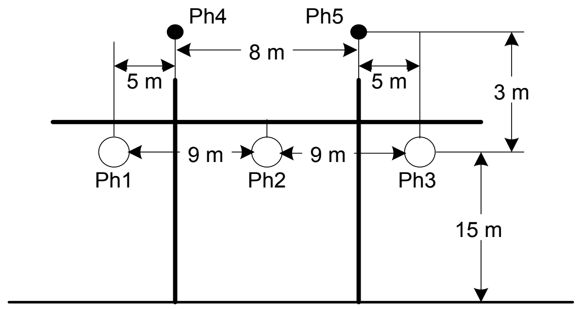

Figure 4. Configuration of local transmission line

Fault:

- Phase a single phase-to-ground fault applied at the end of transmission line at 20 ms, removed at 50 ms.

Breaker contacts:

- For energization, mean value for master contact is 33.3 ms;
- For re-energization, mean value for master contact is 80 ms;
- The random distribution for contacts follows the setting in Table I;
- Pre insertion resistor value 300ohms;

Surge arrester:

- Voltage rating: $\frac{525}{\sqrt{3}} = 303kV$;
- Default I-V characteristics are used.

B. Simulation Results

For the system described in Part A, the switching overvoltage simulation results in terms of receiving-end absolute peak single phase-to-ground voltage are provided in Table II to IV for original case, with pre-insertion resistor and surge arrester, respectively. For each case, both energization and re-energization results are provided. The initial conditions for the transmission line for use in the re-energization study are set the same for PSCAD and EMTP-RV simulations. The recorded or calculated parameters for comparison include the maximum value, mean value, standard deviation, 2% statistical switching overvoltage, simulation time and total CPU time.

In EMTP-RV, since the Cumulative Probability Distribution (CDF) plot of the switching overvoltages can be viewed through MPLOT function, the 2% statistical value is determined through the 0.98 point in the plot. In PSCAD, the 2% statistical switching overvoltage is calculated using

$$E_2 = \mu + 2.054\sigma \tag{3}$$

where,

- μ is the mean switching overvoltage;
- σ is the standard deviation of the switching overvoltages.

TABLE II. SIMULATION RESULTS FOR ORIGINAL CASE

	Energization		Re-energization	
	PSCAD	***EMTP-RV***	***PSCAD***	***EMTP-RV***
Maximum Value	1068.086 kV	1107.908 kV	1773.545 kV	1891.453 kV
Mean Value	862.942 kV	890.286 kV	1011.762 kV	1167.401 kV
Standard Deviation	101.188 kV	94.042 kV	322.759 kV	353.114 kV
2% Statistical Switching Overvoltage	1070.759 kV	1051.95 kV	1674.628 kV	1808.22 kV
Simulation Time	100 ms	100 ms	70 ms	70 ms
Total CPU Time	142.98 s	79.53 s	120.28 s	56.078 s

Note: Trapped charge for the transmission line: phase b: -479.793 kV, phase c: 447.249 kV

TABLE III. SIMULATION RESULTS FOR PRE-INSERTION RESISTOR CASE

	Energization		Re-energization	
	PSCAD	***EMTP-RV***	***PSCAD***	***EMTP-RV***
Maximum Value	552.699 kV	583.555 kV	763.355 kV	802.371 kV
Mean Value	501.27 kV	516.206 kV	593.957 kV	618.323 kV
Standard Deviation	21.105 kV	27.124 kV	71.77 kV	76.201 kV
2% Statistical Switching Overvoltage	544.61 kV	573.893 kV	741.354 kV	763.681 kV
Simulation Time	100 ms	100 ms	70 ms	70 ms
Total CPU Time	157.15 s	87 s	122.59 s	64.5 s

Note: Trapped charge for the transmission line: phase b: -485.887 kV, phase c: 450.609 kV

TABLE IV. SIMULATION RESULTS FOR SURGE ARRESTER CASE

	Energization		Re-energization	
	PSCAD	***EMTP-RV***	***PSCAD***	***EMTP-RV***
Maximum Value	568.667 kV	620.929	590.641	637.391 kV
Mean Value	554.319	606.451	553.581	596.214 kV
Standard Deviation	8.59	10.053	25.233	32.294 kV
2% Statistical Switching Overvoltage	571.94	619.821	605.404	635.789 kV
Simulation Time	100 ms	100 ms	70 ms	70 ms
Total CPU Time	191.70 s	139.734	141.76 s	100.87 s

Note: Trapped charge for the transmission line: phase b: -383.018 kV, phase c: 368.159 kV

From Table II to IV, the simulation results in terms of maximum value, mean value, standard deviation and 2% statistical overvoltage were found to be similar, especially for the original case and the case with pre-insertion resistors. For the case with surge arresters, since default I-V characteristics may be different for PSCAD and EMTP-RV, the difference in statistical results can be explained. However, it can be noticed that in the PSCAD simulation, the 2% statistical overvoltage value is greater than the maximum value for the original energization case and the re-energization with surge arrester case. The reason is that the equation method is used to get the 2% statistical value in PSCAD. (3) is based on the assumption that the statistical distribution for the overvoltage results is Gaussian distribution. However, the distribution is not strictly Gaussian.

All simulations were run on a Pentium (R) 4 2.26-GHz processor running Windows XP operating system. the execution time was recorded from the Time Summary shown on the output window in PSCAD and by CPU time shown on EMTP simulation output table. From the comparison of total CPU time, EMTP-RV has better performance on the prompt simulation for every case. The time difference is about one third for each simulation.

VI. CONCLUSION

A detailed comparison of the performance of two simulation environments (PSCAD/EMTDC and EMTP-RV/EMTPWorks) has been demonstrated by modeling the switching overvoltage using a typical system. Both programs produced almost identical results for the statistical overvoltage. In terms of computational speed, EMTP-RV was found to show better performance.

REFERENCES

[1] F. Jurado, N. Acero, J. Carpio, and M. Castro, "Using various computer tools in electrical transient studies," in *Proc. Int. Conf. 30th ASEE/IEEE Frontiers in Education*, Kansas City, MO, Oct. 18-21, 2000, pp F4E17-F4E22.

[2] PSCAD User's Guide, Manitoba HVDC Research Centre, Feb, 2010.

[3] G.D. Irwin, D. A. Woodford, and A. Gole, "Precision simulation of PWM controller ," in *Proc. Int. Conf. Power System Transients*, Rio de Janerio, Brazil, 2001, pp. 301-306.

[4] Electromagnetic Transients Program (EMTP) Theory Book. Bonneville Power Administration, Portland, Oregon, June, 1987.

[5] IEEE Modeling and Analysis of System Transients Working Group, "Modeling Guidelines for Switching Transients," *Modeling Analysis of System Transients Using Digital Programs*, TP-133-0.