Using Electromagnetic Transient Program (EMTP) for accurate prediction of faults location

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***Abstract* — Electrical power systems are sophisticated networked grids, which need to function with high reliability to provide electricity to customers. With high number of interconnected busses and devices in both transmission and distribution networks, electrical power systems need powerful programs to perform high speed calculations. This paper describes the Electromagnetic Transient Program - Alternative Transient Program (EMTP-ATP) and its usage in modeling of faults behavior in complex electric power systems. The results from EMTP-ATP modeling were compared to models in PSCAD to validate developed models. EMTP-ATP is further used in this paper to show steps in designing a system with a Single-Line-Ground fault (SLG) to analyze high frequency composition of SLG faults.**

***Index Terms* — Electromagnetic Transient Program - Alternative Transient Program (EMTP-ATP), Power System CAD (PSCAD), electrical power system, high frequency fault information, Single-Line-Ground fault (SLG).**

I. Introduction

There is a wide variety of numerical programs available for simulation of electrical power systems in order to analyze power system under both steady and transient conditions. This paper will be discussing application of EMTP-ATP program to analyze performance of electric power systems. From the design of complex power systems, information can be extracted to show the high frequency information that occurs during different fault scenarios. There are many fault types, but in this paper will only address at Single-Line-Ground faults (SLG) to capture high frequency fault information. Other fault types will be analyzed using similar methodology in future.

II. Overview of EMTP-ATP

A. EMTP-RV and ATP

The Electromagnetic Transients Program originated in the seventies from the Bonneville Power Administration and its theory and usage are well documented in the EMTP 'Theory Book' [1] as well as in the proceeding of the International Conference on Power System Transients [2]. In the nineties, various groups, such as Manitoba Hydro(PSCAD/RSCAD) [3], Development Coordination Group (EMTP-RV) [2], and others, began to commercialize the EMTP code, while the original code remained in the public domain under the name 'Alternative Transients Program' (ATP). Other tools such as Matlab/Simulink's™ Simpower/Simscape [4] also use many of the models originally created for ATP. ATPDraw™ was developed as a public domain graphical user interface by the European EMTP_ATP user's group [5]. ATP was originally developed to study switching transients in long, extra- and ultra- high voltage (EHV, UHV) transmission lines. ATP uses the simple trapezoidal rule and the method of companion networks [1], to solve the differential equations that apply to a power system model. Nonlinear elements are most commonly accommodated via compensation techniques, which may require special treatment [1]. EMTP-RV [2] uses iterative solution for nonlinear elements. As with any simulation method the user must carefully understand and model not just the main elements in a system, but all parasitics as well. Over the last fifty years, the code has grown to include the modeling of rotating machines, transformers, substation equipment, power electronics and control systems. Some key features include nonlinear models (e.g., saturation), frequency dependence models, corona and arc models and statistical analysis. Some of these models involve simplifying assumption that the user must understand. A large library of models, many of which have been field tested, are available. ATP normally is used on a multicore desktop or workstation, but has been compiled to run on Graphical Processor Units (GPU) [6] and real-time implementations have also been reported (e.g., [7]).

B. PSCAD/EMTDC

PSCAD/EMTDC is a powerful tool for simulating time domain instantaneous responses and electromagnetic transients in electrical systems. This software solves the electromagnetic and electromechanical systems' differential equations in the time domain. Differential equations are calculated based on a fixed time step. PSCAD/EMTDC accommodates the simulation of transients on lines and cables using a frequency dependent (phase) model. The frequency dependent model is built upon a traveling wave (TW) model in which all line/cable parameters are frequency dependent. Moreover, the model's internal transformation matrices are all frequency dependent. This facilitates the detailed simulation of different frequency components of TWs. In the frequency dependent model, curve fitting is utilized to approximate the impedance and admittance

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of line/cable with a Nth order approximation. Users can specify a frequency range for these calculations.

III. Simulation Methodology and Approach

The EMTP-ATP program has many aspects to it and uses the ATPDraw™ interface to design any power system that is desired for simulation. Users need to make sure that they have the product license if they want to use the full features of the program. For the process of designing a power system, users need to begin by setting up the file system and then creating a new .acp file which will be the bases of the power system. Once the file system is set up, users need to set up the simulation settings in which the program will be used to graph high frequency signals. Next, power system components are picked and placed into correct positions on the program. After the components are selected and placed, the user needs to input the parameter information that the components need for the program to run successfully. Finally, when the program runs with no errors, users can now either extract the data for plotting or use built-in plotters to plot graphs and edit them to their specifications.

A. Setting up ATP file system and creating an ATP file

Before making a complex power system within EMTP-ATP, users need to make sure the installation of the program is successful before proceeding. Without proper installation, the program will not detect the solver needed to compile any code. Once that is completed, users need to set up directories that their files are going to be saved too. That can be done by going to the tab *Tools|Options/Files&Folders* seen in Fig. 1

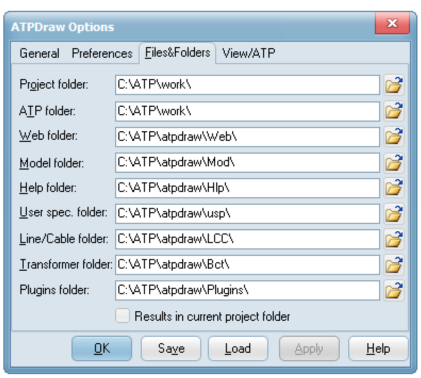

Fig. 1. File option directory window

Once users have specified the location there .acp files are going to be placed, they can now create a .acp file which is done by clicking on *File|New*, or if opening a previous .acp file users can click *File|Open* and selecting a .acp file.

B. Setting up simulation

After completing the file system setup in EMTP-ATP, users can now set up simulation settings. This can be done by either clicking on *ATP|Settings* or by pressing F3 seen in Fig. 2. Once the simulation settings window opens up, users can set up their simulation to their requirement by entering end time of simulation (Tmax) and time step (delta T) and other parameters as needed. For the high frequency fault simulation, settings will have a small simulation time and a very small-time step for a better resolution of the fault signal.

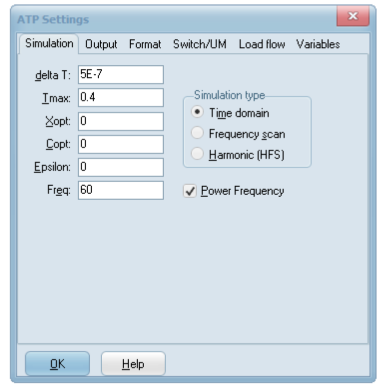

Fig. 2. Simulation setup window

C. Placing electrical components

The power system that will be used to analyze high frequency fault information will include: two 230 kV three phase sources with source impedances, one delta tower 200 km transmission line seen in Fig. 3, and a SLG fault placed in the middle of the 200 km transmission line, and fault impedance [8]. Fig. 4 shows the PSCAD model that EMTP-ATP will be trying to follow as a sample power system. EMTP-ATP's phase angle will have to be changed to accommodate PSCAD using an AC sine source while EMTP-ATP uses an AC cosine source. Fig. 5 is the power system that is designed in EMTP-ATP. To place power system components the best way would be to right-click and there are many components seen on the drop-down list. Another way to find a certain component would be to right-click and select *All standard comp…* tab. From there, users can input a keyword to find a component. Table I shows the parameters that will be used in the simulation.

TABLE I
Parameters Used in the Simulation

Parameters	Values
Source 1 (3 phase)	230 kV < -90° (Phase A)
Source 2 (3 phase)	230 kV < -110° (Phase A)
Source 1_Impedance (3 phase)	1.31 Ω, 39.78 mH, 0 μF
Source 2_Impedance (3 phase)	2.62 Ω, 79.57 mH, 0 μF
Transmission Line (Delta Tower)	Semlyen Line Model
Soil Resistivity	100 Ω * m
Fault Impedance (Rf)	0.01 Ω
Fault Begins/ Fault Ends	0.210 s/0.260 s

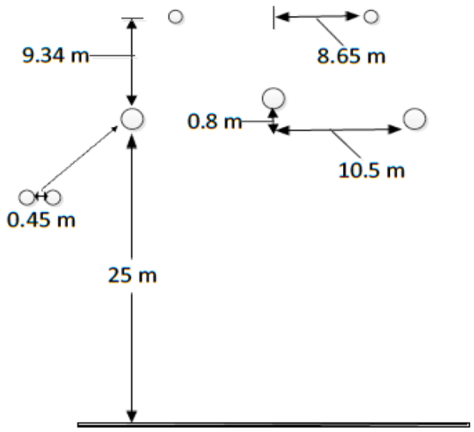

Fig. 3. Delta Tower Transmission line

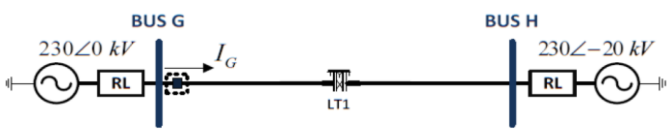

Fig. 4. Delta Tower Transmission line

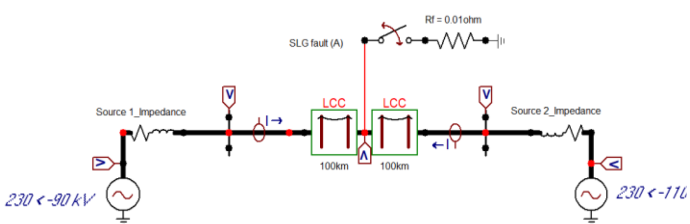

Fig. 5. EMTP-ATP power system

After placing electrical components, users will need to place measurement probes to measure voltages and currents onto the system. Without probes the program will not run properly. With the probes placed, users can request certain phases to record or even see the steady-state values at those probe locations. Certain nodes seen in the system can be assigned certain names. The Red nodes in Fig. 5 indicate that those nodes are assigned certain names. With nodes named, it helps when plotting many phases onto a single graph.

D. Editing electrical component parameters

To edit the parameters seen on Table 1, users would need to right-click or double-click on the desired component. For example, when editing the source parameters, users are asked to input attributes including: Amplitude of phase A voltage, steady-state frequency, and so on. For the transmission line model, users have a variety of line models to choose from which consist of: transposed/untransposed lines, different number of phases, and so on. For the purpose of simulating high frequency fault information, the simulation will use a delta tower transmission line as seen in Fig. 3, and using the Semlyen line model for high frequency-dependent line calculations seen on Fig. 6. With this line model, wave propagation characteristic at high frequency is very significant for studying fault currents [9]. There are other transmission line models that could be used, but those models have different aspects that are suitable for different line types. Users can also select the system type of transmission line like an overhead three phase line to a single phase underground enclosed line. Users will also need to input the geometry of their transmission line they want to simulate by opening the component window and clicking on the *Data* tab. Table II shows the transmission line parameters and Fig. 7 shows that visual output of what the transmission line looks like. Comparing Fig. 3 with Fig. 7, both lines look very similar in geometry. With this geometry EMTP-ATP will use mathematical formulas like Carson's equations to solve for the impedance matrix and admittance matrix of the multiphase transmission line as seen in Fig. 8.

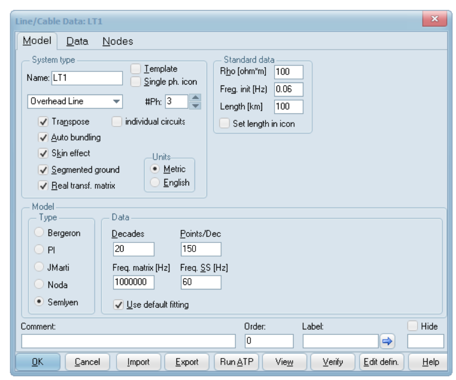

Fig. 6. Line/cable parameter setting window

TABLE II
TRANSMISSION LINE PARAMETERS

	Ph.no.	Rin	Rout	Resis	Horiz	Vtower	Vmid	Separ	Alpha	NB
#		[cm]	[cm]	[ohm/km DC]	[m]	[m]	[m]	[cm]	[deg]	
1	1	0	1.59	0.0513	-10.5	25	15	45	0	2
2	2	0	1.59	0.0513	0	25.8	15.8	45	0	2
3	3	0	1.59	0.0513	10.5	25	15	45	0	2
4	0	0	0.39	2.2	-8.65	34.34	24.34	0	0	0
5	0	0	0.55245	2.8645	8.65	34.34	24.34	0	0	0

For the fault on phase A, EMTP-ATP needs to separate the line into two sections to properly place the fault in the desired location. A bold black line indicates a three-phase line while a single-phase line is any other color that is not black. EMTP-ATP uses: phase A is red, phase B is green, and phase C is blue or users can set their own phase colors as desired. To engage the fault the user needs to short the line along the transmission line. That is controlled by a time-controlled switch which can be set to open/close at a given time. For the fault, this paper is looking at a SLG fault in this simulation with a small fault impedance.

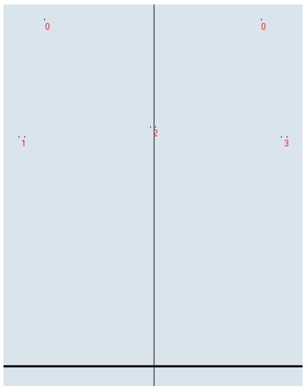

Fig. 7. Geometry of the transmission line

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                                        Frequency = 6.00000000E+01
                                        --------------------------

      Series impedance matrix                   Shunt admittance matrix
         (Ohm/mile)                                 (mho/mile)

2.1500261E-01                         0.0000000E+00  0.0000000E+00  0.0000000E+00
1.0552880E+00                         6.1024180E-06 -7.6345680E-07 -7.6345680E-07

1.7072579E-01  2.1500261E-01                         0.0000000E+00  0.0000000E+00
4.2756028E-01  1.0552880E+00                         6.1024180E-06 -7.6345680E-07

1.7072579E-01  1.7072579E-01  2.1500261E-01                         0.0000000E+00
4.2756028E-01  4.2756028E-01  1.0552880E+00                         6.1024180E-06
```

Fig. 8. Transformation Matrices

E. Running EMTP-ATP

Once all the components and probes are placed and their parameters are entered, it is time to run the program. To execute the program the user can click *ATP|Run ATP* or press F2. A command window will pop-up and the program will run. Once the program runs successfully, users can graph voltages and currents needed for their studies. Two common graph plotters that EMTP-ATP has at disposal are PL4 viewer and PlotXY. To open PL4 viewer, users can click on *ATP|ATP Launcher* or press F8 to open the plotter. PL4 viewer plotter also has a feature to export certain portions of a graph in which users can save as an excel file. To open PlotXY, users can click *ATP|PlotXY* or press CTRL+0 to open the plotter. This plotter is better to use to make graphs appealing for presentations. For the high frequency fault information, current and voltage will be looked at. The PSCAD fault current can be seen on Fig. 9. The EMTP-ATP plot fault current is seen on Fig. 10, and Fig. 11 shows the voltage at the fault.

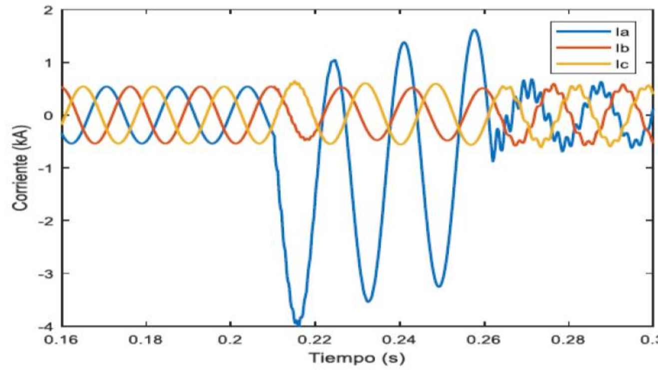

Fig. 9 PSCAD SLG fault current

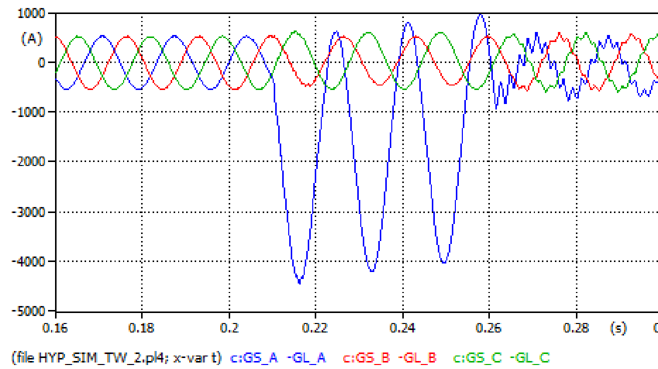

Fig. 10. EMTP-ATP SLG fault current

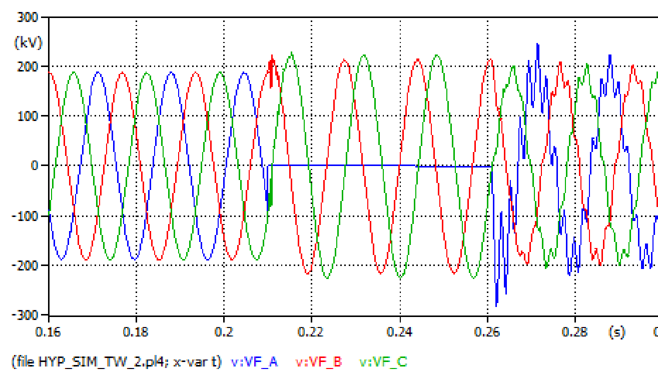

Fig. 11. EMTP-ATP SLG fault voltage

IV. ANALYSIS & RESULTS

The current waveform shows a large current spike around 4 kA while the steady-state current stays around 550 A for Fig. 9. Everything is similar in Fig. 9 compared to Fig. 10 except for the fault transient magnitudes. It seems the EMTP-ATP fault current spike is greater than 4 kA and before 0.26 s the current is less than the PSCAD current waveform. The line model in the literature is not specified directly but shows to be a frequency-dependent transmission line [9]. Not having the same modeling of the frequency-dependent lines can change the results gradually.

The current has a fast-changing transient when the fault is cleared because the fault does not close at the zero crossing. For the voltages in Fig. 11 shows that phase A voltage drops down close to zero volts while the other phases are higher than the steady-state voltages. Same as the currents, the voltages have a high frequency transient and takes some time to come back to steady-state. One thing that is slightly different to the PSCAD fault current compared to the EMTP-ATP fault current is the magnitude. The main issue that could be causing that discrepancy could be how both programs calculate the transformation matrices. Fig. 12 and Fig. 13 are zoomed in plots of the currents and voltages around the fault inception time to look at the high frequency fault information.

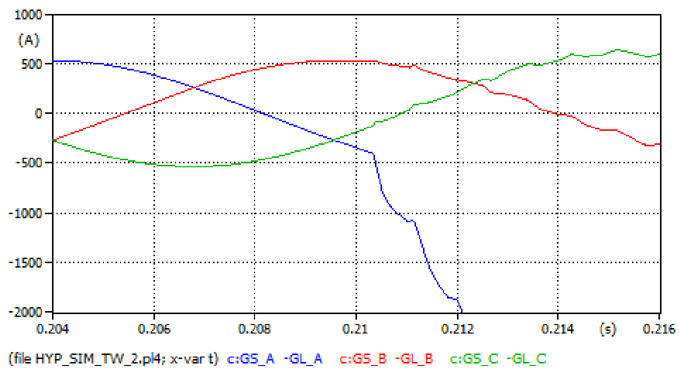

Fig. 12. Zoomed SLG fault current

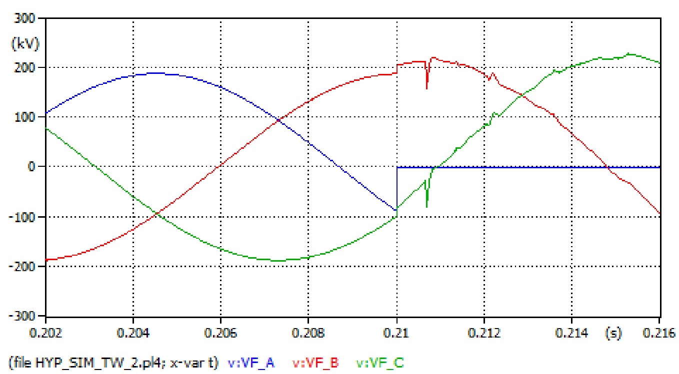

Fig. 13. Zoomed SLG fault voltage

Small ripples are seen in the plots. Those are indicative of the high frequency traveling waves propagation of the fault waves. This information is used in many studies and in electric power system protection. Using these high-frequency fault signatures in power systems, we can detect and locate faults which are otherwise not detectable by other protection algorithms and devices. For example, using this high frequency fault information to distinguish high impedance faults from switching events (capacitor bank switching, load switching, and etc.).

With the frequency-dependent Semlyen line model, those ripples are evident. In Fig. 14 shows different line models (PI model, Bergeron model) compared to the Semlyen line model while a SLG fault occurs at phase A. Fig. 15 shows a zoomed in portion of the graph of when the fault happens. As seen on Fig. 14, The Semlyen model has a different characteristic compared to the PI and Bergeron model. All three lines share very similar steady-state current, but once the fault happens is when they have different transients. For the fault clearing, all three-line models have a chaotic reclosing transient. The reason for that is the Semlyen model is frequency-dependent which uses a band of frequencies to calculate the transformation matrices of the lines. The PI and Bergeron model use only constant parameter lines models, which are not frequency-dependent. Depending on the scenario, all three-line types can be used to detect certain types of faults. Both the Semlyen and Bergeron model lines show similar waveforms and the PI model shows a steady sloping transient on Fig. 15.

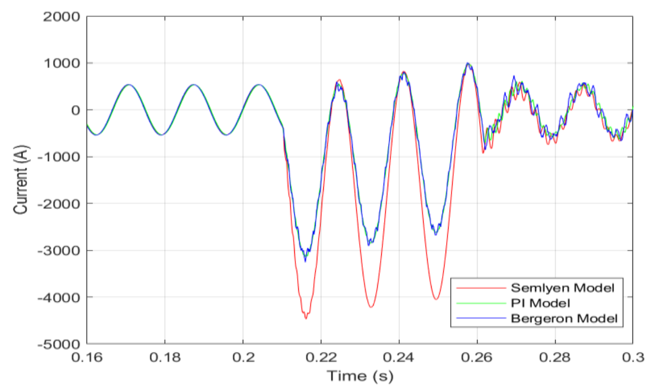

Fig. 14. Different line models during SLG fault

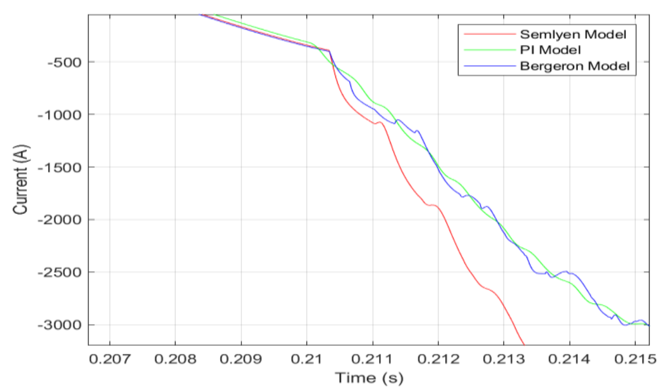

Fig. 15. Zoomed line models during SLG fault

IV. Conclusions

In conclusion, this paper uses a PSCAD model with an EMTP-ATP model to compare similar test results. Both electrical power system programs have many features to help users' model and simulate power systems that are desired. The design of a SLG fault on a system is one of many studies to help look for potential problems that electric power systems may encounter.

With more distributed resources and inverter-based generation resources getting interconnected onto the power systems, it is even more important to be able to accurately detect and locate these faults [10]. Therefore, it is important to distinguish and classify different types of faults based on their high-frequency signatures. In this paper, we illustrate how a SLG fault can be modeled to extract high frequency signatures. Future work will include detection of high frequency signatures of other types of faults.

With the high frequency fault information, power systems engineers can formulate new algorithms and protections schemes to detect certain fault types to ensure the power system can clear it with excellent accuracy and time.

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