Parameters for Modeling Transmission Lines and Transformers in Transient Simulations

Summary

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Most investigations of power system transient behaviors are performed using computer simulation packages like the Electromagnetic Transients Program (EMTP). Scale modeling using Transient Network Analyzers (TNA) is still done, but decreasingly so as computer simulation models for system components are gradually improved.

Engineers and researchers who perform transient simulations typically spend only a small amount of their total project time actually running the simulations. The bulk of their time is spent

- Constructing the overall system model,
- Obtaining parameters for component models,
- Benchmarking the components models to confirm proper behaviors, and
- Benchmarking the overall system model to verify overall behavior.

Only after the component models and the overall system model have been verified can one confidently proceed to run meaningful simulations. Even then, if there are some transient event records to compare against, more model benchmarking and adjustment may be required.

Here, we present recommendations on how to obtain the parameters needed to model overhead transmission lines and transformers, the two most prevalent components of a power system. The reader is directed to references [1,2,3] for background on the overall development of transient simulation models and the simulation of transients.

Transmission Line Models

Appropriateness of line model depends on the line length and the highest frequency to be simulated. For “short” or “medium” transmission lines, a simple lumped coupled-δ model, or several in series, may suffice [2 – Ch.11]. For longer lines or higher frequencies, distributed parameter behaviors must be included. Development of presently used transient transmission line models for this case are based on the “traveling wave model” presented in many textbooks [2 - Ch.9]. For multi-conductor overhead transmission lines, the basic equations are

\[-\frac{\partial v}{\partial x} = Z i \quad \text{and} \quad -\frac{\partial i}{\partial x} = Y v ,\]

where \(v\) and \(i\) are the vectors of node voltages and line currents at a distance \(x\) along the multiple conductor transmission line. \(Z\) is the matrix of coupled series impedances of the conductors for an incremental length, and \(Y\) is the matrix of coupled shunt admittances for that same length. Details of solution are given in [2] and in references [4,5,6,7,8]. Convolution methods are used to convert the frequency-domain solution to a time-domain equivalent that can be implemented in time-domain simulation programs like EMTP.

Errors in this approach are due to the fact that the solution is only valid for the frequency that the model was developed [4,5]. Improvements have been made by applying frequency-dependent weighting functions to the convolution [6,7], by developing improved frequency fitting techniques, and by developing the model directly in the phase domain and thus avoiding modal transformation [8]. In any case, it is desirable to confirm that the line model being implemented is valid within the range of frequencies to be simulated.

Transmission Line Parameters

Since transient studies evolved after load flow, short circuit, and stability studies, existing databases of transmission line parameters may consist only of synchronous frequency (50- or 60-Hz) line impedances. Short-circuit line data is often just the positive, negative, zero, and series mutual impedances. Load flow line databases might contain only a per-phase positive sequence β-representation. In all cases, line data is stored only as impedances.

In order to develop line models for transient simulations, however, the physical line parameters must be available. For example,

- (x,y) coordinate, each conductor and shield wire,
- Bundle spacings,
• Phase designation of each conductor,
• Phase rotation at transposition structures,
• Physical dimensions of each conductor, and
• Earth resistivity of the ground return path.

All transient simulation packages have a so-called “line constants” utility or interface. Users of the software enter the line’s physical parameters into the line constants utility, select the type of line model desired, and the model is created. Since all models are developed from physical transmission line parameters, it is highly recommended that a database of physical line parameters be created.

**Example Cases**

Two example cases will be presented: one single-circuit line and one double-circuit line. A detailed discussion will be made. Points covered will be

• Proper input of physical parameters,
• Examination of line constants output,
• Benchmarking impedances $Z_0$, $Z_1$, $Z_2$, and $Z_m$,
• Benchmarking for frequency response, and
• Application considerations.

**Transformer Models**

Unlike transmission lines, the physical construction details of transformers are not typically known. Many variations on core and coil construction are possible. Key physical attributes whose behavior, depending on frequency, may need to be correctly represented by the model are:

• Core configuration (core-form, shell-form, etc),
• Coil configuration,
• Capacitive effects of coils,
• Self- and mutual inductances along each coil,
• Leakage flux,
• Skin effect and proximity effect in coils,
• Magnetic core saturation, and
• Hysteresis and eddy current losses in core.

Transformer models generally available in EMTP-like programs are suitable for low frequency behaviors, such as short circuits at synchronous frequency. By adding a saturable core representation, excitation and inrush might be simulated. By adding capacitive coupling between coils, ferroresonance and higher frequency situations like switching can be simulated. Fast-front transients like lightning require a very detailed model that is usually not standardly available.

**Example Cases**

Two of the most frequently used models in EMTP are the multi-winding saturable transformer which can be used to implement duality-derived models [9], and the so-called BCTRAN model [10]. Parameters for both models are electrical, not physical. Example cases using both models will be presented and examined in detail.

BCTRAN is attractive to use since it has a preprocessor which converts nameplate and factory test data directly into a model. The model created represents the short-circuit impedances of all coils including mutual inductive coupling. A linearized core representation may be included in the model, or a saturable core equivalent may be attached externally at the terminals of the model.

**References**