Intricacies in PSCAD/EMT Analysis

"A discussion of intricacies in EMT simulation of power electronic controllers, which can lead to varying results and poor benchmark/comparisons"

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Introduction

PSCAD/EMT analysis is not new but is being applied to new types of studies (such as transmission planning dynamic performance studies) that used to be performed exclusively with rms/transient stability tools. This white paper describes some of the intricacies involved with PSCAD/EMT analysis, particularly with power electronics (ie wind, solar etc.) and high frequency effects.

EMT Analysis – Applications and Level of Detail Required in Models

PSCAD/EMT analysis includes a wide variety of studies that can be performed, including:

- Transmission Planning Studies:
    - Large scale dynamic performance testing
    - Control interaction
    - Ride-through testing
- Device/site level implementation studies:
    - TRV, lightning analysis
    - Insulation coordination, switching transients, line/transformer/capacitor bank energization
- Other:
    - SSR/SSTI/SSCI (sub-synchronous phenomena)
    - Harmonics
    - Ferro-resonance
    - Other

The level of detail required for each type of study varies greatly – ie the same tool can be used for a wide variety of studies, sometimes requiring very different modeling and data (even for the same site/object!).
Some examples:

- a dynamic performance study may lump all wind turbines in a wind farm into a single equivalent/scaled model, equivalence all individual feeder cables etc. (which would generally be valid for system side faults and wide area dynamic performance). This model would not however be suitable for studies that require great detail to high frequency responses/resonances (such as PWM harmonic studies, faults on the MV feeder/collectors etc.) – significant effort would be required to extend the model to the high frequency range and variations due to feeder impedances.
- A line switching transients study may determine the peak TOV that occurs due to a fault or fault recovery – the same model would not be valid for dynamic performance studies (as the electro-mechanical aspects from nearby machines and controls may not be represented). Similarly the same model would not be valid for lighting studies (as the stray capacitance and lead inductance of equipment is not modeled, and individual span-by-span line models would be required).

In general, the experience of the engineer doing the study is required to determine the range of studies required, and to select/input the relevant level of detail into their PSCAD model – it is all PSCAD, but a lightning transients model will look very different compared to a dynamic performance study, even at the same location. Things like transformer stray capacitance, use of lumped feeder or scaled inverter models, frequency dependence of lines (or even transformer resistance!) all can affect the responses at increasingly higher frequencies.

EMT Analysis – Subtle Modeling Factors That Affect High Frequency Transients

You may have run an EMT simulation, made a seemingly small/minor change (change of time step, even selection of Fortran compiler, slightly different fault impedance etc.) and got very different result. This sensitivity to modeling can be un-nerving – you would think that a good model should give the same result at one time step as compared to a simulation with a smaller time step.

Non-linearities can change this however – transformer saturation, surge arresters etc. are clearly non-linear models, but what about power electronic controllers? If the controller has a mode-switch (or changes operation based on a certain event) you can get drastically different results for seemingly small changes. Such changes can include deadbands, limits, mode-switches, LVRT thresholds etc. – ie a simulation can perform fine for one simulation, but a slightly different simulation (even with identical data) may trigger a threshold to be exceeded, resulting in different performance and results.

As an example, I have observed high frequency harmonic distortion in a simulation, that seemed to appear and disappear at random (or with minor changes to modeling data). This was tracked down to the PWM (Pulse Width Modulation) distortion from a power electronic inverter, the filtering in the converter, and the frequency response of the grid model – sometimes the simulation resulted in high VTHD, other times it did not.

Similarly, we have observed differences in ride-through dynamics during and after fault clearing – small changes in the simulation (or fault location etc.) could trigger a threshold in the power electronic controller (say blocking for one simulation and continuing for another nearly identical simulation), resulting in large differences in the results.

Small changes in a model can greatly affect high frequency effects, including:

- Change in time step:
    - Corresponding changes in the damping of Bergeron and Frequency Dependant traveling wave line model due to the interpolation of the travel time. If the traveling wave travel time is not an exact integer multiple of the time step chosen, then the line models will interpolate the traveling wave to get a response on the time step grid – this interpolation effect adds high frequency damping, similar to a low-pass filter effect. This effect is increased with short lines with small travel times (relative to the time step).
    - Accuracy of the trapezoidal integrator at high frequencies (relative to the time step)
- Power Electronic Converter Representations:
    - Averaged source models vs IGBT/diode switching models
    - Use of lumped collector models vs detailed collector models and individual turbines
    - Method of scaling of distributed inverters:
        - The current injection scaling method is included in the PSCAD Master library, but can create negative damping and instabilities (due to the time step delay in the multiplication/injection of a measured current)
        - Electrical scaling (ie dividing all RLs be N, and multiply all capacitors by N, divide measured currents and PQ flows by N before the signals go into controls). This method

can result in numerical issues associated with small switch resistances (or failures in the solution due to numerous ideal branch loops).

        - Scaling Transformer – this method replaces a transformer with a short (one time step) Bergeron line model and "steals" a portion of the transformer inductance as the series impedance of the line. This method is guaranteed stable (as it is exactly a short Bergeron line in series with a normal transformer) but does introduce capacitance (ie the B necessary to get a one step Bergeron line model delay time). It could be argued that the B introduced is real (similar to transformer stray capacitance which is often neglected) but the B introduced is time step dependant (so the high frequency response is time step dependant).

- Selection of a line/cable model – uses are generally able to model a line with 3 different methods (each of which has intricacies in modeling):
    - PI Section models – these are the simplest to understand (as you can visualize the series RX and shunt B) but are the least accurate at high frequencies – in fact this model is only valid at 60 Hz, and will create high frequency resonances at a relatively high frequency (known as a Gibbs resonance) due to the lumped LC resonance. PI sections can sometimes be used for short lines (where the travel time requirements to use a Bergeron of frequency dependant line are too difficult).
    - Bergeron models – if you split up a line into an infinite small number of sections and used a pi to represent each section, then this would give the same answer as a Bergeron model. The distributed traveling wave representation will result in:
        - Reasonable accuracy over a wide range of frequencies (ie the resonances occur at the correct frequencies)
        - Undamped response at high frequencies (due to a constant XL/XC representation and lack of skin effect modeling)
        - Use of a constant transformation (this model can mistakenly show coupling for DC currents and other effects).
    - Frequency Dependant Phase Domain Line/Cable Models – these are the most accurate models available, and do include the skin effect and other frequency dependant effects. Even this model has intricacies, including varying high frequency damping due to the use of interpolation for non-integer multiple traveling waves (which is likely better than turning interpolation off, which would result in the wrong pattern of regularly repeating resonances).
- Other
    - Transformer saturation (and damping needed to stabilize time-step delayed injections of inrush current)
    - Use of multi-rate components - ie the scaling transformer or parallel processing line models have parallel processing counter-parts (so allow a PSCAD case to be split up into separate cases). If the time step is the same, the parallel Bergeron line model (and the scaling that can be performed with this model) is not an approximation (and results are 100.0% identical to a full non-scaled model). If the time step is different however, then similar to the PSCAD Master library traveling wave models (Bergeron or Frequency Dependant) the algorithms interpolate/extrapolate the traveling waves from each end, and traveling wave delays with non-

integer multiples of the time step will result in the use of interpolation (which can add high frequency damping depending on the time step alignments and travel time).

When the above intricacies are combined with non-linear controller models (which may have different control action depending on small variations that may be on one side or another of a non-linearity or critical mode switch) can result in very different results (for what may seem to be minor changes in a simulation).

Benchmarking RMS/Transient Stability Models

A related concern is the requirement to have RMS model results (for transient stability results) to precisely match EMT study results (say within X %). It seems like good engineering practice to specify some tolerances (ie X%) however in reality the fundamental differences between RMS/transient stability and EMT analysis makes even this seemingly generous level error margin difficult to achieve.

Some factors in the benchmarking (that make benchmarking difficult) include:

- Fundamental limitations in RMS transient stability tools to model any electrical effect except fundamental frequency. The RMS algorithm inherently cannot represent any electrical device effects other than fundamental – this includes:
    - Transient responses
    - Sub-synchronous effects (ie series capacitors)
    - Traveling wave effects
    - Non-linearities
- Power Electronic Controllers:
    - As discussed previously, many controllers have non-linearities or mode switches which depend highly on the input results – through inherent removal of all effects other than fundamental, the non-linear mode switch may occur on one case (or one type of simulation tool) but not the other
    - Many power electronic models use a PLL (phase locked loop) whose job is to track frequency and determine the angle of the AC voltage, During a fault, the AC voltages become very low (or zero) so the PLL often freezes its output – the precise nature of the PLL and the freezing logic will vary from the real controls/emt analysis as compared to rms/transient stability analysis. This can cause drastically different behaviour of the power electronic controller when comparing PSCAD to PSS/E (or other rms tools) due to the phase angle PLL locking effect etc.
- Differences during Fault and Immediate Fault Recovery Period
    - In addition to PLL effects, other transients can influence the EMT simulations, but would be different in the transient stability world (due to rms averaging and inherent differences it the solution algorithms).

In general, good comparisons between EMT and transient stability programs are relatively easy to achieve for simple models, but not so easy for power electronic controllers, particularly when operated in a weak grid. A good explanation of the differences from the supplier should still be expected, to document non-linearities or specific aspects of a given project which could justify different results.

Conclusions

The intricate EMT analysis factors discussed above make it difficult to directly compare rms/transient stability models to EMT models (ie PSS/E to PSCAD), particularly within a specific target like X % error comparison), and make it difficult to get consistent results for varying system simulation and events (particularly in weak grids where small changes can have larger impacts)

It is important to understand the nature of any discrepancies, and support from the manufacturer (who supplied the controllers/device models) is required to describe any mode changes, non-linearities, or sensitive parts of a controller, for a full understanding.

It is still recommended to perform benchmarks, but with an understanding of some of the above intricacies, and if justified, to be prepared to accept higher error tolerances during challenging periods of the overall simulation (such as during or immediately after a fault) or in weak networks. The overall response should be evaluated to ensure that the linear small signal portion (ie in steady state and after the immediate fault clearance portion) are valid.

The EMT/PSCAD result will be more accurate (ie using real-code models etc.), so should be the definitive result in the event any discrepancies are found.