Power system model decoupling for real-time simulation

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Introduction

The accurate decoupling of power system models is important when considering concurrent or parallel simulation. Decoupling allows bigger systems to be computed in real-time.

In power transmission systems, the presence of ‘long’ transmission lines allows the use of Distributed Parameter Line (DPL) models such as Bergeron line with losses or frequency-dependent line model (Wideband line model) that include explicit delays in their formulation. These delays, expressed in the z-domain by 1/z, allows for equation decoupling without any approximations. This technique in used since the mid-90s by RTDS Technologies in their power system simulators.

In distribution systems however, the typical line lengths much less and do not allow the use of DPL model directly. The threshold or line length can be approximated by the time it takes for a current-voltage wave to propagate along a line. Do let’s have the speed of light c (300000 km/s), and the simulation time step, Ts, in seconds.

The minimum length of a line, LLlim, to have a propagation delay greater than Ts is then equal to LLmin=c*Ts.

For aerial lines, the fastest mode is actually very close to the speed of light. So, with a time step of 25 microseconds, LLmin=7.5km. The propagation speed in cable is typically much less than in aerial lines. Considering a cable propagation speed of 200000 km/s, LLmin=5 km.

So when dealing with networks with line length less than LLmin, DPL cannot be used to decouple the power system equations and approximation model must be used.

The stubline

A stubline, in the context of power system simulation, is a special DPL model (i.e. a Bergeron line model with losses) in which the internal equations are tuned to obtain exactly a one time step propagation delay.

Normally in DPL, the propagation delay is computed with the following equations:

$$v = \sqrt{L * C}$$

$$\tau = l/v$$

L is the total line inductance (Henry); C is the total line capacitance (Farad); v= speed of propagation (m/s); l is the line length; τ is the propagation delay. For multi-phase lines, modal transformations produce similar model propagation delays.

In the stubline model, we instead set τ=Ts (the simulation time), then compute in reverse the DPL equation. In practice, a stubline will replace some existing inductance, typically a pi-line or a transformer leakage inductance. The approximation of the model will consequently be that the stubline will add some equivalent capacitance.

Typical stubline usages are shown is the IEEE 13 node standard model (MATE_IEEE13Node.slx), namely Compensated multi-phase stubline and transformer with stubline. The use of both model allowed the accurate decoupling of the IEEE 13 node model into 3 subsystems that can be computed concurrently on a proper target, such as SpeedGoat.

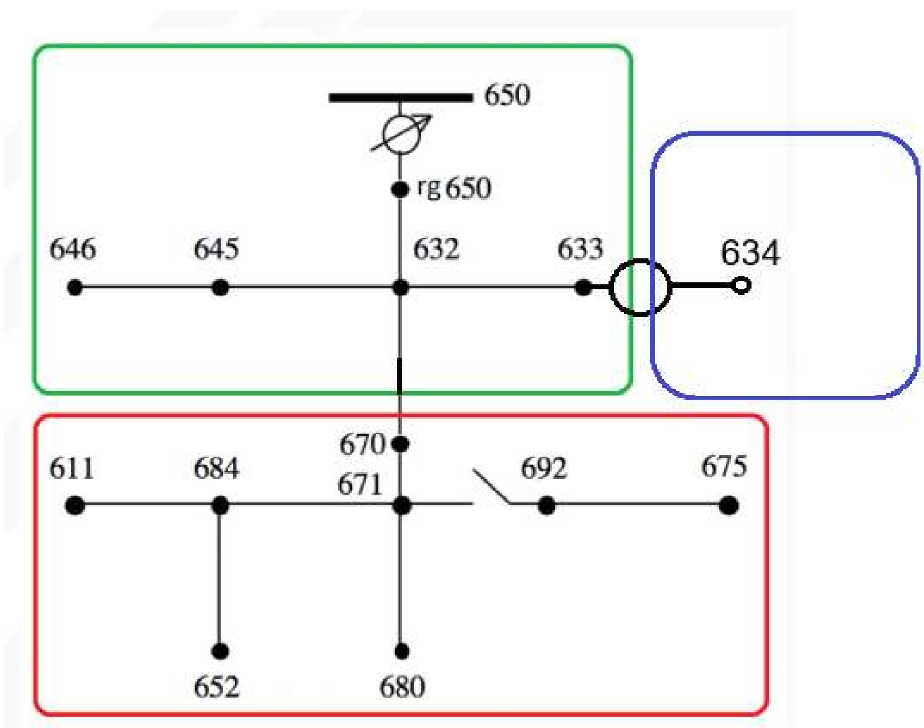

Figure 1 IEEE 13 node model

Stubline transformer

One of the most common usage of stubline is with power transformers. By replace the secondary leakage inductance and resistance by a stubline having the same inductance value, we have created a clever way to decouple the power system at the transformer connection points.

This is shown is the IEEE 13 node standard model (MATE_IEEE13Node.slx), where the stubline transformer is between nodes 633 and 634.

In the SimScape Electrical model, the stubline transformer appears like in Figure 2, in two parts. This specific implementation allows Simulink Coder to actually generate separated tasks. It is also possible to to make the model appear in a single block, including then both sides of the stubline transformer. The single block option will not permit to build distinct executable tasks but still decouples the systems of equations in 2 distinct and smaller parts, thus accelerating the simulation.

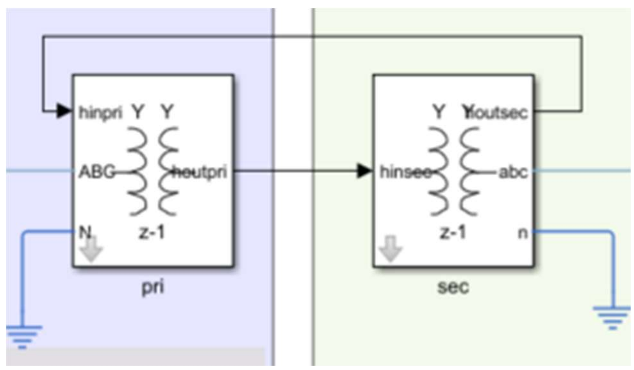

Figure 2: stubline transformer in 2 sections.

Compensated 3-phase stubline

In the same MATE_IEEE13Node.slx, a Compensated 3-phase stubline is used to decouple the grid between nodes 632 and 670-671, replacing the 2000 ft (0.61 km) line of the original model. The stubline has a one time step delay and the same total inductance; the internal stubline equation are then equivalent to a DPL of length of ~7km at 25 us. This is equivalent to adding spurious shunt capacitance (and reactive power) to the power system. The model is designed to compensate for the reactive power at the power frequency, by adding some shunt inductance.

Note that the 3-phase stubline is coupled, meaning that some phase-to-phase capacitance and mutual inductance in included in the resulting stubline. This is a better approximation than standard uncoupled 3-phase stubline which completely neglects inter-phase capacitances and inductance.

A single-phase-to-ground fault is made on bus 671 for test. Figure compares the original pi-line to the standard and Compensated stubline cases. Shown is the main feeder input current (bus 632): Compensated Stubline response matches the case with a real 2000 ft pi-line.

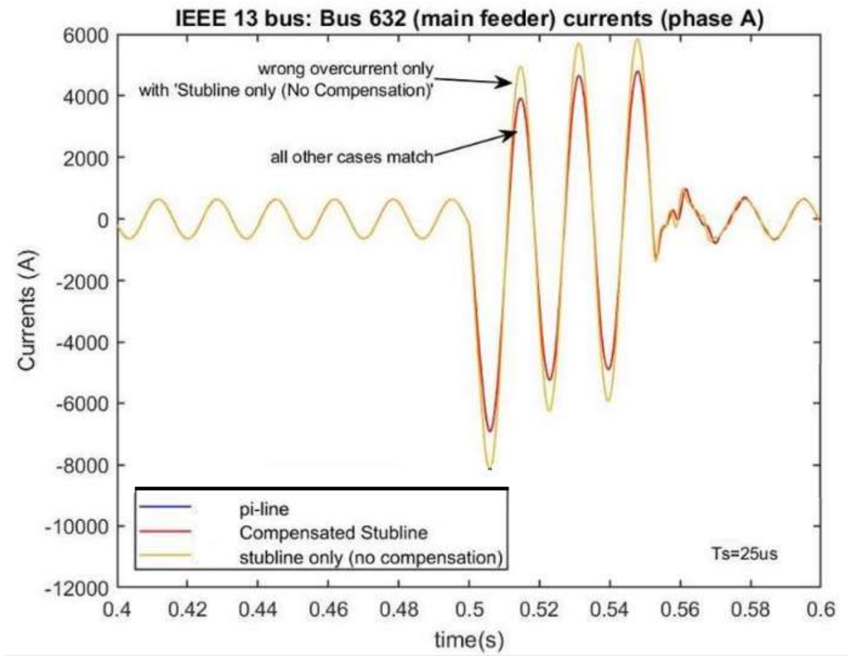

Figure 3 Single-phase fault response: main feeder input current

References

[1] B. Ahmed, A. Abdelgadir, N. Saied and A. Karrar, "A Compensated Distributed-Parameter Line Decoupling Approach for Real Time Applications," in IEEE Transactions on Smart Grid, doi: 10.1109/TSG.2020.3033145.