Open Implementation of Extended Piecewise Algorithm

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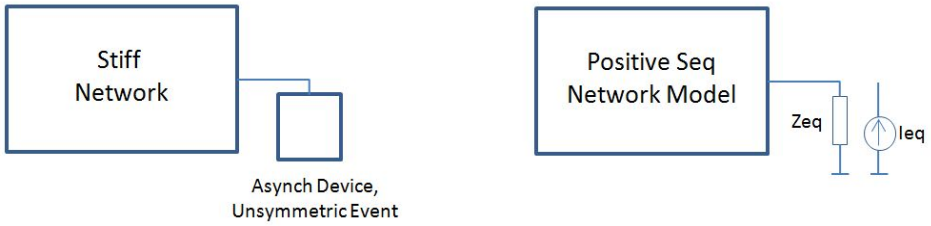
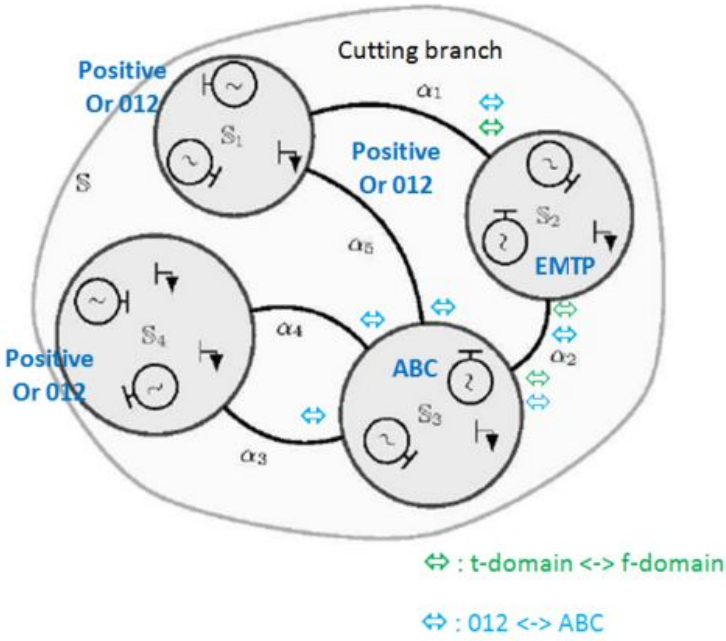
Background

Traditionally we model a power grid as a synchronous and "stiff" positive sequence network model in the transient stability (TS) simulation. Asynchronous devices, such power electronic devices, and unsymmetric events, such as single line to ground fault, are modeled as an equivalent impedance Zeq or equivalent bus inject current Ieq to the positive sequence network model, as shown in the following figure.



With the increasing installation of power electronic devices, such as PV and wind generation system, HVDC, FACTs, and the increasing penetration of distributed generation and power electronic based loads, portions of a power grid becomes inertia-less and more "dynamic". The existing positive sequence network model based transient stability simulation tools have inherent limitations in representing large number of power electronic devices and more "dynamic" distribution systems in detail.

Traditionally in the transient stability simulation, we use the [Y]-matrix to represent positive sequence network. In the foreseeable future, power grid as a whole will be operated a synchronous power transmission and distribution network. However, certain portions of a power grid, especially during the dynamic process, might exhibit strong asynchronous behaviour. To represent such a mixed synchronous and asynchronous behaviour, as shown in the following figure, a power network could be broken into a number of subareas connected by a set of cutting-branches. The sub-area might be represented by positive network model, 012 sequence network model, ABC three phase network model or time-domain EMTP network model. The cutting-branches are represented by a positive or 012 sequence network model. In the simulation process, network state variables (voltage or current) might need to be transformed between the time-domain and the frequency-domain, or between 012 sequence coordinates and ABC three phase coordinates.



The piecewise algorithm [1] could be used as the base to formulate our solution approach. In the piecewise algorithm the subarea network is represented by the [Y]-matrix and the cutting-branch network is represented by the [Z]-matrix, as shown in the following equation[1]:

$$\left[\begin{array}{cccc|c} \mathbf{Y}_1 & & & & \mathbf{P}_1 \\ & \mathbf{Y}_2 & & & \mathbf{P}_2 \\ & & \mathbf{Y}_3 & & \mathbf{P}_3 \\ & & & \mathbf{Y}_4 & \mathbf{P}_4 \\ \hline & & & & \mathbf{Z}_l \end{array}\right] \cdot \left[\begin{array}{c} \mathbf{v}_1 \\ \mathbf{v}_2 \\ \mathbf{v}_3 \\ \mathbf{v}_4 \\ \hline \mathbf{i}_l \end{array}\right] = \left[\begin{array}{c} \mathbf{i}_1 \\ \mathbf{i}_2 \\ \mathbf{i}_3 \\ \mathbf{i}_4 \\ \hline \mathbf{e}_l \end{array}\right]$$

$$\mathbf{Z}_l = \mathbf{Z}_0 + \sum_{\forall k} \mathbf{Z}_k \qquad \mathbf{e}_l = \sum_{\forall k} \mathbf{e}_k$$

$$\mathbf{Z}_k = \mathbf{P}_k^T \left(\mathbf{Y}_k\right)^{-1} \mathbf{P}_k \qquad \mathbf{e}_k = \mathbf{P}_k^T \left(\mathbf{Y}_k\right)^{-1} \mathbf{i}_k$$

$$\mathbf{P}_k(i,j) = \begin{cases} -1, & \text{if link } j \text{ injects current into bus } i \\ 1, & \text{if link } j \text{ draws current from bus } i \\ 0, & \text{otherwise} \end{cases}$$

For sub-areas represented by ABC three-phase network model or EMTP time-domain network model, they are treated by a set of injection currents at the cutting-branch network interface buses.

A New Piecewise Algorithm Based Hybrid Simulation

A new hybrid simulation tool, named OpenHybridSim, based on the above piecewise algorithm [2-4,7] has been developed in Prof. Vittal's research group at ASU. An important component within the tool is the implementation of piecewise algorithm for electromagnetic transient(EMT) and TS hybrid simulation. As discussed above, there are an increasing number dynamic phenomena that require integrated simulation approaches based on an extended piecewise algorithm, where there are more than one phasor representations in the phasor modeling portion of the system.

A Proposed Open Implementation

InterPSS[5] has open and flexible architecture. InterPSS power network model has been extended in the Hybrid-Simulation project led by ASU[3] to implement the extended piecewise algorithm. InterPSS development team provided strong support during the project implementation. It is our intention to refactor the extended piecewise algorithm implementation contributed by the Hybrid-Simulation project and make it available to the power engineering community, including higher level of abstraction, intuitive and easy-to-use programming API, detailed documentation, tutorial material and sample test cases. The primary goal of the open implementation is to make future InterPSS core library based Hybrid-Simulation-like project implementations more straight-forward and have minimum dependency on the InterPSS development team's support.

Software Development Methodology

InterPSS uses Java program language and the object-oriented programming approach[6]. Its development follows modern software development methodology and best practice. The same approach will be used in the proposed open implementation. The following is a code snippet for calculating network bus voltage using the piecewise algorithm.

```
// 1) create an AclfNetwork object
AclfNetwork aclfNet = ...;

// 2) define the cutting branch set
CuttingBranch[] cuttingBranches = new CuttingBranch[] {
                      new CuttingBranch("4->71(1)"), ...};

// 3) define a bus injection current calculation function
Function<AclfBus,Complex> injCurrentFunc =
        bus -> { return bus.isGen()?
              bus.getNetGenResults().divide(bus.getVoltage()) :
              new Complex(0.0, 0.0); };
```

```
// 4) process the SubArea topology
List<SubAreaPos> subAreaList =
     new SubAreaPosProcessorImpl<SubAreaPos>(aclfNet, cuttingBranches)
                .processSubAreaNet();

// 5) define a piecewise algo object and calculate the network bus voltage
//    based on the cutting branches set and the injection current
//    calculation function
PiecewiseAlgoPosImpl<SubAreaPos>(aclfNet)
           .calculateNetVoltage(subAreaList, cuttingBranches, injCurrentFunc);
```

As you might have noticed that some advanced programming concepts, such as functional programming, are used the piecewise implementation. A piecewise algorithm usage sample can be found here.

Participation

Any interesting party, including university research groups, research institutes and organizations, and volunteers are welcome to participate by contributing their resource or spare-time. Currently, the following parties have shown their interests to participate in the open implementation.

[1] InterPSS development team (www.interpss.org)
[2] Prof. V.J. Vittal's research group at Arizona State University
[3] Prof. Shen Chen/Chen Ying's research group at Tsinghua University

A GitHub project has been created for hosting the open implementation source code.

Reference

[1] José R. Martí, Luis R. Linares, Jorge A. Hollman, and Fernando A. Moreira. "OVNI: Integrated software/hardware solution for real-time simulation of large power systems." In Proceedings of the PSCC, vol. 2. 2002.

[2] Q. Huang, V. Vittal, "Application of electromagnetic transient-transient stability hybrid simulation to FIDVR study," IEEE Transactions on Power Systems, early access, 2015. DOI: 10.1109/TPWRS.2015.2479588

[3] Q. Huang, V. Vittal, OpenHybridSim, Aailable from: https://github.com/OpenHybridSim

[4] V. Vittal, "Hybrid Time Domain Simulation : Application to Fault Induced Delayed Voltage Recovery (FIDVR)", PSERC Seminar 2015 (available on the Web)

[5] InterPSS Project www.interpss.org

[6] E.Z. Zhou, "Object-oriented Programming, C++ and Power System Simulation", IEEE Trans. on Power Systems, Vol.11, No.1, Feb. 1996 pp 206-216

[7] Q. Huang, V. Vittal, "Integrated transmission and distribution system power flow and dynamic simulation Using Mixed Three-Sequence and Three-Phase Modeling", Accepted for publication in IEEE Trans. on Power Systems