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Dynamic Equivalents for RTDS Applications

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SUMMARY

Power electronics devices, including HVDC/FACTS devices and generator controllers, are among many critical technologies for ensuring and enhancing the controllability, reliability, and safety of modern power networks. As the penetration of these devices into the grid increases, their impact is becoming more significant, and careful investigation of controls interaction is becoming a standard requirement before the devices can be integrated into the grid. The typical design process for power electronic devices starts with studies performed using system data with tools such as PSSE. Once the high-level requirements have been established, a more detailed design is performed using time-domain tools such as PSCAD followed by verification in RTDS. The RTDS is a real-time simulator that can be used to represent network dynamics of interest, allowing connection and testing of the actual controls, significantly increasing confidence that the design will work correctly once installed in the field. The size and complexity of the network that can be represented on the RTDS is constrained by the size of the RTDS simulator requiring the development of dynamic equivalents. The modeling engineer typically spends a significant amount of time developing the optimal topology of the equivalent through a lengthy process of estimation, reduction, and validation against the full ac system.

The process of creating an accurate dynamic equivalent has been explored by several researchers before and can be categorized into two approaches. The first approach tries to keep as many real components as possible without introducing fictitious elements. These types of equivalents have been in use for a long time, and their primary purpose is to reduce the time required to run transient stability simulations for real-time applications such as security analysis. However, they are not suitable for RTDS simulations as they tend to be too big to fit in a typical RTDS setup. The second type of equivalent is mainly based on using fictitious equivalent components to represent system dynamics at the nodes of interest accurately. These are well suited for RTDS applications since the primary constraint applied while generating them is the capability of the RTDS equipment available. The second type is the focus of this paper. These types of equivalents have been developed in tools such as NETOMAC, but their implementation has been limited to trial and error requiring significant expertise as well as many iterations from the modeling engineers to obtain sufficiently accurate dynamic equivalents.

In this paper, a general approach is proposed, which starts with exact network constraints as determined by the RTDS setup. By focusing on reproducing the voltage and frequency at the nodes of interest, only fictitious generators with associated controllers are used to generate the equivalent. A topology consisting of generators and controllers that will fit in a given RTDS configuration is used as a starting point. The optimal parameters are then calculated using optimization routines in an iterative

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fashion. This is implemented as MATLAB routines, which can easily be ported to other platforms. A sample case study will be used to demonstrate the capabilities and accuracy of the routines. Future improvements planned will also be elaborated.

KEYWORDS

Static equivalencing, dynamic equivalencing, RTDS, PSCAD, PSSE, MATLAB, HVDC, FACTS devices.

INTRODUCTION

With the increased penetration of power electronics devices, including HVDC, FACTS and inverter-based renewables, the dynamic behavior of power grids is becoming more complex and coupled, making accurate dynamic representation essential.

In power system analysis, it is common practice to represent large parts of the interconnected grid by equivalents due to simulation limitations of tools like EMTP, PSCAD or RTDS. In contrast to equivalents motivated by reducing simulations times, in which case there are no hard constraints to meet for the reduction process, equivalents for RTDS have a hard constraint purely driven by the RTDS hardware available. As such, an automated tool that can take these constraints as an input and generate an accurate equivalent will be very useful for end-users eliminating a lengthy and error-prone trial and error approach.

In this paper, an automated set of tools for the automatic extraction of dynamic equivalents that is based on RTDS constraints is described. Given the closed nature of most commercial tools such as PSSE, a different approach is used. Instead of working within PSSE, conversion to MATLAB is first performed, followed by the extraction process. An existing library of tools based on the MATLAB language, PST [1], is used for basic load flow and transient stability analysis. PSSE data is converted to the PST format before being processed within MATLAB to generate the static and dynamic equivalents. The generated files are in PSSE format by default, but can also be saved in other formats including RTDS and PSCAD. A high-level overview of this process is shown in Figure 1. The figure shows different modules as part of the design, with the conversion routines separated from the principal reduction routine. This approach allows for more flexibility in terms of adding or improving functionality.

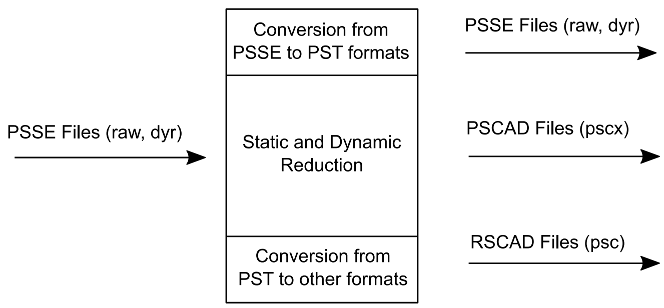

Figure 1 High level overview of the conversion tool showing the different components

Previous approaches to dynamic reduction have tried to balance between “real” and synthetic generators as part of the equivalencing process. A key component of this approach was determining the coherency of generators in the network to try and determine which ones can be aggregated together. By definition, this approach does not work with hard constraints in terms of the number of generators since the number of resulting generators in the equivalent are driven by coherency of the generators.

The approach in this paper bypasses the coherency check and uses only synthetic equivalents, which are not determined by network characteristics. Two steps are involved:

1. Construction of passive network to match the short circuit and load flow parameters at the equivalent nodes. [2]
2. Determination of the dynamic parameters of the synthetic generators and their associated controls to match the dynamic responses at the equivalent nodes.

This paper focuses on the automation and testing of the second part. Automation of the first part and the interfaces is currently in progress and is planned to be reported as a follow-up to this paper.

The next section describes the methodology used to generate synthetic dynamic equivalents based on hard constraints. This is followed by a description of sample results obtained using a 140 bus, 50 machine NPCC system [1]. Finally, future plan for the project is described.

METHODOLOGY

This section provides a description of the methodology used to create the dynamic equivalents. The first section describes the general approach to system modelling as it is done in transient stability problems. Once this is established, the dynamic reduction method is described and how it is fitted into the program.

Transient Stability Solution

In slower time scales of which transient stability is relevant, dynamic power system behaviour can be described in a set of differential-algebraic equations (DAEs) by assembling the differential equation models for generators, loads and other devices in the system and then connecting them appropriately via the network algebraic equations. In a simplified form, a typical solution process flow is shown in Figure 2 [3]. Initially, a load-flow solution is obtained and the values are used to back-calculate the initial values of rotor angles and fluxes of the generators. If there are generator controllers, the exciter initial values will be computed from the generator field voltage and the governor initial parameters will be computed from the mechanical input power. This is then followed by a time evolution simulation using a given time step calculating the network solution and dynamics calculations for each time step. For each time step, a check is also performed to determine whether there is a disturbance or not.

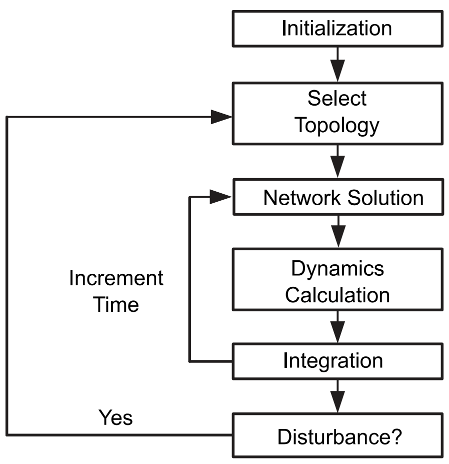

Figure 2 Typical solution flow for a transient stability problem.

In the network solution step, network currents are determined based on calculated voltages from the previous time-step. These currents are then used to calculate the generator field voltages and electrical power which in turn used to solve the dynamic equations of the network completing the cycle for one time-step. If there is a disturbance applied (i.e. switching of some sort), this will change the network topology resulting in a different admittance matrix for the given solution cycle.

Dynamic Equivalence Calculations

An important criterion for dynamic equivalents is to have the same responses at the buses of interest when comparing between the original case and the reduced case. The responses that capture system dynamic behaviour and need to match are: real power *P*, reactive power *Q*, voltage amplitude *V* and voltage angle θ [4]. Figure 3 shows the steps followed in the determination of the dynamic equivalent. The first step in the process is the size allowed for the equivalent network which constraints the number of equivalent generators allowed. Based on the number of generators allowed, a generic set of parameters is defined for each synthetic generator with an associated exciter and governor and they are given typical values as a starting point.

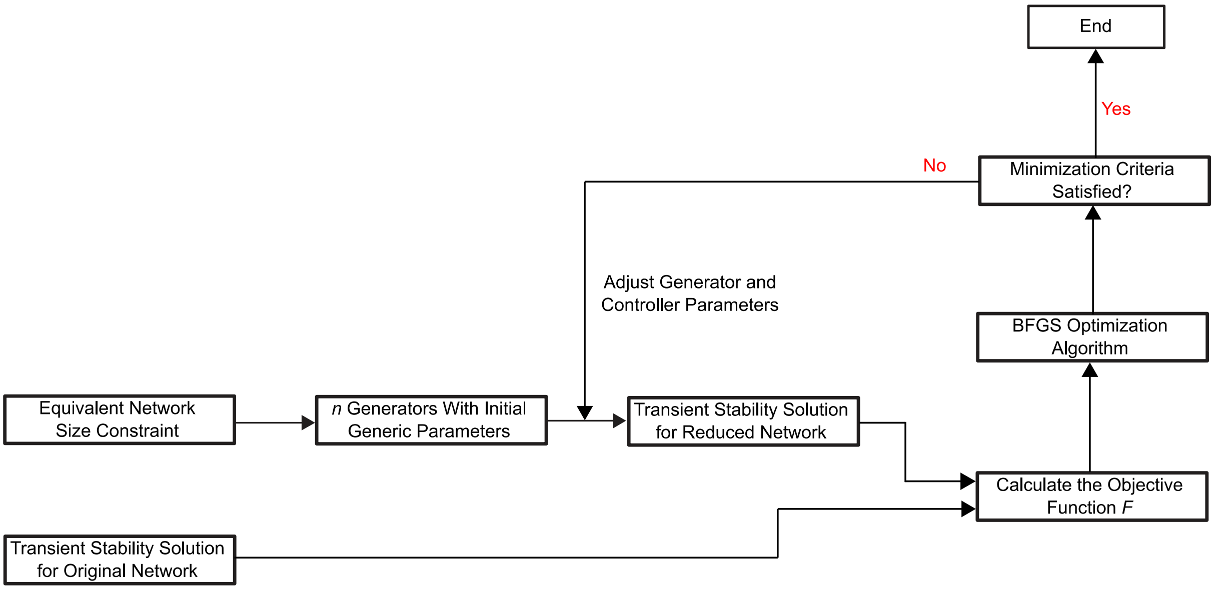

Figure 3 Typical solution flow for a transient stability problem.

An objective function F is defined as follows:

$$F = \int_{t=0}^{t} \sum_{i=1}^{k} \left\{ \left(\frac{P_{orig,i}(t) - P_{equiv,i}(t)}{P_{orig,i}(t)} \right)^2 + \left(\frac{Q_{orig,i}(t) - Q_{equiv,i}(t)}{Q_{orig,i}(t)} \right)^2 + \left(\frac{V_{orig,i}(t) - V_{equiv,i}(t)}{V_{orig,i}(t)} \right)^2 + \left(\frac{\theta_{orig,i}(t) - \theta_{equiv,i}(t)}{\theta_{orig,i}(t)} \right)^2 \right\}$$

The function compares the effective error for the key network parameters P, Q, V and θ between the original network and the equivalent network at the buses of interest (defined by parameter k). This is done over the simulation timeframe.

The objective function is then used as an input to an optimization algorithm that takes an array of initial generator and controller parameters as a starting point and iteratively calculates the parameters that will minimize the objective function.

SAMPLE RESULTS

This section shows a sample set of results obtained by reducing the NPCC system to a small case with two synthetic generators with exciters. The original system [1] had 50 machines with associated exciters and stabilizers for some of the machines. The structure of the generator models and the exciters for the synthetic equivalent were chosen from a subset of the orginal data and typical paremeters were used as a starting point. Figure 4 shows a comparison of the voltage response at the bus of interest between the original network and the reduced network and Figure 5 shows a similar comparison for real power flow in one of the transmission lines connected to the bus of interest. It can be seen that the reduced equivalent captures the responses well even though there are some discrepancies that are due to the limited number of parameters that can be optimized. Every additional generator in the reduced network will reduce the error further. With the overall process automated, it is possible for the user to rapidly run multiple cases with a different number of generators to determine the hardware required for a given desired accuracy.

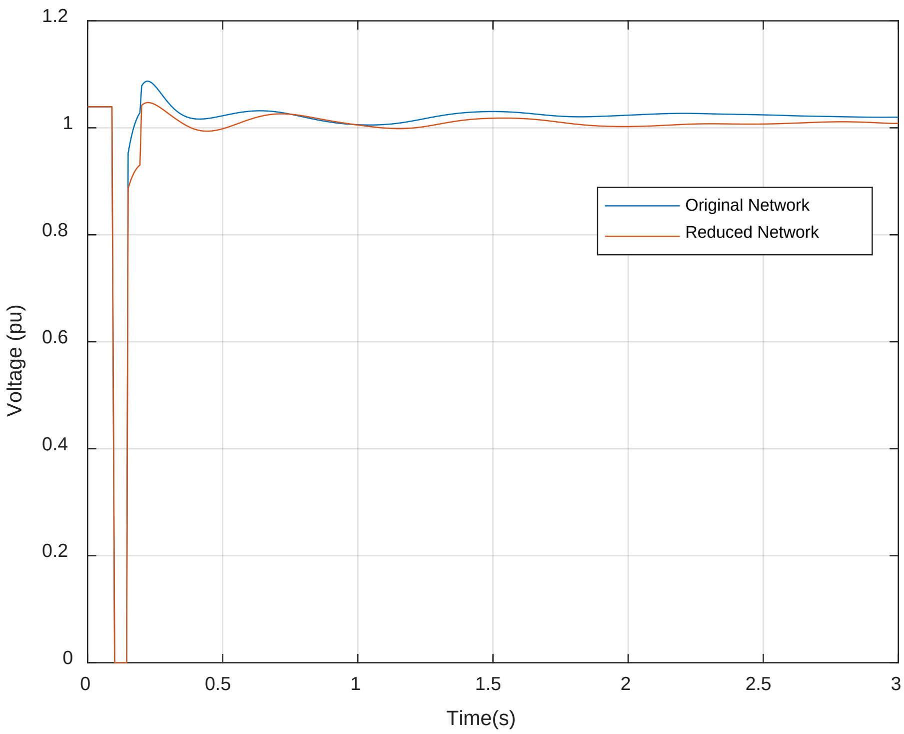

Figure 4 Comparison of bus voltage at the bus of interest between the original network and the reduced network.

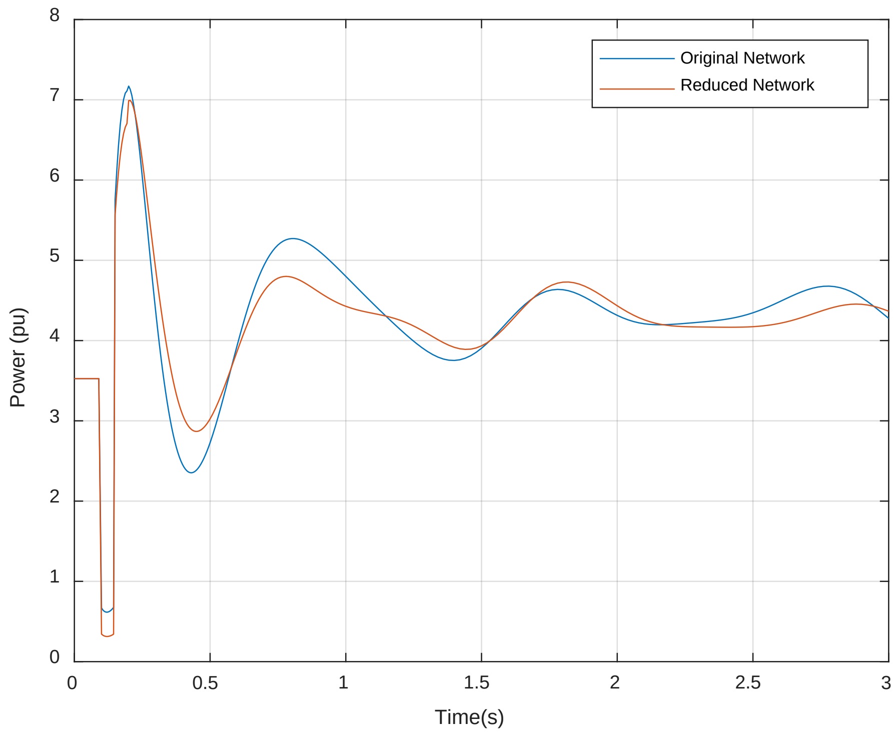

Figure 5 Comparison of a line real power flow at the bus of interest between the original network and the reduced network.

FUTURE WORK AND CONCLUSIONS

This paper describes an approach for creating dynamic power system equivalents using synthetic components. The method takes hard constraints in terms of the size of the equivalent as an input and determines the best equivalent by tuning the parameters of the synthetic generators. Instead of working directly with the large models in native software like PSSE, the cases are first converted to MATLAB. This open approach removes the dependence on closed platforms resulting in a more robust tool overall.

Current ongoing and future planned work includes the following tasks:

- Development of the interface routines to interface with PSSE, RTDS and PSCAD.
- Exploration of alternative optimization methods to increase robustness
- Integration of the static equivalencing procedure into the automated tool

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