Coalesced Transmission, Distribution and Energy System Storage Modeling for Power System Stability Analysis

A. Task Team

Faculty: PI: Prof. Luigi Vanfretti (RPI)

Graduate Students: Marcelo de Castro Fernandes

B. Executive Summary (to be provided to industry)

This project aims to establish an integrated modeling framework to unify, at *the equation level,* transmission network models (i.e. those typically developed in the positive-sequence reference frame, e.g. in PSS/E) with three-phase models of sub-systems, such as those used to represent detailed power distribution networks and power electronic-based devices (e.g. EMTP). The proposed modeling approach should allow to study distribution networks with large amounts of renewable energy sources (RES) in the form distributed energy sources (DER) and energy storage, both distributed and utility-scale, to understand the impact of their control and protection systems and power electronic devices on bulk system stability without compromising their modeling detail.

C. Problem Statement

Current power system modeling and simulation methods require the user to analyze different behavior in different modeling tools. Positive-sequence models are developed for extra high voltage transmission and subtransmission networks due to their virtually nonexistent unbalancies [1]. On the other hand, distribution networks require a three-phase modeling approach due to the unbalanced nature. The two systems are modeled and studied separately, in different tools. Similarly, EMT models are developed to design and analyze the operation of power electronic-based devices, such as high frequency converters used in the connection of energy storage and renewable energy generation systems to the power grid. Nevertheless, the impact of distribution networks with high levels of RES-based DER penetration and energy storage systems are not decoupled from the bulk power network, and with the constant increase of the connection of such systems in the power grid, a unified analysis framework should be developed.

This project addresses this problem by proposing a “modeling magnifying glass”. This magnifier would allow an analyst to “zoom” into a specific portion of the power network and be able to specify the granularity of the model’s mathematical description without requiring the co-simulation of two separate models with different modeling detail in two different platforms, but instead models are coalesced at the equation level using physically meaningful interfaces. Hence, such a concept would require developing a unified modeling framework that can help increase the granularity of the selected portion of the model.

An integrated modeling framework and associated analysis methods may enable analysts to better understand the dynamics of more integrated models. To avoid tool-specific simulator interaction, and to leverage advances in the field of *openly standardized* computer languages, this project will leverage the Modelica standardized language to develop large-scale "hybrid" models.

D. Task Goals and Focus

The focus of the project will be largely concentrated on integrated grid modeling of transmission and distribution systems, with RES-based DER and storage systems. The modeling will be such that it can represent correctly the dynamics and controls of all these systems. The models will be developed using the standardized Modelica language and will complement and expand the OpenIPSL library of power system components to include the additional needed models, i.e. distribution networks, RES-based DER, storage systems, and power electronic devices. In order to couple the EMT-like to three-phase phasor-based models, a specific interface will be designed. It is also a focus to make the modeling developments available through the open source software library.

The following tasks are proposed in this work:

A. Enhancement of "hybrid" power system component models which allow to physically couple positive sequence models to three-phase models.
B. Development of an interface between EMT-like and three-phase phasor representations.
C. Development of "active" distribution network models including RES-based DER dynamics, control and protections.
D. Development of storage systems models with different levels of granularity, from simple dynamic models, to full three-phase EMT-type models.

E. Background and Justification

The world is undergoing an important transition regarding electrical power systems [2]. The power transmission and distribution based on large-scale centralized generation plants may be replaced in the coming years by a new architecture, based on small-scale distributed energy resources (DERs). These sources are, commonly, based on renewable energy resources and integrated at lower voltage grid levels, which can lead to challenges in wide-area power system operation. This aspect will become more important for transmission system operators for several countries, such as Germany [3] and the United States, as they continue to expand their fossil-fuel-free energy initiatives. In areas with large penetration of DERs, the system becomes very sensitive to frequency variations because the system inertia is low. In addition, DERs are mainly dependent on environmental conditions, creating intermittencies in power injection.

In this context, energy storage systems and the very ones DERs may help manage the loss of inertia in the system by giving a more controlled and predictable output in response to network changes or disruptions. In addition, these systems may provide essential ancillary services needed to ensure bulk power system reliability [4] in the expected increase of 35 gigawatts (GW) of capacity, about 70% of which comes from variable generation sources [5].

This project will enable modeling and integrated simulation of joint transmission & distribution system dynamics (i.e. "transient" stability simulations), RES-based DERs and energy storage devices, their control systems and protections, *without creating a specialized power system transient stability simulation tool*; but instead, by taking advantage of the Modelica standardized modeling language and other computational tools that will be expanded or developed within the project. The results will enable much faster analysis of DER and energy storage systems impacts on both transmission and distribution systems, providing a unique solution for the transient dynamics time domain, ultimately leading to higher reliability and lower costs in expediting clean DER technology.

F. Technical Approach and Scope

The Modelica language is a non-proprietary, open-source, object-oriented, equation-based language developed since 1996. The language enables users to easily model physical systems described by differential, algebraic, and discrete equations with time and state events, using equation-based unambiguous representation of the system dynamics. In addition, Modelica tools usually support the FMI standard avoiding vendor lock-in, because the same models can be used with different tools.

OpenIPSL [6] is a library of power system components developed using the Modelica language and, therefore, its models take advantage of the rich-features associated with the language. The library is developed by the technical lead of RPI during and after the EU-FP7 iTesla project [7]. Each of the components in OpenIPSL can be used to model a power system using the “positive sequence” representation (for the transmission grid), including the dynamics of energy sources, their controls, and loads.

The OpenIPSL library now includes a vast number of components, most of which have gone through a software-to-software verification against domain-specific tools, mainly PSS/E, which provides confidence in the models developed. In addition, it is possible to model power networks for stability analysis routines, such as small-signal analysis via linearization of the system model, and nonlinear simulations by using any of the solvers available in Modelica tools.

This project will expand the capabilities of the OpenIPSL library, to provide models of DERs, energy storage and distribution systems with transient dynamic behavior representation, which are needed for analysis of networks. In addition, it is necessary to modify some existing models for typical components (e.g., generators and loads) so they can be coupled in three-phase models, and not only positive sequence; this will be achieved by joint modeling through the “Monotri” *physical coupling approach* [1],[8].

G. Expected Outcome/Benefits and Deliverables

A. An integrated modeling framework to unify, at *the equation level,* transmission network models with three-phase models of sub-systems, such as those used to represent detailed power distribution networks and power electronic-based devices.
B. New insight on the impact of control/protection systems from RES-based DER and storage systems on bulk system stability as emerging from lower voltage networks.
C. The models will be developed using the standardized Modelica language and will complement and expand the OpenIPSL library of power system components to include additional distribution network and RES-based DER modeling capabilities; making the majority of modeling developments available through this open source software library.

H. Plan for Demonstration in Testbed(s)

Using the Opal-RT real-simulation targets at RPI, the developed models will be recomposed for use in the ePhasorSim simulation environment for demonstration purposes. The Opal-RT targets will be used for ultra-fast simulation. The aim to show issues with model portability, and simulation performance between three tools: ePhasorSim, Dymola, and OpenModelica when dealing with large scale transmission and distribution models.

I. Expected Tech Transfer (e.g., report, software, hardware, demonstration, other)

A. All developed models to be integrated into the OpenIPSL library, which is open source software, and released on Github.
B. Documentation of the OpenIPSL library components developed.
C. Power electronic-based component devices, including energy storage, will be included in a new MicroGrid library. This library will be developed to expand the capabilities of OpenIPSL which only deals with positive-sequence power system dynamic models.
D. New methods for version control, verification, and maintenance of the developed libraries through a cloud-based continuous integration and regression testing infrastructure

J. References

[1] Marinho, J. M. T., & Taranto, G. N. (2008). A hybrid three-phase single-phase power flow formulation. *IEEE Transactions on Power Systems*, *23*(3), 1063-1070.
[2] International Energy Agency - IEA (2017). World energy outlook 2017. OECD/IEA. Paris, France.
[3] Federal Ministry of Economics and Technology, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2010). Energy concept for an environmentally sound, reliable and affordable energy supply. Berlin, Germany.
[4] New York Battery and Energy Storage Technology Consortium (2016). Energy storage roadmap for New York's electric grid. Albany, New York, United States of America.
[5] North American Electric Reliability Corporation - NERC (2015). Integration of variable generation task force: summary and recommendation of 12 tasks. NERC. Atlanta, Georgia, United States of America.
[6] OpenIPSL. Link: http://openipsl.org.
[7] iTesla Project. Link: http://wiki.uvig.org/index.php/Main_Page.
[8] G. N. Taranto, J. M. T. Marinho, D. M. Falcão, T. M. L. Assis, S. L. Escalante, J. I. R. Rodriguez & C. E. V. Pontes, "Simulador de Redes de Distribuição Ativas com Modelagem Monofásica/Trifásica" (SEPOPE 2012). In Portuguese.

K. Statement of Work for 2019-2020

Project:	Task													
Statement of Work		**Schedule**												**Subtask Milestones and Deliverables**
No.	Subtask Description	2019					2020							Description
		A	S	O	N	D	J	F	M	A	M	J	J	
1	Enhancement of “Hybrid” component	X	X	X	X	X								Enhancement of hybrid three-phase/positive-sequence formulation. Development of a documentation to allow the use of such interface. Update hybrid models in OpenIPSL.
2	Development of interface between EMT-like and phasor-based models			X	X	X	X	X						Development of interface between wave and phasors to allow the development of detailed power electronics models.
3	Development of EMT-like models for RES-based DER				X	X	X	X	X	X	X			Development of detailed power electronic models to assemble RES-based distributed energy resources such as PV panels.
4	Development of EMTP-like models for energy storage							X	X	X	X	X		Development of detailed power electronic models to assemble converters needed for energy storage systems.
5	Development of Large Scale Test Systems								X	X	X	X	X	Implementation of large systems, such as WECC model, to test the proposed interface and approach.
6	Implementation and Testing	X	X	X	X	X	X	X	X	X	X	X	X	Implementation of the proposed models and methods in Modelica and additional platforms.