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Generic EMT Modeling for IBR

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Prepared for
Essential Grid Operations for Solar (EOS) Project

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Generic EMT Modeling for IBR

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In support of IEEE P2800.2, PNNL is developing an informative annex about "Generic EMT Modeling for IBR". A literature review has been conducted, covering an IEEE Task Force, Cigre Working Group, IEEE standards, NERC reports, and research articles. In addition, the vendors of widely used simulation tools have been contacted to verify the availability of real-code models of inverters. Illustrative computer simulations will be conducted, once real-code models become accessible. If the simulation results of a real-code model are obtained, a comparative study will be performed.

Motivation and Goal

The EMT models of IBR include the generic, custom, and real-code types. Generic models are publicly documented and used without confidentiality restrictions, but they are less accurate than real-code models. They are typically tested under selected conditions without protection models. In addition, the same generic model may vary with respect to its development in different simulation tools, e.g., PSCAD, EMTP®, PowerFactory, Simulink, etc. Real-code models include the actual inverter control logic, including protection functions, in simulation. They are the most accurate, but are not always available from inverter vendors. When available, real-code models may run in just one simulation tool, and require NDAs to address IP concerns. Furthermore, real-code models cannot be obtained until the inverter hardware product has been selected for installation. In planning stages, generic models are needed for computer simulation and analysis.

If generic EMT models are not used properly for stability analysis, the deviation from real-code models and field performance can be significant, leading to severe contingencies. The goal of this effort is to show how generic models can be used in EMT studies, and to compare results between generic and real-code EMT models. Guidance on the development of generic models is not in scope of this effort, because research papers and task forces already cover that topic. Instead, PNNL aims to provide industry guidance for situations when generic models must be used. The informative annex will:

- illustrate the differences between real-code and generic models in EMT simulations,
- illustrate the impact of real-code model parameters and settings on EMT simulations,
- provide references on the selection and usage of generic models.

Literature Review

In [1], protective replays are investigated using the currents and voltages obtained from a study, in which EMT simulations are performed using real-code models of inverters. It provides

insights into the line-protection challenges in systems with IBRs, considering the delay in IBR response time and the present lack of standardization in most countries. The behavioral similarities and differences between different types of IBRs are considered and characterized. It also provides application guidance that allows adjustment of relay settings already deployed in the field.

There are several identified cases in which IBR stability was incorrectly predicted due to the inaccurate models of inverters. On August 16, 2016, the Blue Cut Fire erupted in Southern California's Cajon Pass, leading to the unexpected loss of 1,200 MW of solar PV power generation. This event is considered as severe. Details of this event are reported by NERC in [2]. This type of event highlights the importance of EMT modeling, and is actively investigated by the NERC IRPWG.

There are not established common practices for EMT models of IBR. To address this, a joint IEEE Task Force on "Use of Real-Code in EMT Models for Power System Analysis", and Cigre Working Group B4.82 on "Guidelines for Use of Real-Code in EMT Models for HVDC, FACTS and Inverter based generators in Power Systems Analysis", have begun work on a binary-level dynamic link library (DLL) model interface. The joint IEEE/Cigre team will also provide guidance to manufacturers, utilities, consultants, and system operators on the development and use of real-code EMT models. A recent Cigre publication [3] provides guidance on balance-of-system EMT models for IBR impact studies.

In 2020, IEC 61400-27-1:2020 [4] defined standard electrical simulation models for wind turbines and wind power plants. It also defines generic terms and parameters for electrical simulation models. The specified models are time domain, positive sequence simulation models, intended for use in power system and grid stability analyses. Models are applicable for dynamic simulations of short-term stability in power systems.

In 2022, IEEE Std. 2800-2022 [5] provided uniform technical minimum requirements for the interconnection, capability, and performance of IBRs interconnecting with transmission and sub-transmission systems. The on-going P2800.2 will define recommended practices for test and verification procedures that should be used to confirm plant-level conformance of IBRs interconnecting with bulk power systems in compliance with IEEE Std. 2800-2022.

Some utilities may have specific requirements and guidance on the model of IBRs. For instance, the requirements of National Grid are reported in [6]. Firmware code may be directly used to create an extremely accurate PSCAD model of the controls. The controller source code may be compiled into DLLs or another binary format if the source code is unavailable due to confidentiality restrictions.

A custom EMT model would accurately represent a specific IBR, without incorporating real control code. There are pitfalls in assembling these custom EMT models using standard blocks from the PSCAD master library, or any other simulator's library. Furthermore, models manually translated block-by-block from MATLAB or control system drawings may be unacceptable.

These processes are all essentially manual. They are subject to errors of interpretation, missing functionality in built-in simulator components, erroneous handling of limits, unrecognized interactions, dependencies between blocks, etc. Extra validation steps are required for manually assembled models, leading to a validated custom EMT model.

Real-Code Model Access

PNNL contacted many inverter vendors and simulation vendors about the availability of real-code EMT models for IBR. In a typical response, one vendor replied, "some manufacturers have real-code models available in [product] but they are not available for the public." Even the manufacturer identities could not be shared. Anecdotally, we know real-code EMT models are available for EMTP, PowerFactory, PSCAD, Simulink, and possibly more software-only simulators. In [1], it is reported that four IBR manufactures provided real-code EMT models for a study initiated by NERC and led by SNL, comprising a mix of Type 3 Wind, Type 4 Wind, and Solar PV IBR models. Clearly, multiple OEMs have developed real-code models in PSCAD for EMT simulations. In other projects, PNNL researchers have also been able to use real-code models, but the NDAs are not extensible to the EOS project. Inverter vendors are especially reluctant to publish results from real-code models that could be used to reverse-engineer the product, or disclose proprietary design innovations.

Computer Simulations

The behaviors and responses of IBRs and synchronous generation resources differ during power system faults. When generic EMT models are adopted for simulations, results are less accurate compared with results from real-code models. This brings additional challenges to protection system design, and operating reliability. Because the topic is so important, EOS is taking steps to obtain real-code EMT model results for comparison to generic EMT model results, under controlled conditions that allow for publication. These comparisons will be performed on a test power system of limited size.

For IBR model evaluations at a larger scale, PNNL will use and extend two test power systems that have publicly available data [7, 8]. Model developers and users could then use these test power systems for model development, validation, and acceptance testing.

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Abbreviations

- Cigre, International Council on Large Electric Systems
- DER, Distributed Energy Resource
- DLL, Dynamic Link Library
- DOE, U. S. Department of Energy
- EMT, Electromagnetic Transient
- EOS, Essential Grid Operations from Solar
- FACTS, Flexible Alternating Current Transmission System
- HVDC, High-Voltage Direct Current
- IBR, Inverter-Based Resource
- IEC, International Electrotechnical Commission
- IEEE, Institute of Electrical and Electronics Engineers
- IP, Intellectual property
- IRPWG, Inverter-Based Resource Performance Working Group of NERC
- NDA, Non-Disclosure Agreement
- NERC, North American Electric Reliability Corporation
- OEM, Original Equipment Manufacturer
- PNNL, Pacific Northwest National Laboratory
- SNL, Sandia National Laboratories
- WECC, Western Electricity Coordinating Council