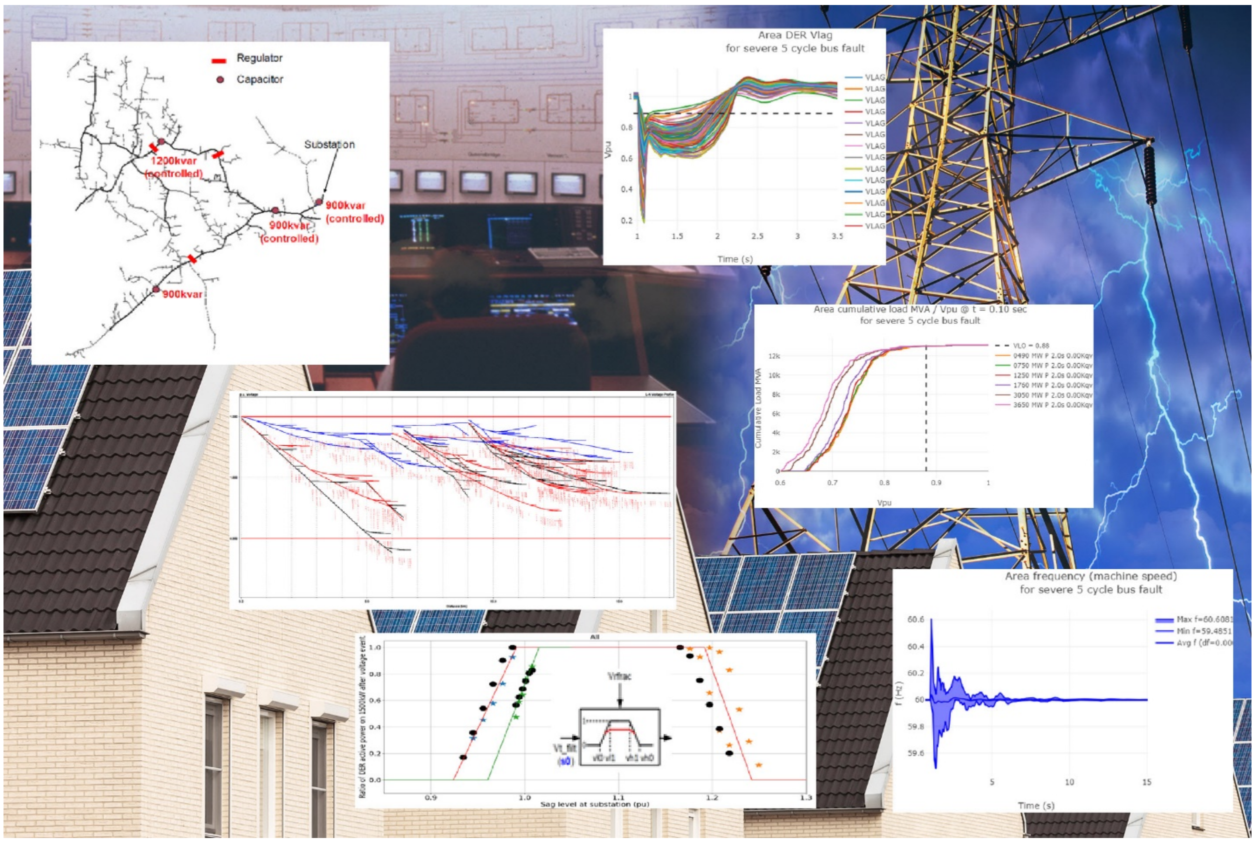
DER Modeling Guidelines for Transmission Planning Studies

2018 Summary

3002013503



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Technical Update, December 2018

EPRI Project Manager

J. Boemer

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

THE ELECTRIC POWER RESEARCH INSTITUTE (EPRI) PREPARED THIS REPORT.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

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Principal Investigators
D. Ramasubramanian
K. Dowling
E. Vittal
P. Mitra
A. Gaikwad
J. Boemer
P. Dattaray
I. Alvarez-Fernandez (intern)

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ABSTRACT

The installed capacity of distributed energy resources (DERs) has been increasing significantly in recent years. Experiences from the United States and other countries around the world have shown that the actual deployment of residential photovoltaic systems may occur even faster than anticipated. High-penetration of DERs presents new challenges in the planning and operation of bulk power systems. Adequate modeling of DERs in transmission-planning studies is required to address challenges about ensuring adequate bulk system reliability in terms of voltage and frequency performance under high levels of DERs, and to explore the contribution of new emerging technologies. This report summarizes key results from detailed investigations discussed in other Electric Power Research Institute (EPRI) reports. The high-level findings and methods presented in this report can help transmission-planning engineers in Independent System Operators (ISOs), transmission owners (TOs) and operators, and vertically integrated utilities with transmission-planning responsibilities to analyze the bulk system with large amounts of DERs—with the ultimate goal of maintaining bulk system reliability in the future.

Keywords

Advanced/Smart Inverters
Bulk system reliability
Case study
Distributed energy resources (DERs)
Partial voltage trip
Ride-through and trip

EXECUTIVE SUMMARY

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Product Type: Technical Update

Product Title: DER Modeling Guidelines for Transmission Planning Studies: 2018 Summary

PRIMARY AUDIENCE: Transmission-planning engineers in Independent System Operators, transmission owners and operators, and vertically integrated utilities with transmission-planning responsibilities

SECONDARY AUDIENCE: Researchers, consultants, policy makers

KEY RESEARCH QUESTION

High-penetration of distributed energy resources (DERs) presents new challenges in the planning and operation of bulk power systems. Adequate modeling of DERs in transmission-planning studies is required to address challenges about ensuring adequate bulk system reliability in terms of voltage and frequency performance under high levels of DERs, and to explore the contribution of new emerging technologies.

RESEARCH OVERVIEW

This report summarizes key results from detailed investigations discussed in other Electric Power Research Institute (EPRI) reports. The high-level findings and methods presented in this report can help transmission-planning engineers in Independent System Operators (ISOs), transmission owners and operators, and vertically integrated utilities with transmission-planning responsibilities to analyze the bulk system with large amounts of DERs—with the ultimate goal of maintaining bulk system reliability in the future.

KEY FINDINGS

- DERs should not be netted with load, but should be explicitly modeled in power flow and dynamic stability studies for bulk system planning. Minimum data requirements and the sharing of information across the transmission and distribution (T&D) interface will have to be ensured in order to allow adequate assessment of future DER deployments.
- The *der_a* model presented in an EPRI White Paper (Product-ID 3002013498) was approved by the Western Electricity Coordinating Council (WECC) Modeling and Validation Work Group in March 2018, and has been endorsed by the North American Electric Reliability Corporation (NERC) Load Modeling Task Force. The model is a significant step forward on DER modeling for transmission planning studies. The *der_a* model strives for a reasonable balance between modeling accuracy, computational requirements, and handling of the system model. Going forward, the *der_a* model should be the model of choice to represent retail-scale DER (R-DER) and, to a certain extent, utility-scale DER (U-DER) in a bulk system planning case. Its availability in commercial modeling software is discussed in the body of this Technical Update.
- The parameters *vl0, vl1, vh1,* and *vh0* and *Vrfrac* of the *der_a* model represent the partial voltage tripping characteristic of legacy DER, and the dynamic performance of modern DER that ride through abnormal voltage conditions. Their values are regionally specific and may differ significantly from thedefault values provided by WECC. The Technical Update *Detailed Distribution Circuit Analysis and Parameterization of the Partial Voltage Trip Logic in WECC's DER Model (DER_A)* (Product-ID 3002013500), proposes some default values that are currently considered for inclusion in an updated DER modeling guideline by NERC's Load Modeling Task Force (LMTF).
- The Aggregate Distributed Energy Resource Model Integration (ADMI) Tool for Siemens PTI PSS®E, first published by EPRI in 2017, has been updated with various improvements, including new flexibilities to use various load models, allow multiple U-DER on the same bus, and compatibility for

PSS®E versions v33.11+ and v34.3+. The tool (Product-ID 3002014316) automates the process to explicitly represent the distribution circuit, along with the load and DER, in a power flow case on user-specified substations of the bulk system model.

- A case study analyzing the impact of aggregate DERs on a large bulk power system presented in an EPRI Technical Update (Product-ID 3002013502) applies the research results and software tools listed above to analyze the impact of aggregate amounts of utility-scale DER (U-DER) on a large bulk power system. The scope of the study included a sensitivity analysis with regard to various contingencies, DER rated penetration level, under voltage trip clearing delay, inverter current priority setting, as well as the dynamic voltage support gain and deadband. The analysis was carried out in close collaboration with Duke Energy Progress.

WHY THIS MATTERS

The installed capacity of DERs has been increasing significantly in recent years. Experiences from the United States and other countries around the world have shown that the actual deployment of residential photovoltaic systems may occur even faster than anticipated. Only when transmission planners have the models and tools available to analyze the aggregate impact of these DERs on the voltage and frequency performance of bulk power systems, can they take appropriate measures to ensure that the reliability of the bulk system is maintained under high levels of DERs.

HOW TO APPLY RESULTS

Transmission planners can immediately apply these DER modeling guidelines to their transmission planning studies. The updated ADMI tool helps users of Siemens PTI PSS®E in the automated creation of study cases with DER. However, the guidelines developed in this research are also applicable to other commercially available software. The presented guidelines of this report go beyond the latest DER modeling guidelines provided by the Western Electricity Coordinating Council (WECC) and the North American Electric Reliability Corporation (NERC). Following the EPRI modeling guidelines presented in this report will lead to more accurate simulation results for bulk system models in which the aggregate penetration of DERs relative to the total substation load is significant, and in which the impact and potential bulk system benefits of advanced smart- inverter functions need to be analyzed.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- EPRI Load Modeling Research and Modeling and Model Validation Tools User's Group (MMVT UG)
- WECC Modeling and Validation Work Group, Renewable Energy Modeling Task Force, and Load Model Task Force
- NERC System Analysis and Modeling Subcommittee and Load Modeling Task Force
- IEEE Power System Dynamic Performance Committee, Wind and Solar Working Group, Task Force on Contribution to Bulk System Control and Stability by DERs connected at Distribution Networks (completed, a report was published in 2018)
- CIGRE JWG C4/C6.35/CIRED Modeling and dynamic performance of inverter-based generation in power system transmission and distribution studies (completed, a report was published in 2018)

EXECUTIVE SUMMARY

EPRI CONTACTS: J.C. Boemer, Principal Technical Leader, jboemer@epri.com

PROGRAM: Transmission Planning (P40) and Bulk System Integration of Variable Generation (P173)

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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1
INTRODUCTION

Background and Context

The installed capacity of distributed energy resources (DERs) has been increasing significantly in recent years. Experiences from the United States and other countries around the world have shown that the actual deployment of residential photovoltaic systems may occur even faster than anticipated. High penetration of distributed energy resources present new challenges in the planning and operation of bulk power systems. Adequate modeling of DERs in transmission-planning studies is required to address challenges about ensuring adequate bulk system reliability in terms of voltage and frequency performance under high levels of DERs, and to explore the contribution of new emerging technologies. Figure 1-1 illustrates the continuous and interrelated improvement of distributed energy resources modeling and interconnection requirements through system studies and actual incidents.

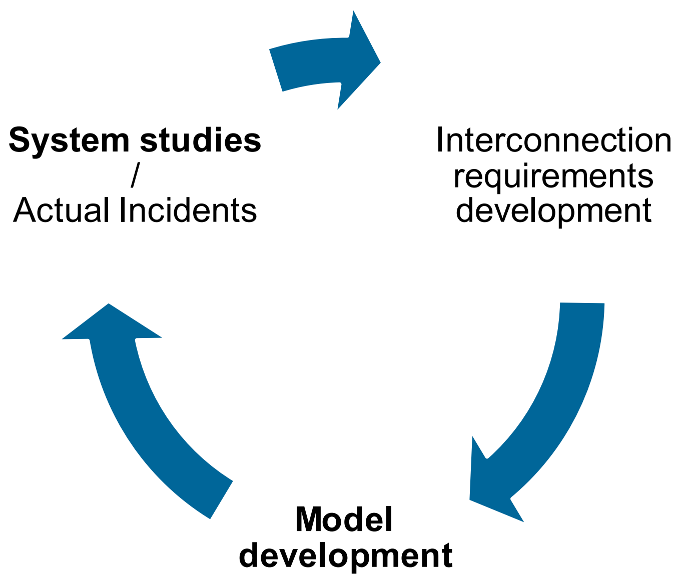

Figure 1-1
Continuous and interrelated improvement of distributed energy resources modeling and interconnection requirements through system studies and actual incidents.

Adequate, and accurate, modeling of DERs in transmission-planning studies is based on three pillars as illustrated in Figure 1-2:

- Accurate model specification
- Accurate model integration
- Accurate model parameters

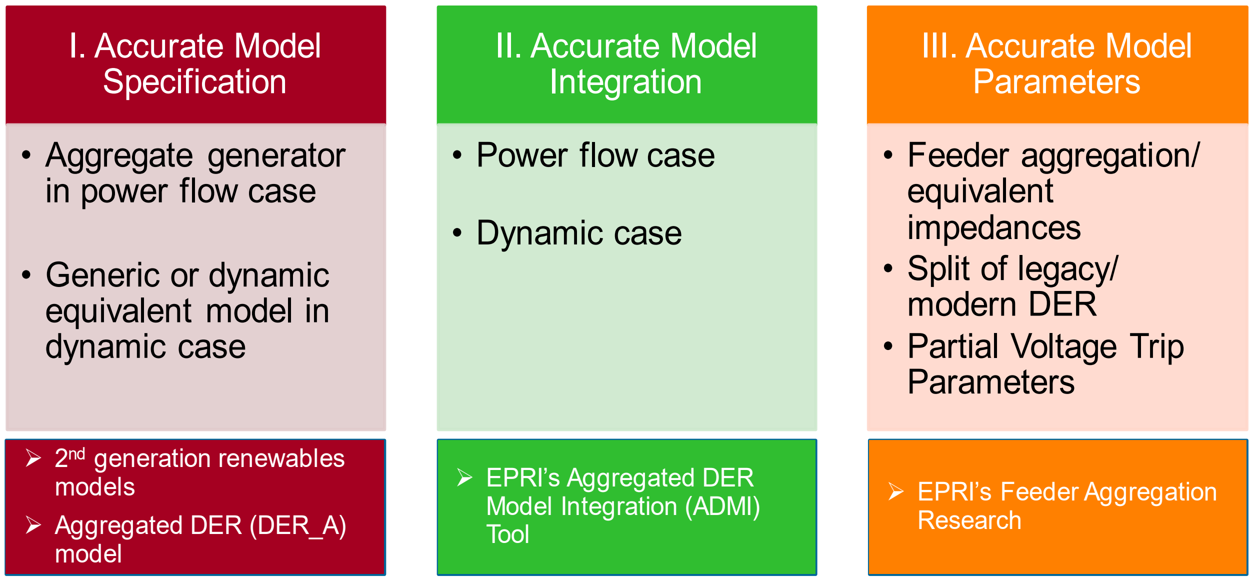

Figure 1-2
The three pillars of accurate modeling of DER for transmission planning studies

The research presented in this and the related reports (see below) contributes to each one of these three pillars and, thereby, to the creation of a technical DER modeling framework that is available for wide application by transmission planners today. The research further contributes to, and was enriched by, the following past, ongoing, or future industry activities:

- EPRI Load Modeling Research and Modeling and Model Validation Tools User's Group (MMVT UG)
- WECC Modeling and Validation Work Group, Renewable Energy Modeling Task Force, and Load Model Task Force [1]
- NERC System Analysis and Modeling Subcommittee and Load Modeling Task Force; in future, System Planning Impacts from DERs Working Group (SPIDERWG) [2]
- IEEE Power System Dynamic Performance Committee, Wind and Solar Working Group, Task Force on Contribution to Bulk System Control and Stability by DERs connected at Distribution Networks (completed, a report was published in January 2018) [3]
- CIGRE JWG C4/C6.35/CIRED Modeling and dynamic performance of inverter-based generation in power system transmission and distribution studies (completed, a report was published in May 2018) [4]

Objective of This Report

This report summarizes key results from detailed investigations discussed in other EPRI reports. The high-level findings and methods presented in this report can help transmission-planning engineers in Independent System Operators (ISOs), transmission owners and operators, and vertically integrated utilities with transmission-planning responsibilities to analyze the bulk system with large amounts of DERs—with the ultimate goal of maintaining bulk system reliability in the future.

Related EPRI Work

This Technical Update is one in a series of reports from the joint efforts by EPRI projects P40.016 (Planning Study Model Development & Management) and P173.003 (Model Development & Validation of Renewable Energy Technologies) to improve models, modeling techniques, and model parameters to adequately represent aggregate distributed energy resources in transmission planning studies. The following reports and software deliverables have been developed in 2018 and are summarized in the chapters of this report one by one:

- **Chapter 2:** *The New Aggregated Distributed Energy Resources (der_a) Model for Transmission Planning Studies.* EPRI White Paper: 3002013498. This White Paper describes the specifications of the model and the results of the benchmark tests conducted during the approval process of the model through the WECC's Modeling & Validation Working Group (MVWG).
- **Chapter 3:** *PRE-SW: Aggregate Distributed Energy Resource (DER) Model Integration (ADMI), version 2.1 – Beta.* EPRI Pre-Software: 3002014316. First published by EPRI in 2017, the Python script for Siemens PTI PSS®E has been updated with various improvements, including new flexibilities to use various load models, allow for multiple U-DER on the same bus, and compatibility for PSS®E versions v33.11+ and v34.3+. The tool automates the process to explicitly represent the distribution circuit, along with the load and DER, in a power flow case on user-specified substations of the bulk system model and thereby enables immediate analysis capability to observe the interaction of DER with the bulk power system.
- **Chapter 4:** Detailed Distribution Circuit Analysis and Parameterization of the Partial Voltage Trip Logic in WECC's DER Model (DER_A): Towards regional default settings in the absence of detailed distribution circuit data. EPRI Technical Update: 3002013500. The parameters vl0, vl1, vh1, and vh0 and Vrfrac of the der_a model represent the partial voltage tripping characteristic of legacy DER, and the dynamic performance of modern DER that ride through abnormal voltage conditions. Their values are regionally specific and may differ significantly from the default values provided by WECC. This Technical Update proposes some default values that are currently considered for inclusion in an updated DER modeling guideline by NERC's LMTF.
- **Chapter 5:** Selected Case Studies Analyzing the Impact of DER on the Bulk System Voltage Performance: Impact of Aggregate Distributed Energy Resources on a Large System. EPRI Technical Update: 3002013502. This Technical Update applies the research results and software tools listed above in a case study to analyze the impact of aggregate amounts of utility-scale DER (U-DER) on a large bulk power system. The scope of the study included a sensitivity analysis with regard to various contingencies, DER rated penetration level, under voltage trip clearing delay, inverter current priority setting, as well as the dynamic voltage support gain and deadband. The analysis was carried out in close collaboration with Duke Energy Progress.
- **(This Report):** *DER Modeling Guidelines for Transmission Planning Studies: 2018 Summary.* EPRI Technical Update: 3002013503. This Technical Update summarizes key results from detailed investigations discussed in the previously mentioned EPRI reports and software deliverables. The high-level findings and methods presented in this report can help transmission-planning engineers in Independent System Operators (ISOs), transmission

owners and operators, and vertically integrated utilities with transmission-planning responsibilities to analyze the bulk system with large amounts of DERs—with the ultimate goal of maintaining bulk system reliability in the future.

Application of the Research

This body of research provides guidelines and tools that can be applied to create a technical basis to inform about the timeline and specifics of new DER interconnection requirements, including the assignment of the new IEEE Std 1547-2018 'abnormal performance categories' that determine new DER interconnections' ride-through capability and, further, the degree to which that capability may be utilized by specifying voltage and frequency trip settings (Figure 1-3).

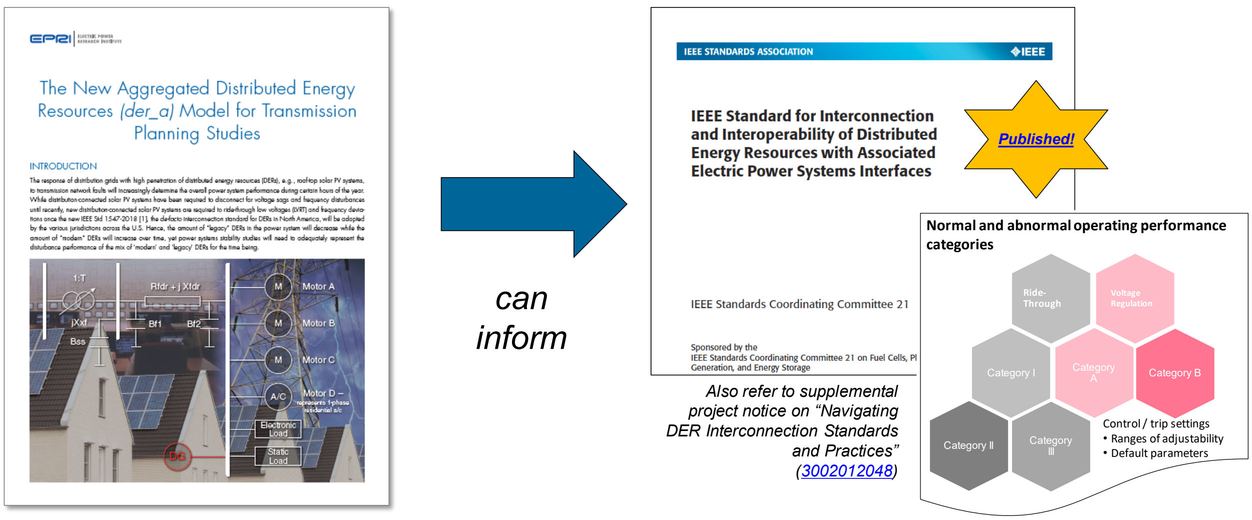

Figure 1-3
Providing guidelines and tools to create a technical basis for assignment of `abnormal performance categories' specified by IEEE Std 1547-2018.

For further information on IEEE Std 1547-2018 and its potential adoption, refer to the following Computer-Based Training modules in EPRI-U's Learning Management System:

1. *Overview on IEEE Std 1547-2018: Navigating DER Interconnection Standards and Practices - Training Module #1.* EPRI Computer-Based Training: 3002014545. This training module gives a high-level overview on IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces (IEEE Std 1547-2018) for interested parties that are not yet familiar with the new standard. It can serve as a reference point for understanding the scope, limitations, and key revisions of DER interconnection performance and functional capability requirements. For interested parties already familiar with the new standard and interested in the short-term application of (parts of) the new IEEE 1547 standard, a potential stopgap solution for certification of advanced inverters prior to the IEEE 1547.1 and UL 1741 updates is presented. With regard to the utilization of advanced DER functions, a potential hierarchy and process for determining functional settings is discussed.
2. *DER Ride-Through Performance Categories and Trip Settings in IEEE Std 1547-2018: Navigating DER Interconnection Standards and Practices - Training Module #2. EPRI Computer-Based Training: 3002014546*. This training module reviews the key changes in

IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces (IEEE Std 1547-2018) with regard to voltage and frequency trip requirements for interested parties that are not yet familiar with the new standard. These changes were necessary due to the newly required voltage and frequency ride-through performance. Drivers like bulk system reliability and aggregated impact of DER will be discussed alongside with potential impacts/trade-offs for distribution reliability and safety.

3. Transmission and Distribution Coordination for DER Ride-Through and Trip Requirements: *Navigating DER Interconnection Standards and Practices - Training Module #3. EPRI Computer-Based Training: 3002014547.* In this training module, our members ISO NE and PJM share their hands-on experiences with applying the bulk system reliability related requirements of the new IEEE Std 1547-2018 across their reliability regions in the short term (interim solution) and mid-term (full implementation). The training conveys the practical realities of assigning DER ride-through performance categories and coordinating voltage trip settings across the transmission & distribution interface. The training addresses questions like: How to identify the need for an interim solution to adopt IEEE Std 1547-2018 in the short term? What is the role of stakeholder coordination between distribution and transmission planners? How could example language of boilerplate interconnection agreements look like? What road mapping efforts exist to fully adopt IEEE 1547 in the mid-term?

These Computer-Based Training modules were produced by the Electric Power Research Institute (EPRI) in Part I of our 'Navigating DER Interconnection Standards & Practices' supplemental project (SPN 3002012048). EPRI informs members from various research programs on both sides of the transmission and distribution interface, including those from programs P39, P40, P94, P161, P173, P174, and P200 about IEEE Std 1547-2018. Knowledge transfer, clarifications, technical information and education, and analysis of technical and economic impacts are in the focus of this project. Other project deliverables include standardized spreadsheets to validate and document DER functional settings, an interconnection standards adoption roadmap, and technical reports. The project identified the need to make these training modules publicly available, e.g., for educational purposes of non-participating distribution utilities in the reliability region of a participating RTO/ISO.

2

THE NEW AGGREGATED DISTRIBUTED ENERGY RESOURCES (DER_A) MODEL FOR TRANSMISSION PLANNING STUDIES

The *der_a* model presented in a EPRI White Paper (Product-ID 3002013498) was approved by the WECC Modeling and Validation Work Group in March 2018 and has been endorsed by the NERC Load Modeling Task Force (LMTF). The model is a significant step forward on DER modeling for transmission planning studies. The *der_a* model strives for a reasonable balance between modeling accuracy, computational requirements, and handling of the system model. Going forward, the *der_a* model should be the model of choice to represent retail-scale DER (R-DER) and, to a certain extent, utility-scale DER (U-DER) in a bulk system planning case.

While distribution-connected solar PV systems have been required to disconnect for voltage sags and frequency disturbances until recently, new distribution-connected solar PV systems are required to ride-through low voltages (LVRT) and frequency deviations once the new IEEE Std 1547-2018 [5], the *de-facto* interconnection standard for DERs in North America, will be adopted by the various jurisdictions across the U.S. Hence, the amount of “legacy” DERs in the power system will decrease while the amount of “modern” DERs will increase over time, yet power systems stability studies will need to adequately represent the disturbance performance of the mix of ‘modern’ and ‘legacy’ DERs for the time being.

The Western Electricity Coordination Council (WECC)’s distributed PV system model (*pvd1*), originated from research in Japan and had then been further specified by WECC in the years 2011–2015 to represent small-scale distribution-connected systems. It integrated multiple subsystems as well as multiple PV systems on a feeder into a single dynamic equivalent model. The model used simple logic to model the partial loss of generation due to bulk system voltage sags. A further simplified version of the *pvd1* model had also been integrated into the WECC-approved composite load model (*cmpldw**g***).

Recent efforts of the WECC LMTF and REMTF have resulted in pursuing modularization of the WECC composite load model structure. Thus, one of the ideas has been, as also recently proposed by NERC, to have various distributed generation (DG) models that can be plugged into the composite load model at the end of the distribution feeder model, as shown in Figure 2-1. Here we are interested primarily in what is defined in as Retail-Scale Distributed Energy Resources (R-DER): distributed energy resources that offset customer load. Although, conceptually this model could also be used for the U-DER. These types of DG are primarily residential and commercial distributed energy resources, and the majority of these types of DG is photovoltaic (PV) generation. To date the best model available for distributed PV generation has been the *pvd1* model that was developed in WECC and exists in a few of the commercial software tools used in WECC. However, after discussions at several WECC REMTF meetings, it was concluded that the *pvd1* model is quite limited as it is not able to represent some of the various functionalities that are at present under discussion in the IEEE 1547 standard development process and also discussed in the California Rule 21 document(s).

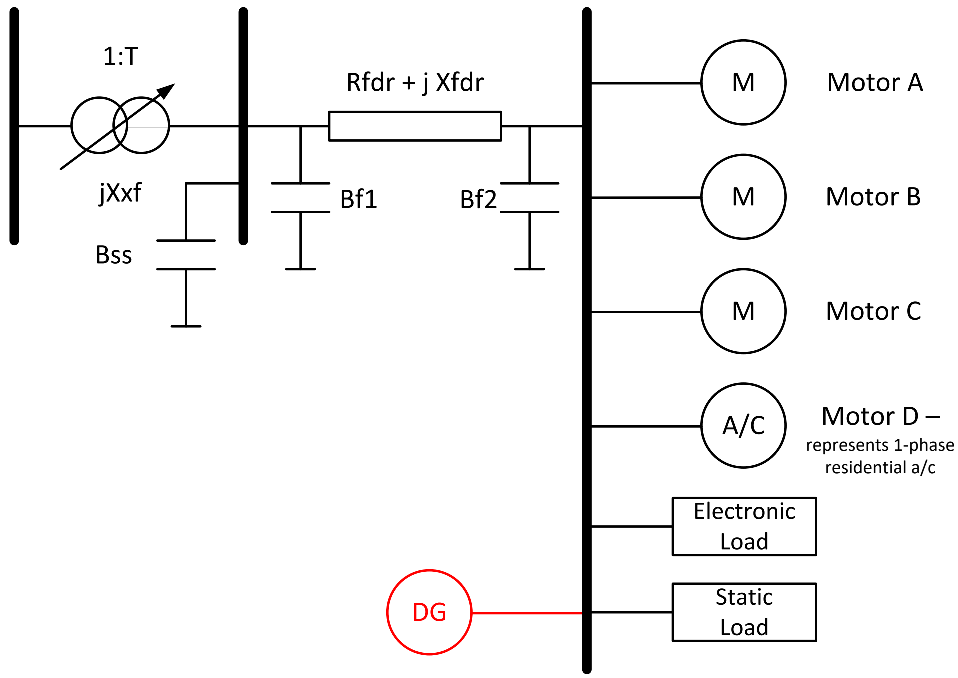

Figure 2-1
Location of distributed generation (DG) plugging into the composite load model. [1]

To that end, a proposal was made for the creation of a new aggregated distributed energy resources positive sequence model, named *der_a* [1]. The main differences between the existing *pvd1* and the new *der_a* model are as specified below in Table 2-1.

The new *der_a* model is replacing the existing *pvd1* model in the latest releases of the five major positive sequence simulation software used in North America, Europe, South Africa, South America, and Australia: GE-PSLF™, Siemens PTI PSS®E, PowerWorld Simulator, PowerTech Labs TSAT, and DIgSILENT PowerFactory. The EPRI White Paper (Product-ID 3002013498), published in May 2018, describes the specifications of the model and the results of the benchmark tests conducted in all mentioned software, but PowerFactory, during the approval process of Version 1 of the *der_a* model through the WECC's Modeling & Validation Working Group (MVWG).

Following the publication of the White Paper, EPRI worked with DIgSILENT to benchmark the *der_a* model's implementation in their integrated power system analysis software "PowerFactory". DIgSILENT is a German software and consulting company that develops and distributes PowerFactory, a software widely used by transmission and distribution planners in Europe, South America, and Australia. The results of the PowerFactory benchmarking of the *der_a* model will be included in a 2019 update of the White Paper and showed a good match with the model performance in the other commonly used power system analysis software. Note that during the course of working with DIgSILENT, the need for an improvement of the active current ramp limitation in study cases, where the *der_a* model were used to represent a distributed energy storage system in charging mode, was identified. This suggested improvement was communicated to WECC, NERC LMTF, and software vendors and has been considered in Version 2 of the *der_a* model which has also been benchmarked by EPRI and will be reflected in the 2019 update of EPRI's White Paper.

Table 2-1
Comparison between aggregated DER models

Functions	CMPLDWG	PVD1	DER_A
Q-V Control	✘	Limited (Simple voltage drop based Q)	✓ (Q-control and proportional V-control)
Power Factor Control	✘	✘	✓
Post fault P recovery	✘	✘	✓ (Can also specify ramp rate limits)
Frequency Control	✘	Only down droop (Curtailment at over frequency)	✓ (Both up and down droop)
Partial Tripping and Reconnection	✓	✓	✓
Timer in Tripping Function	✘	✘	✓
Network Interface	Current Injection	Current injection (With low voltage active power and high voltage reactive power logic similar to REGC_A)	Voltage source (improved numerical stability)
Representation in Power Flow	Explicit value of P_{dg}/Q_{dg} in load table or fraction of P_{load}	Generator (and associated transformer/ feeder if applicable)	Generator (and associated transformer/ feeder if applicable)

Table 2-2 summarizes the availability of the *der_a* model in the five major positive sequence simulation software used in North America, Europe, South Africa, South America, and Australia: GE-PSLF™, Siemens PTI PSS®E, PowerWorld Simulator, PowerTech Labs TSAT, and DIgSILENT PowerFactory.

Table 2-2
Availability of the new aggregated distributed energy resources model (*der_a*) in the five major positive sequence simulation software

Version of *der_a*	GE-PSLF™	Siemens PTI PSS®E	PowerWorld Simulator (Patch)	PowerTech Labs TSAT	DIgSILENT PowerFactory
Version 1	v21.0_05 (March 2018)	v33.12 (August 2018) v34.4	Simulator 19 (04/20/2018) Simulator 20 (04/20/2018)	Version 18 (April 2018)	Not available
Version 2	v21.0_06 (upcoming)	v34.5 and up (October 2018)	Simulator 19 (09/10/2018) Simulator 20 (08/30/2018)	Version 18.0.20 (pending)	Version 2019 (January 2019)

3

PRE-SW: AGGREGATE DISTRIBUTED ENERGY RESOURCE (DER) MODEL INTEGRATION (ADMI), VERSION 2.1 – BETA

In 2017, EPRI developed Python scripts for users of Siemens PTI PSS®E to facilitate the automatic creation of study cases to model the impact of aggregated distributed energy resources (DER) in a bulk power system planning study, for both steady state and dynamic analysis. The latest version of the so called Aggregate Distributed Energy Resource (DER) Model Integration (ADMI) tool was released by EPRI in August 2018 (PID 3002014316) and can handle study cases created either in PSS®E v33 or v34.

Figure 3-1 compares the DER-modeling approach recommended by the Western Electricity Coordinating Council (WECC) and the North American Electric Reliability Corporation (NERC) in their DER Modeling Reliability Guideline published in September 2017 [2] (left) with the output of EPRI's ADMI tool (right) that explicitly represents an equivalent distribution feeder with aggregate load and DER in a power flow case. Besides its applicability in Siemens PTI PSS®E where the *cmpldw**g*** and anticipated modular *cmpld2* models from GE-PSLF™ may not become available in the near future to represent DER in a straight forward way in power flow study cases, the expected benefit of the ADMI tool—which is still subject to further investigation in 2019—may be an increased accuracy over the NERC recommended practice for power flow and dynamic study cases for high substation wide DER penetration that is close or beyond the traditional DER hosting capacity and that may either require the utilization of advanced DER functions like Volt/Var response and/or that may cause reverse power flow (backflow) from the distribution to the transmission grid.

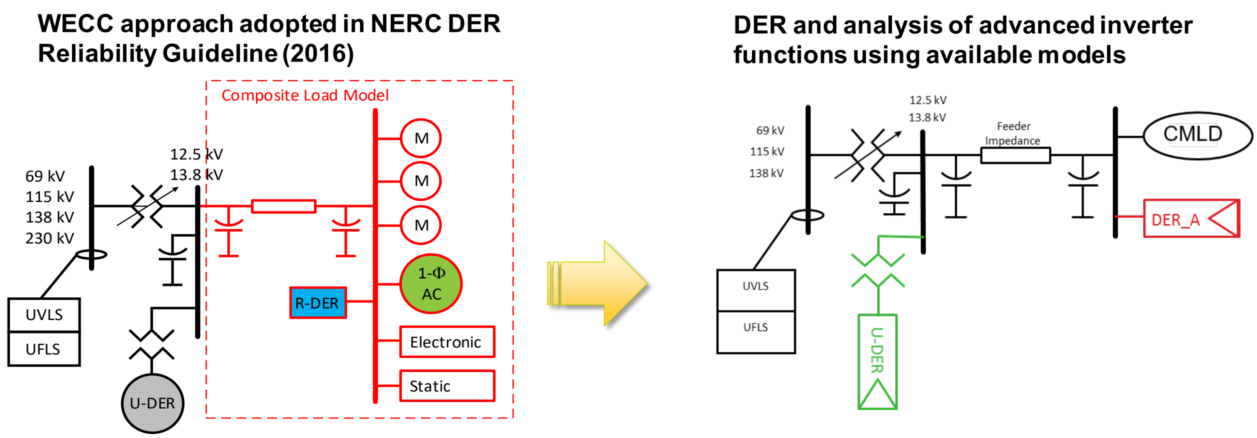

Figure 3-1
Use of the ADMI tool to represent an equivalent distribution feeder with aggregate load and DER in power flow studies

Based on feedback from ADMI users since its first release in 2017, the Python scripts were further improved in 2018 with major improvements being:

1. Added capability to handle more than one U-DER at the same load bus. A common load step down transformer is added and the multiple U-DERs are connected through their individual step up transformers at the low voltage side of the common load step down transformer.
2. Improved handling of added shunts at the U-DER location.
3. Added functionality to use PSS®E v33.9 and above for addition of U-DER.
4. Improved sanctity of power flow solution with U-DER. The reactive power criteria remains at 1% but the active power criteria is now reduced to 0.5%.
5. Rudimentary capability has been added to handle R-DER in PSS®E v33. It is rudimentary as it is a stop gap feature using an input value from the user to specify the value of the MW of R-DER in form of a new data column in the input *.txt file*. In future releases, obtaining the MW value automatically either from the *powerflow .sav* file or the dynamic data file will be implemented. The additional column is only used when PSS®E version 33 is selected by the user and when the DER at the bus is a R-DER. For all other scenarios, i.e., U-DER and/or version 34, the new data column in the *.txt* file is ignored by the scripts. The additional data column is not required for version 34 as in this version of PSS®E, the load data table in the power flow file has a column that holds the bus specific value for the R-DER capacity.
6. Capability to handle instances of the complex load (CLOD) model both in PSS®E versions 33 and 34, in addition to the composite load model (CMLD).
7. Transformer base when no composite load model is present. The MVA base for the equivalent distribution transformer is now chosen as 1.25*(Pg of U-DER + MVA load at the bus). The MVA base of the GSU transformer is chosen as 1.1*MVAbase of the U-DER. The transformer value on the composite load model is subsequently jumper-ed out.

The use of these Python scripts for Siemens PTI PSS®E aid a transmission planner in the fast setup of power flow cases required to assess the impact of DERs on the bulk power system. Such power flow cases are also the prerequisite to perform any dynamic simulations that may be needed to study the bulk system voltage and frequency performance for potential wide-area tripping of distributed energy resources due to lack of ride-through capability or unfavorable voltage and/or frequency trip settings. Refer to the subsection ‘Potential Application Areas’ in Chapter 1 (Introduction).

4
DETAILED DISTRIBUTION CIRCUIT ANALYSIS AND PARAMETERIZATION OF THE PARTIAL VOLTAGE TRIP LOGIC IN WECC'S DER MODEL (DER_A)

With the details of the deployment of distribution connected inverters on a feeder often being 'invisible' for a transmission planner, the ability to generically represent the under voltage tripping characteristic of an aggregation of inverter-based distributed energy resources in a transmission planning study is becoming increasingly important. Now that the aggregate DER (*der_a*) model presented in Chapter 2 has been approved by the WECC Modeling and Validation Work Group in March 2018 and has been endorsed by the NERC Load Modeling Task Force, the research in 2018 continued to address the question what are reasonable model parameter values to represent legacy DER (conforming to IEEE Std 1547-2003 or IEEE Std 1547a-2014) and how may these parameters depend on regionally-specific distribution circuit characteristics and DER deployment?

The parameters *vl0, vl1, vh1,* and *vh0* (with their respective timers) and *Vrfrac* of the *der_a* model represent the so called 'partial voltage trip characteristic' of legacy DER, and the dynamic performance of modern DER that ride through abnormal voltage conditions. Their values are regionally specific and could also be specific to the type of feeder (rural or urban) on which DERs are connected. The EPRI Technical Update 3002013500 proposes some default values that are currently considered for inclusion in an updated DER modeling guideline by NERC's LMTF.

The 2018 work focused on investigating the partial voltage trip characteristic parameters with regard to common variations that occur in the power system such as: the uncertainty associated with the location of the inverters on the feeder; the impact of 1-Φ transmission voltage events along with positive sequence modeling limitations; and the power imbalance across the feeder. The performance of the positive sequence aggregated DER model (*der_a*) was compared in GE-PSLF™ with detailed 3-Φ feeder level simulations obtained by use of the system dynamics module in the open-source OpenDSS simulation platform as applied on the widely known IEEE 8500 node feeder and a feeder from Southern California. Additionally, recommendations have been provided on rules of thumb to obtain regional default parameter values for the aggregated DER model.

The key findings from the 2018 research include:

- A computationally-improved parameterization process for the DER_A model is presented that is based on detailed distribution circuit analysis using the systems dynamics module in OpenDSS.
- The new process allows to determine the fraction of legacy DERs that trip following a transmission voltage event, depending on a user-defined (here: random) placement of individual DERs along a distribution feeder and the distance of the individual DER with respect to the substation.

- The obtained results were used to parameterize the positive sequence *der_a* model with generic parameters for the partial voltage trip logic. To date, two distribution circuits have been analyzed: the well-known IEEE 8500 node feeder and a feeder from Southern California. Future work will analyze additional feeders to obtain a set of generic *der_a* model parameters for regional/feeder type default settings in the absence of detailed distribution circuit data.
- The comparison between the detailed distribution feeder simulation in OpenDSS and the positive sequence simulation in GE - PSLF™ shows a reasonably good match of voltage and current at the substation. Rules of thumb are proposed for transmission planners to deliberately adjust the partial voltage trip parameters of the *der_a* model to account for the uncertainty associated with the location of the inverters on the feeder, the impact of 1-Φ transmission voltage events along with positive sequence modeling limitations, and the power imbalance across the feeder.
- This work has not yet analyzed modern DER that may ride through voltage dips in Momentary Cessation mode (i.e., blocking of current injection).

It cannot be overstressed that *transmission planners should deliberately parameterize the partial voltage trip characteristic of the* der_a *model, depending on whether 3-Φ or 1-Φ transmission voltage events are to be studied.*

Transmission planners that use the new aggregated distributed energy resources (*der_a*) model for transmission planning studies can use the generic parameters for the partial voltage trip logic presented in this report in the absence of detailed distribution circuit data.

Going forward, some parameters of the positive sequence *der_a* model may have to be further adapted to represent the simplistic performance of a legacy inverter. Further, the applicability and scalability of this process for multiple categories of distribution feeders is to be analyzed. Additionally, with DERs, the importance of consideration of unbalanced faults for transmission planning studies has been highlighted and may need further exploration. Finally, further analysis of modern DER that may ride through voltage dips in Momentary Cessation mode (i.e., blocking of current injection) is warranted; such analysis may require further deliberations and potentially modifications of the simplified OpenDSS representation of DER used in this study.

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SELECTED CASE STUDIES ANALYZING THE IMPACT OF DER ON THE BULK SYSTEM VOLTAGE PERFORMANCE

The impact of an increase in percentage of distributed energy resources (DER) in the distribution system on reliability and stability of the transmission system is of increasing concern to bulk power system transmission planning engineers and operators. Now that the *der_a* model presented in Chapter 2 has become available in recent releases of Siemens PTI PSS®E and with the updated ADMI Tool described in Chapter 3 also being applicable in PSS®E, the EPRI Technical Update 3002013502 investigates the question what insight can be derived from applying these new models and tools on a large bulk system with regard to the impact of legacy and modern DER on bulk system voltage performance?

The research work conducted in 2018 discusses a case study to analyze the impact of wide spread distributed energy resources tripping on the transient performance of a large utility transmission system.

The scope of the study included a sensitivity analysis with regard to various contingencies of normally-cleared transmission faults, DER rated penetration level, under voltage trip clearing delay, inverter current priority setting, as well as the dynamic voltage support gain and deadband. The parameters of the DERs were set according to the IEEE Std 1547a-2014 and the DERs were connected in aggregated form near the substation. The impact of the voltage ride-through and voltage support features of DERs were ascertained by evaluating the cumulative MVA of load exposed to a retained voltage of less than or equal to a specific value at the instance when a DER decided to execute an under voltage trip. This cumulative MVA amount of load also serves as a proxy for the amount of predicted DERs that can be affected. The analysis was carried out in close collaboration with Duke Energy Progress.

The case study results can be summarized as follows and suggests these conclusions:

1. For normally-cleared transmission faults and as long as DER that comply with IEEE Std 1547a-2014 do not trip significantly sooner than the default clearing times specified in the standard (2.0 seconds with a voltage threshold of 0.88 pu), no voltage or frequency performance beyond acceptable planning limits was observed for the aggregate U-DER capacity expected to be installed by the end of 2023. Pending further studies of delayed-cleared transmission faults, this suggests no short term adoption and utilization of DER ride-through requirements may be warranted based on bulk power system reliability needs.
2. Voltage dips caused by transmission faults within Duke's two Carolina service territories can cause DERs in adjacent areas to also be affected by low voltages. This inference is obtained from the cumulative MVA of load impacted by low voltage. This thus suggests a broader, regional perspective may be required when informing recommendations for adoption and utilization of DER ride-through requirements based on bulk power system reliability needs.

3. DER tripping in significantly less time (0.1 seconds) than the default clearing times specified in IEEE Std 1547a-2014 can cause the loss of substantial amounts of aggregate U-DER generation; this loss of generation can reach MW values close to the currently held contingency reserve and is partly balanced out by change in inter-connector flows from adjacent areas into Duke's two Carolina service territories. This however also suggests a need for regional coordination of grid operations and contingency reserve planning where substantial amounts of U-DERs are at risk of tripping due to under voltage.
4. Loss of aggregate U-DER generation can be caused by many kinds of transmission faults that, altogether, have a higher combined likelihood of occurrence than incidents that cause the loss of the largest or second-largest generator on which transmission planning has focused in the past. This suggests that grid operations practice and protocols may need updates to account for more regular loss of generation.
5. For the normally-cleared transmission faults studied and under the assumption of U-DER remaining connected until close to the first under voltage protection layer clearing time specified in IEEE Std 1547a-2014 (see above), dynamic voltage support from modern U-DER had only a slight effect of boosting the voltage seen by loads (and potential R-DER connected with these loads).

Future work may include

- Analysis of off-peak study cases where conventional synchronous generation is de-committed to accommodate DER infeed and instantaneous DER penetration levels are higher than the rated DER penetration levels studied so far.
- Analysis of delayed-cleared transmission faults that may trigger the DER's second under voltage trip layer with a IEEE Std 1547-2018 default clearing time of 0.16s below 0.45pu voltage.
- Analysis of bulk system voltage and frequency performance when U-DER ride through voltage dips in momentary cessation mode (i.e., blocking of inverter current injection).
- Analyze whether dynamic voltage support from modern DER can prevent tripping of legacy DER due to voltages below the second under voltage protection layer following delayed-cleared transmission faults.
- Conduct a case study on a smaller system and/or a system with large amounts of retail-scale DER (R-DER).

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CONCLUSION

Summary

This Technical Update presented a summary of the research on distributed energy resource (DER) modeling for transmission planning studies, performed under the EPRI Transmission Planning (P40) and Bulk System Integration of Variable Generation (P173) projects P40.016 and P173.003 in 2018.

High penetration of transmission-connected variable generation and DERs present new challenges in the planning and operations of bulk power systems. To address challenges about ensuring adequate bulk system reliability in terms of voltage and frequency performance under high levels of DERs and to explore the contribution of new emerging technologies, EPRI's research contributed to each of the three pillars of accurate modeling of DER for transmission planning studies: model specification (*der_a* model, Chapter 2), model integration (ADMI tool, Chapter 3), and model parameterization (OpenDSS benchmarking, Chapter 4). These contributions have been integrated into, and enriched by, recent industry discussions and guidelines, most notably NERC's DER Modeling Reliability Guideline [2] and WECC's new aggregate DER (*der_a*) model specification [1]. The latter has been described and benchmarked across all major positive-sequence software in an EPRI White Paper published in May 2018 [6].

In 2018, no supplemental projects with regard to distributed energy resources modeling for transmission planning studies have been carried out. Instead, the developed DER modeling framework was applied as a case study on one member's large power system (Chapter 5) and proved suitable and insightful for future application in supplemental projects with interested members.

Recommendations

Based on the research on modeling of DER in transmission planning studies performed in 2018, the following recommendations are given:

1. Continued collaborative research, knowledge exchange, and learning across the industry in this evolving research area is recommended to better understand the voltage and frequency performance of an Integrated Grid, especially at the transmission & distribution (T&D) interface.
2. DERs should not be netted with load but be explicitly modeled in steady-state power flow and short-circuit studies as well as in transient stability, frequency, and voltage stability studies for bulk system planning. The level of detail may depend on how close the substation wide DER penetration level is to the traditional hosting capacity and whether the utilization of advanced DER functions like Volt/Var response may be necessary and/or whether reverse power flow (backflow) from the distribution to the transmission grid may be modeled.
3. The approved *der_a* model is a significant step forward on DER modeling for transmission planning studies. It combines parts from WECC's large-scale renewable energy models (*reec_x*) and an enhanced version of the voltage trip logic from WECC's former distributed

PV (*pvd1*) model. The *der_a* model strives for a reasonable balance between modeling accuracy, computational requirements, and handling of the system model. Now that the *der_a* model has become available in recent releases of all five positive sequence simulation software, the *der_a* model should be the model of choice to represent R-DER and, to a certain extent, U-DER in a bulk system planning case.

4. The parameters *vl0*, *vl1*, *vh1*, and *vh0* (with their respective timers) and *Vrfrac* of the distributed energy resources (*der_a*) model represent the partial tripping characteristic of legacy DER and the dynamic performance of modern DER that ride through abnormal voltage conditions. Their values are regionally specific and could also be specific to the type of feeder (rural or urban) on which DERs are connected. Transmission planners may use the default values presented which are currently considered for inclusion in an updated DER modeling guideline by NERC's LMTF.
5. Minimum data requirements and the sharing of information across the Transmission & Distribution (T&D) interface will have to be ensured as outlined in prior years Technical Updates (e.g., Chapter 4 of 3002010932 [7]) in order to allow for adequate assessment of future DER deployments.
6. The Aggregate Distributed Energy Resource (DER) Model Integration (ADMI) tool for Siemens PTI PSS®E has been improved and should be used to explicitly represent the distribution circuit, along with the load and DER, in a power flow case on user-specified substations of the bulk system model.

Future Work on DER Modeling

Figure 6-1 shows the milestones of DER modeling research in programs P40.016 and P173.003 over a four year-horizon. Next year's efforts will be to

1. derive *der_a* model partial voltage trip characteristic parameters for more distribution feeders to provide generic regional settings in absence of detailed distribution circuit data,
2. conduct DER modeling case studies to understand where representation of equivalent distribution feeder in transmission power flow cases (application of ADMI tool) is preferred over use of a composite load/DER model,
3. improve phasor domain stability modeling, including combined T&D simulation in positive and negative sequence and representation of advanced inverters/DERs to verify the *der_a* model performance.

The longer-term vision continues to be the development of a framework that would integrate geographic information system (GIS)-based processing of forecasted regionalized load and DERs adoption into bulk system planning cases without DER data.

Case studies may be carried out in form of supplemental projects with interested members (*please contact EPRI staff to express your interest*).

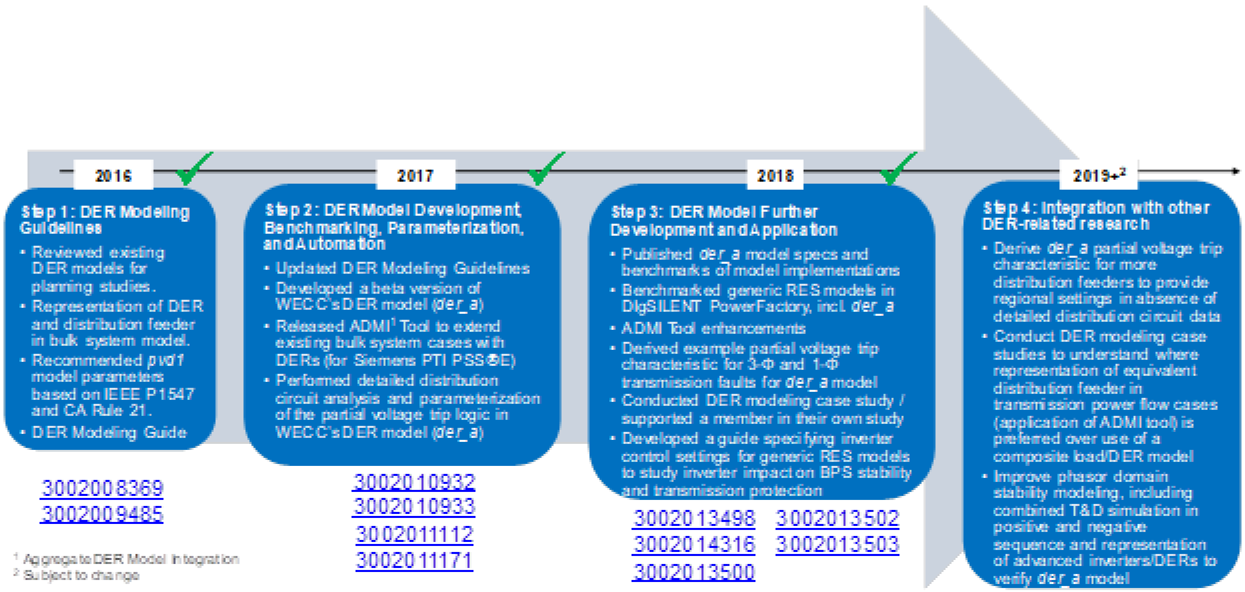

Figure 6-1
Milestones of DER modeling research in programs P40.016 and P173.003.

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com