Recommendations for Simulation Improvement and Techniques Related to DER Planning White Paper

NERC System Planning Impacts of Distributed Energy Resources Working Group (SPIDERWG)
August 2022

Disclaimer: This document is intended to be a resource for software vendors to help guide the next generation of software tools and techniques that will aid power system planners as they contend with the increased proliferation of distributed energy resources (DER). This document is not intended to be an endorsement of any particular software platform nor as a critique of the existing capabilities of any software program. Screenshots of various software tools appear in the document only as a means of offering further clarity on the topic at hand.

Purpose

The NERC System Planning Impacts of Distributed Energy Resources Working Group (SPIDERWG) has developed a number of guidelines and studies relating to DER integration. Tracking DERs will add a significant level of complexity to the planning process, stressing data fidelity, modeling accuracy, and computational limitations. This document provides a distilled version of the NERC SPIDERWG recommendations that may be pertinent to power system software developers and outlines some of the related literature that may aid in developing further software improvements and techniques.

This finalized document is a product of a multi-part collaborative effort. These recommendations were developed based on feedback from a range of industry participants (see **Contributors** section for full list), representing utilities, ISOs, consultants, and OEMs. The initial recommendations were subsequently provided to software vendors for further input and revision. The SPIDERWG then reviewed and provided additional comments and feedback.

This white paper is broken down into three sections.

PART I provides an overview of SPIDERWG efforts to quantify and qualify the manner in which DERs are changing the system planning process. This section also provides a review of related literature from government, industry, academic sources.

PART II identifies a number of issues related to the representation of DERs in power system planning models that may strain the existing capabilities of power system software.

PART III discusses the seams that exist between typical power system planning analysis (e.g., transmission versus distribution studies, positive-sequence load flow versus electromagnetic transient analysis) and how DERs may necessitate new software solutions that stitch these seams together.

PART I: Overview of NERC SPIDERWG and Related Efforts

When DERs were introduced on the power system, they were initially viewed as a distribution system concern only. DER interconnection requirements, such as IEEE 1547-2003, tended to recommend immediate tripping for DERs during abnormal system conditions in order to protect utility workers and avoid unexpected distribution system voltage dynamics. However, the profusion of DERs throughout the power system has led planning engineers to reconsider the bulk system impacts of these devices. Recent events have highlighted the effects that a large amount of inverter-based resources can have on the transmission system. For instance, the Blue Cut Fire incident in 2016 involved the loss of roughly 1,200 MW of solar generation in Southern California (See **Figure 1**) due to a fault on a nearby transmission line. This sudden drop in generation was not anticipated by operators at the time, emphasizing the need for better system visibility in both the planning and operations horizon.

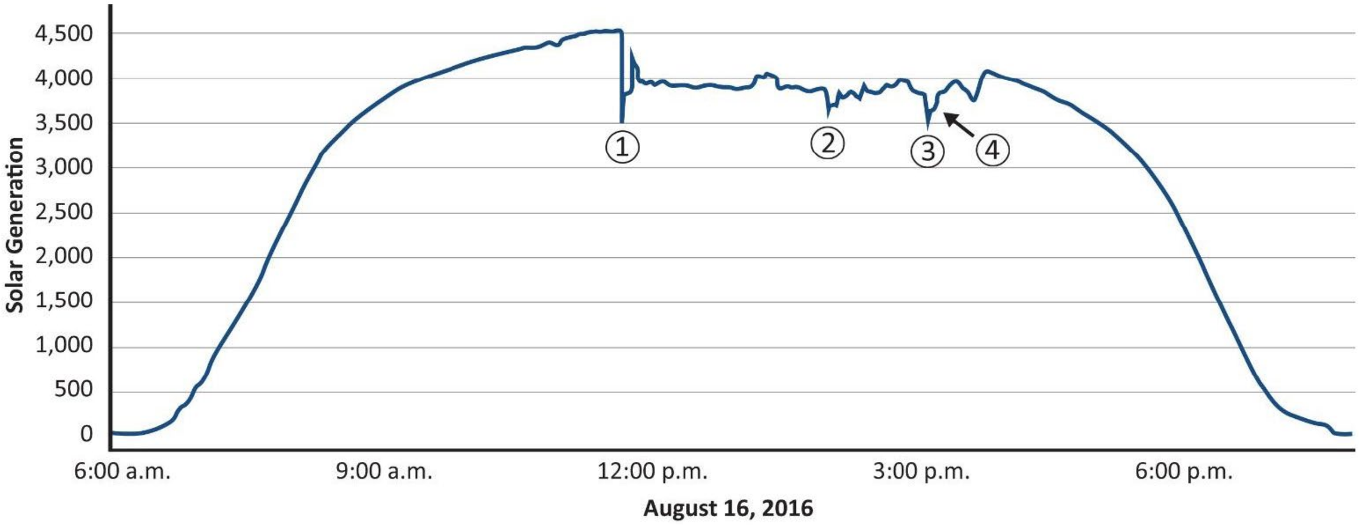

Figure 1: Utility Scale Solar PV Output in SCE Footprint on August 16, 2016[1]

While the reduction in generation during the Blue Cut Fire was primarily driven by utility-scale solar, this incident highlights the concerns that system planners have as DERs continue to proliferate. If a large number of DERs were to trip off simultaneously during a fault or other abnormal system condition, it could trigger transient instability, inadequate contingency reserves, unanticipated thermal overloads, and potential voltage collapse.

Even without tripping, DERs will cause significant change to system-wide power flows (both in magnitude and direction), rising feeder voltage profiles, and potential reduction in the effectiveness of underfrequency and undervoltage load shed schemes to name a few issues. It is therefore imperative that system planning

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[1] 1200 MW Fault Induced Solar Photovoltaic Resource Interruption Final.pdf

engineers have the visibility via accurate and up to date models to adequately catalog the distributed energy resources deployed on their systems. This is increased with the increased rate of deployment across some areas as in **Figure 2**.

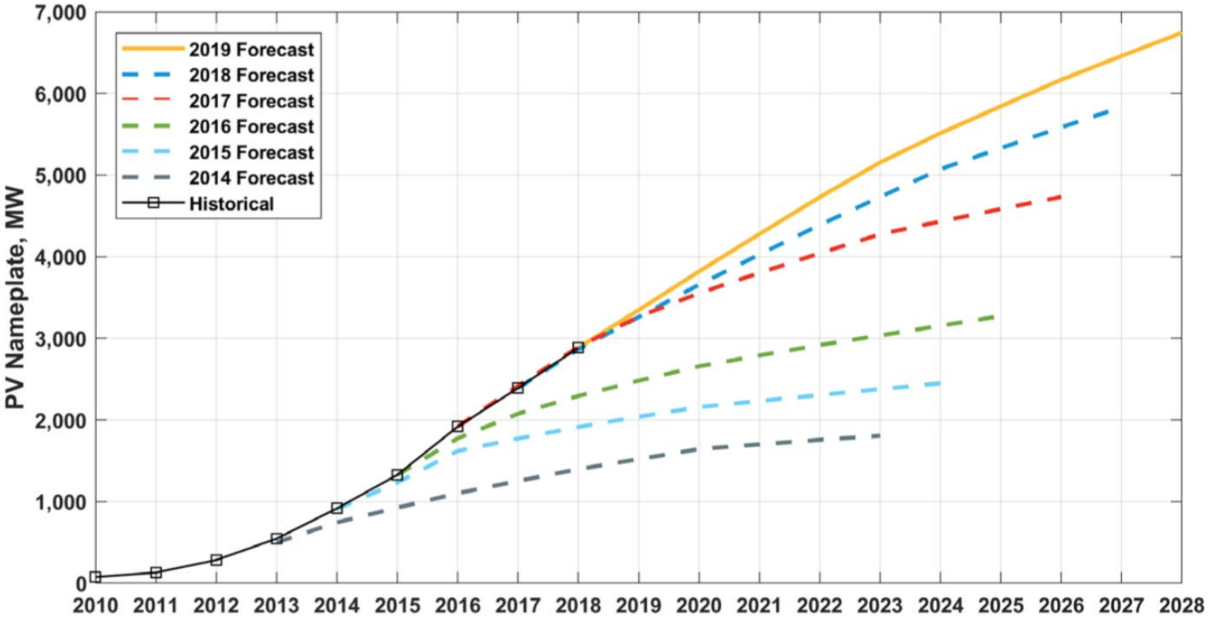

Figure 2: DER deployment at ISO-NE. [Source: ISO-NE][2]

The NERC System Planning Impacts from Distributed Energy Resources (SPIDER) Working Group (WG) was created to address aspects of these key points of interest related to system planning, modeling, and reliability impacts to the bulk power system (BPS). It builds on related work from the NERC BPS-connected Inverter-based Resources and Distributed Energy Resources Task Force summary report[3] and the NERC *Distributed Energy Resources: Connection Modeling and Reliability Considerations* Task Force report.[4]

The NERC SPIDERWG has authored a number of documents related to system planning impacts of DERs. A few which may be of interest to power system software vendors include the following:

- The NERC *SPIDERWG Scope Document*[5] provides an overview of the purpose, activities, and deliverables of the SPIDERWG.
- The NERC *Reliability Guideline: Bulk Power System Reliability Perspectives on the Adoption of IEEE 1547-2018*[6] discusses how the inverter trip settings and reactive power control modalities described in IEEE Standard 1547-2018 are expected to impact the Bulk Electric System.

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[2] https://www.iso-ne.com/static-assets/documents/2019/04/final-2019-pv-forecast.pdf

[3] Summary is available here: https://www.nerc.com/comm/PC/Documents/Summary_of_Activities_BPS-Connected_IBR_and_DER.pdf

[4] This report is available here: https://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/Distributed_Energy_Resources_Report.pdf

[5] https://www.nerc.com/comm/RSTC/SPIDERWG/SPIDERWG%20Scope.pdf

[6] https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_IEEE_1547-2018_BPS_Perspectives.pdf

- The NERC *White Paper: Assessment of DER impacts on NERC Reliability Standard TPL-001*[7] provides a context for how the proliferation of DERs may affect transmission studies going forward, and provides guidance on potential touchpoints that involve DERs and the TPL-001 document. NERC Reliability Standard TPL-001 specifies how Transmission Planners evaluate the performance of the transmission system, including the types of studies that are considered (e.g., steady-state load flow, PV/QV curve analysis, transient stability) and the acceptable criteria for each of the studies.
- The NERC *Reliability Guideline: DER Data Collection for Modeling in Transmission Planning Studies*[8] provides guidance when conducting NERC Reliability Standard MOD-32 data collection efforts involving DERs.
- The NERC *Reliability Guideline: Bulk Power System Planning under Increasing Penetration of Distributed Energy Resources*[9] is a reference for planning engineers that includes a range of example studies incorporating DERs as well as suggested best practices for accounting for DERs in various system planning efforts.
- The NERC *SPIDERWG Terms and Definitions Working Document*[10] is a useful resource for terms and definitions contained herein as well as in related SPIDERWG documents.

PART II: DER Impacts on Power System Software Tools

Continued proliferation of DERs is expected to cause a number of impacts on the Bulk Electric System.[11,12,13] Future power system studies will require software tools that can track a large number of distributed resources (typically aggregated up to the feeder or substation bus level) while providing the ability to observe and adjust the output of these resources across the entire simulation. At the same time, the addition of new DER tracking capabilities will need to be balanced against the increase in complexity for the user and data fidelity requirements that they will cause.

The recommendations in this section relate to how best to account for DERs in transmission system base case models. Given the sheer size of Bulk Electric System base case planning studies (often >10,000 load serving nodes), it will be crucial that power system software can programmatically handle a large number of DER models while simultaneously presenting information on overall DER behavior to the user in a comprehensible format.

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[7] Available here: https://www.nerc.com/comm/PC/System%20Planning%20Impacts%20from%20Distributed%20Energy%20Re/SPIDERWG_White_Paper_TPL-001_Assessment_and_DER.pdf

[8] Available here: https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_DER_Data_Collection_for_Modeling.pdf

[9] This document is still currently under development by the SPIDERWG and is reflected in the SPDIERWG work plan, which is available here: https://www.nerc.com/comm/RSTC/SPIDERWG/SPIDERWG%20Work%20Plan.pdf

[10] Latest version available here: https://www.nerc.com/comm/RSTC/SPIDERWG/SPIDERWG%20Terms%20and%20Definitions%20Working%20Document.pdf

[11] *Planning Hawai'i's Grid for Future Generations – Integrated Grid Planning Report*: https://www.hawaiianelectric.com/documents/clean_energy_hawaii/integrated_grid_planning/20180301_IGP_final_report.pdf

[12] *Coordination of Transmission and Distribution Operations in a High Distributed Energy Resource Electric Grid* available here: https://pubs.naruc.org/pub/67F0F5A8-F49D-9E86-FD4D-EDDE825B007E

[13] Impact of Distributed Energy Resources on the Bulk Electric System Combined Modeling of Transmission and Distribution Systems and Benchmark Case Studies: https://www.osti.gov/biblio/1433502-impact-distributed-energy-resources-bulk-electric-system-combined-modeling-transmission-distribution-systems-benchmark-case-studies

Organizing DER Information in Load Flow Models

Tracking distributed generation is becoming an increasingly important component of the base case building process and general transmission planning analysis. Future planning scenarios are likely to include large amounts of DERs that will significantly affect the power flow of the transmission network, and it will be critical for planners to have easily accessible information on the amount of dispatched DER in a particular case.

Previous Guidance

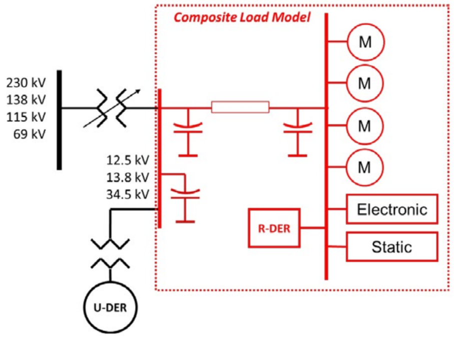
The NERC *Reliability Guideline: Modeling Distributed Energy Resources in Dynamic Load Models*[14] provides guidance for modeling DERs. Two points of the guideline are emphasized here:

- The guide delineates between two types of DER representations, referred to as U-DER and R-DER. To generalize, U-DERs represent utility-scale resources above a specific MW threshold (usually located near the substation) while R-DERs represent an aggregation of smaller and often behind-the-meter resources dispersed across one or more feeders.
- Two of the three following quantities should be accounted for in transmission planning base case load models: gross load, net load, and DER generation (calculated by the difference in gross load and net load).

Per the modeling guideline, U-DERs are modeled as discrete generator models. As such, information about these resources can be tracked within the existing generator modeling framework available in load flow software. However, it is not feasible to include information on every individual DER dispersed across a distribution feeder in a transmission planning base case model. As such, the R-DER representation is used to aggregate a group of DER in an effort to approximate the combined behavior of these resources.

Tracking Distributed Generation Output

As originally discussed in the NERC *Reliability Guideline: Distributed Energy Resource Modeling,*[15] it is recommended that distributed generation fields be provided within power flow software load models and that the distributed generation dispatch be sortable by Area, Zone, Owner, and related fields. An example of R-DER data accounting in PowerWorld (Version 21) is shown in **Figure 3**, **Figure 4**, and **Figure 5** while **Figure 6**, **Figure 7,** and **Figure 8** demonstrate DER tracking in the PSS/E environment (v34.6).



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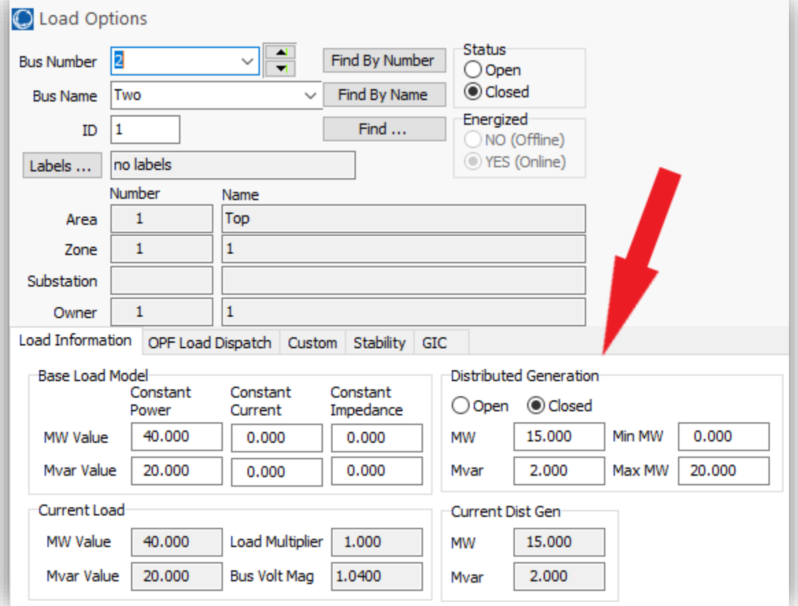
[14] https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_-_Modeling_DER_in_Dynamic_Load_Models_-_FINAL.pdf

[15] https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_-_DER_Modeling_Parameters_-_2017-08-18_-_FINAL.pdf

Figure 3: The U-DER and R-DER Model Representation



Load Options

Bus Number	2
Bus Name	Two
ID	1
Labels ...	no labels

Status: ○ Open ● Closed

Energized: ○ NO (Offline) ● YES (Online)

	Number	Name
Area	1	Top
Zone	1	1
Substation		
Owner	1	1

Base Load Model

	Constant Power	Constant Current	Constant Impedance
MW Value	40.000	0.000	0.000
Mvar Value	20.000	0.000	0.000

Distributed Generation: ○ Open ● Closed

MW	15.000	Min MW	0.000
Mvar	2.000	Max MW	20.000

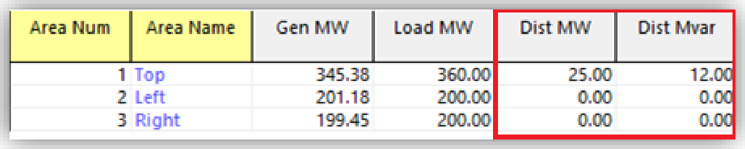
Current Load

MW Value	40.000	Load Multiplier	1.000
Mvar Value	20.000	Bus Volt Mag	1.0400

Current Dist Gen

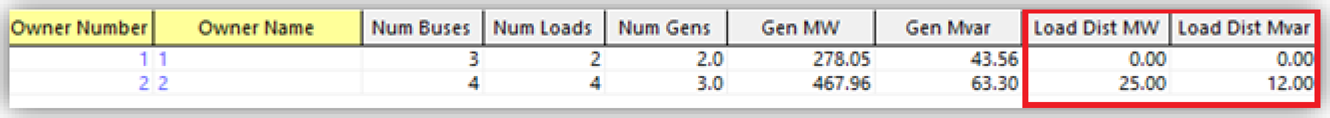
MW	15.000
Mvar	2.000

Figure 4: Load Model Dialog with Distributed Generation Section [Source: Powerworld]



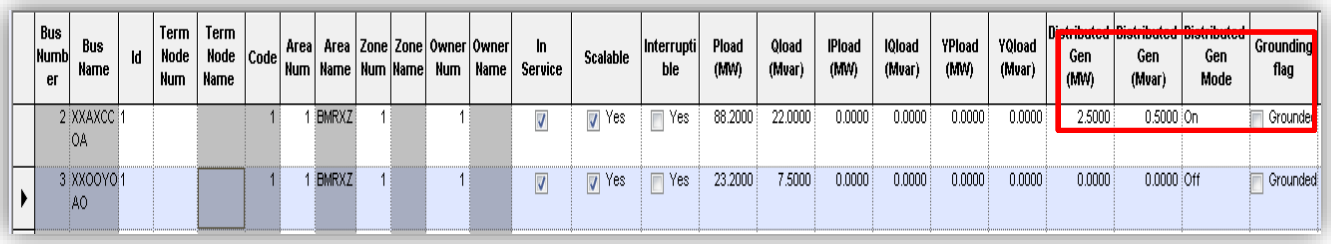
Area Num	Area Name	Gen MW	Load MW	Dist MW	Dist Mvar
1	Top	345.38	360.00	25.00	12.00
2	Left	201.18	200.00	0.00	0.00
3	Right	199.45	200.00	0.00	0.00

Figure 5: DER Deployment Listed by Area [Source: Powerworld]



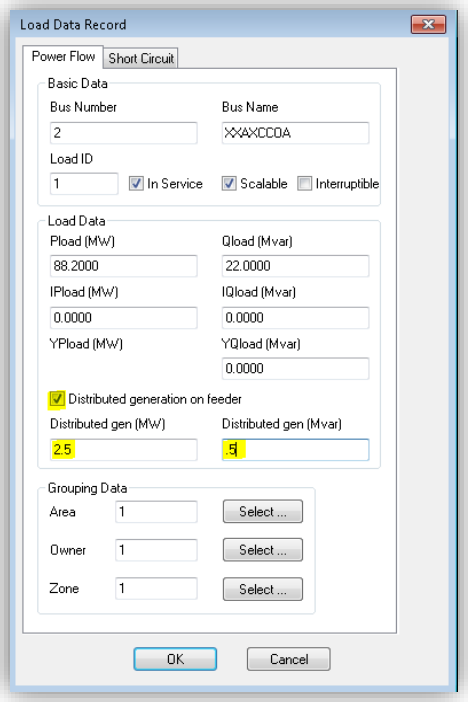
Owner Number	Owner Name	Num Buses	Num Loads	Num Gens	Gen MW	Gen Mvar	Load Dist MW	Load Dist Mvar
1	1	3	2	2.0	278.05	43.56	0.00	0.00
2	2	4	4	3.0	467.96	63.30	25.00	12.00

Figure 6: DER Deployment Listed by Owner [Source: PowerWorld]



	Bus Number	Bus Name	Id	Term Node Num	Term Node Name	Code	Area Num	Area Name	Zone Num	Zone Name	Owner Num	Owner Name	In Service	Scalable	Interruptible	Pload (MW)	Qload (Mvar)	IPload (MW)	IQload (Mvar)	YPload (MW)	YQload (Mvar)	Distributed Gen (MW)	Distributed Gen (Mvar)	Distributed Gen Mode	Grounding flag
	2	XXAXCCOA	1			1	1	BMRXZ	1		1		☑	☑ Yes	☐ Yes	88.2000	22.0000	0.0000	0.0000	0.0000	0.0000	2.5000	0.5000	On	☐ Grounde
▸	3	XXOOYOAO	1			1	1	BMRXZ	1		1		☑	☑ Yes	☐ Yes	23.2000	7.5000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	Off	☐ Grounded

Figure 7: DER Deployment Listed by Bus [Source: Siemens PSS/E version 34.6]



Basic Data

Bus Number: 2
Bus Name: XXAXCCOA
Load ID: 1
☑ In Service ☑ Scalable ☐ Interruptible

Load Data

Pload (MW): 88.2000
Qload (Mvar): 22.0000
IPload (MW): 0.0000
IQload (Mvar): 0.0000
YPload (MW):
YQload (Mvar): 0.0000

☑ Distributed generation on feeder
Distributed gen (MW): 2.5
Distributed gen (Mvar): .5

Grouping Data

Area: 1 Select ...
Owner: 1 Select ...
Zone: 1 Select ...

Figure 8: Data Record for DERs [Source: Siemens PSS/E version 34.6]

Reactive Power Capabilities of DER

Behind-the-meter DERs in power flow are modeled as a part of load with active and reactive power. Currently, limits on the upper and lower bounds on DER reactive capability (here denoted Q_{min} and Q_{max}) are not typically available in positive-sequence software.

The increasing penetration of inverter-based resources in the generation mix will in turn spur increased participation in voltage control and reactive power injection from these same inverters. Increased use of volt-var support and other voltage control methods may eventually lead to a need to model the available reactive power of a set of distributed resources. Many jurisdictions have begun to require a fixed power factor for DER resources as well. It is recommended that software vendors be aware of the implications of DER-supplied reactive power and consider how best to model any reactive power limitations.

Data Tracking Implications of FERC Order 2222

In September 2020, the Federal Energy Regulatory Commission (FERC) adopted *Order No. 2222: Participation of Distributed Energy Resource Aggregations in Markets Operated by Regional Transmission Organizations and Independent System Operators*[16]. Order No. 2222 directs regional trade organizations/independent system operators (RTO/ISO) to submit tariff revisions that open wholesale electricity markets to DER aggregations, specifically requiring them to allow distributed energy resource aggregations to participate directly in the organized wholesale electric markets. The following is an excerpt from to Order 2222:

> **Paragraph 294:** "…this final rule in no way prevents state and local regulators from amending their interconnection processes to address potential distribution system impacts that the participation of distributed energy resources through distributed energy resource aggregations may cause. In addition, coordination between RTOs/ISOs, distributed energy resource aggregators, relevant electric retail regulatory authorities, and distribution utilities during the registration and distribution utility review processes should provide RTOs/ISOs with the information they need to study the impact of distributed energy resource aggregations on the transmission system."

The implications of FERC Order 2222 are still being established within ISO/RTO environments. It is recommended that software vendors stay abreast of the topic and be prepared to support planning engineers with future tools that describe the behavior of DER aggregators once their behavior is better understood.

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[16] Available here: https://www.ferc.gov/sites/default/files/2020-09/E-1_0.pdf

Key Takeaways

- Smaller aggregations of DERs dispersed across a feeder (denoted R-DERs) should be accounted for by using the distributed generation MW and MVAR fields in power flow load models in order to separate these resources from gross load.
- Load values in tables, reports, and Graphical User Interfaces should always be labeled as net or gross.
- Information on the total distributed generation MW and MVAR for a particular area, zone, owner, etc. should be made available within the power flow software structure.
- It is recommended that software vendors be aware of the implications of DER-provided reactive power and consider how best to model any reactive power limitations.
- Vendors should stay abreast of developments surrounding FERC Order 2222 and be prepared to support planning engineers with future tools that describe the behavior of DER aggregators once the behavior of these resources is better understood.

Organizing DER Dynamics Modeling Data

A number of dynamics models, such as REGC_A, REEC_A REPC_A, and PVD1,[17] are available to capture the dynamic behavior of DERs.[18] This guide recommends that power system software support the recently designed DER_A model for DER dynamic behavior.

In dynamic simulation, the DER_A model provides a number of modeling capabilities:[19]

- Multiple control modalities, including constant power factor and constant reactive power control
- Active power-frequency control with droop and asymmetric deadband
- Voltage control with proportional control and asymmetric deadband
- Fraction of resources tripping or entering momentary cessation at low and high voltage, includes a timer feature
- Fraction of resources restoring output following a low or high voltage or frequency condition
- Active power ramp rate limits during return to service after trip or enter service following a fault or during frequency response
- Active-reactive current priority options

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[17] The REEC_B model is no longer recommended as a model for dynamic simulations as it does not capture the momentary cessation behavior of inverter-based resources: https://www.wecc.org/Reliability/Converting%20REEC_B%20to%20REEC_A%20for%20Solar%20PV%20Generators.pdf

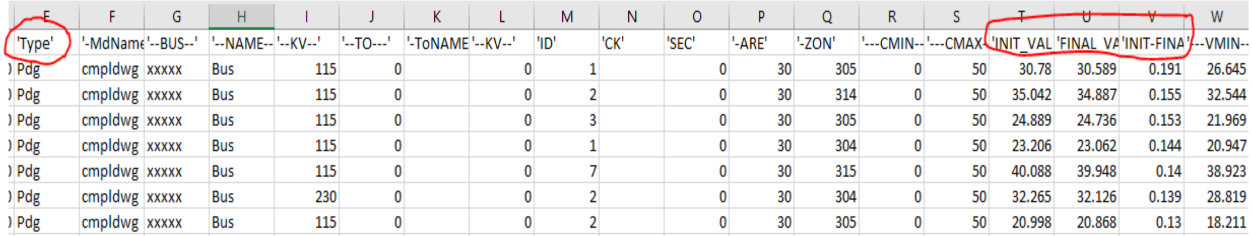
[18] https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_-_DER_Modeling_Parameters_-_2017-08-18_-_FINAL.pdf

[19] https://www.nerc.com/comm/PC/System%20Planning%20Impacts%20from%20Distributed%20Energy%20Re/Modeling-DER_Modeling_Guideline_IG.pdf

- The capability to represent generating or energy storage resources (Thus, DER MW values in power flow data should be allowed to be negative for storage.)

The DER_A model should be usable as part of the composite load model or as a standalone model. Regardless of the DER dynamics model used, the ability to conduct transient simulations of DER behavior will be increasingly important as the power system transitions to greater reliance on these resources. Some desired features of dynamic DER data tracking include the following:

- Tabular organization of post-contingency DER model states and statuses. For instance, GE's Positive Sequence Load Flow (PSLF) provides the statuses of DER following dynamic simulation, which can be tracked with the output table view as shown in **Figure 9**. The difference between the initial and final values of each DER listed in the table provides information about the tripping actions of DERs following an event.



E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
'Type'	'-MdName	'--BUS--'	'--NAME--	'--KV--'	'--TO---'	'-ToNAME	'--KV--'	'ID'	'CK'	'SEC'	'-ARE'	'-ZON'	'---CMIN--	'---CMAX-	'INIT_VAL	'FINAL_VA	'INIT-FINA'	'--VMIN--
Pdg	cmpldwg	xxxxx	Bus	115	0		0	1		0	30	305	0	50	30.78	30.589	0.191	26.645
Pdg	cmpldwg	xxxxx	Bus	115	0		0	2		0	30	314	0	50	35.042	34.887	0.155	32.544
Pdg	cmpldwg	xxxxx	Bus	115	0		0	3		0	30	305	0	50	24.889	24.736	0.153	21.969
Pdg	cmpldwg	xxxxx	Bus	115	0		0	1		0	30	304	0	50	23.206	23.062	0.144	20.947
Pdg	cmpldwg	xxxxx	Bus	115	0		0	7		0	30	315	0	50	40.088	39.948	0.14	38.923
Pdg	cmpldwg	xxxxx	Bus	230	0		0	2		0	30	304	0	50	32.265	32.126	0.139	28.819
Pdg	cmpldwg	xxxxx	Bus	115	0		0	2		0	30	305	0	50	20.998	20.868	0.13	18.211

Figure 9: DER_A Dynamic Model Post-Simulation State Values [Source: GE PSLF]

- It is suggested that the same variables that track DER behavior (e.g., MW output, MVAR output, tripping characteristics) be accessible in the plotting tools associated with transient stability software. Being able to quickly assess, for example, the percentage of DERs that tripped in a specified area following a system disturbance would aid in power system dynamic analysis.

- In some transient stability programs when the results of transient stability are reviewed and plotted, there is no option to see and to plot the gross load, only the net load. Because of this, plots of load may look somewhat counter-intuitive; for example, load sharply increases with reduction in voltage because of the behind-the-meter DER trip. It would be useful to have an option to plot gross load as well as net load.

- There is interest from planning engineers in being able to take information on a DER (e.g., determining percentage of DER that tripped at each model) from the final system state in transient stability runs and import this information back into the power flow case in order to study the post-contingency power dispatch. While it is understood that importing all of the information in the dynamic simulation back into the power flow may not be possible (e.g., if the system frequency was off nominal in the dynamic simulation, this would alter many of the resulting impedances in the steady state simulation), importing DER-specific information would be useful for studying certain situations, such as assessing post-contingency behavior of the system for thermal limit monitoring and PV/QV analysis.

- It would be helpful to provide the functionality to import recorded transient DER behavior into the post-contingency aggregate DER active and reactive power output at each load element back into the load flow case. For example, if a transmission fault causes 5 MW of DER generation to trip offline at a particular bus, it would be helpful to generate a script file that could be applied to the steady-state case that described this resulting 5 MW change in distributed generation at this bus.

The above bulleted recommendations are likely to impact the computation burden required to run transient stability studies, especially when considering a variety of outage permutations. It is recommended that software vendors continue to be cognizant of computational time required for dynamic runs even as DERs increase modeling complexity.

Key Takeaways

- The DER_A model is recommended for use in dynamics studies to quantify DER behavior. The model should be supported in power flow software, both as a standalone model and as a component of the composite load model.
- Post-contingency information on DER behavior, including the fraction of generation that tripped and was restored, should be made available in a tabular format.
- Plotting tools associated with dynamic simulations should provide accessible ways to display DER behavior, both at individual buses and in aggregate (by owner, area, zone, etc.).
- Plotting tools should also provide the ability to view both gross load and net load values.
- The ability to import DER tripping behavior from dynamic simulation back into the power flow model would be useful.
- It is recommended that software vendors continue to be cognizant of the computational time required for dynamic runs even as DERs increase modeling complexity.

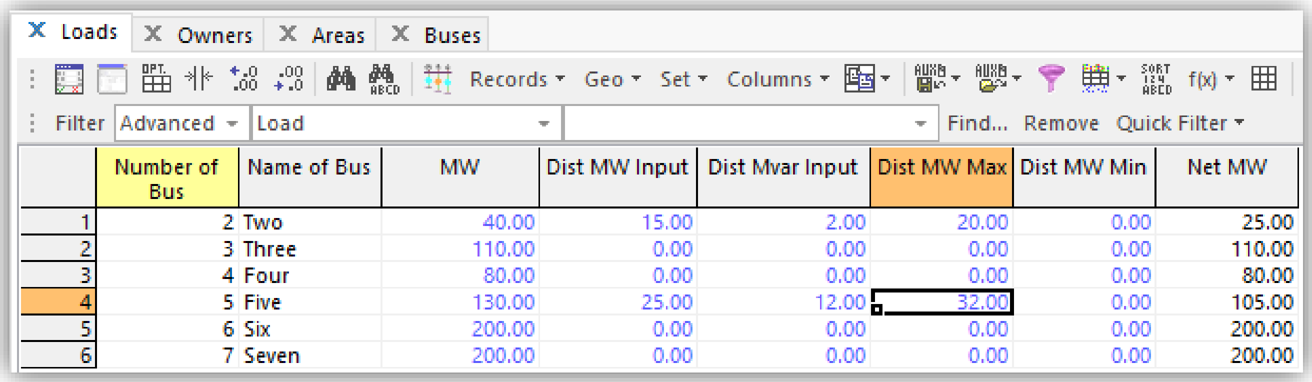
Off-Peak Dispatch of Solar DER

Power Flow Modeling

In transmission planning base case models, all generators have a specified P_{max} that designates the maximum output of the facility, regardless of season or time of day (i.e., the nameplate capacity of the facility). Some distributed generation, especially PV solar generation, will have a range of active power output values that will be at or below this P_{max} level depending on the season and time of day. For instance, a PV resource with a peak capacity of 1 kW at 12:00 p.m. in the summer may only be generating 0.5 kW at 4:00 p.m. in the fall.

The base case building process is moving towards a paradigm in which the specified time of day will have a large impact on the generation dispatch profile. In the future, a Heavy Summer case at 12:00 p.m. may look very different from a Heavy Summer case at 7:00 p.m. given the large change in solar generation (both DERs and utility-scale) between these two times.

In order to provide the ability to adjust DER output to off-peak values, power flow software will need to maintain minimum and maximum active power output capability for each DER model. As shown in **Figure 4**, PowerWorld provides an example of these parameters by tracking the “Min MW” and “Max MW” value within the Distributed Generation section of the load model dialog, which is further expanded in Figure 10. These minimum and maximum values enforce limitations on the active power output of the specified DERs.



Filter Advanced Load

	Number of Bus	Name of Bus	MW	Dist MW Input	Dist Mvar Input	Dist MW Max	Dist MW Min	Net MW
1	2	Two	40.00	15.00	2.00	20.00	0.00	25.00
2	3	Three	110.00	0.00	0.00	0.00	0.00	110.00
3	4	Four	80.00	0.00	0.00	0.00	0.00	80.00
4	5	Five	130.00	25.00	12.00	32.00	0.00	105.00
5	6	Six	200.00	0.00	0.00	0.00	0.00	200.00
6	7	Seven	200.00	0.00	0.00	0.00	0.00	200.00

Figure 10: Distributed Generation Maximum and Minimum Active Power Limit Fields [Source: PowerWorld]

Furthermore, it will be useful to determine an aggregate “headroom” between the dispatched active power of a group of DER and the total possible active power generation of this group. For instance, the PowerWorld “Loads” tab displays a “Dist MW Input” and “Dist MW Max” value for each load (see Figure 10). However, in aggregation tabs, such as “Areas,” it is not possible to view the total “Dist MW Max” across all DERs by area. This functionality would allow planners to quickly view how much of the potential DER active power is currently dispatched in a case.

Adding the ability to adjust the ratio of DER active power that is dispatched in a case would also be helpful. This could involve a controllable variable that represented the ratio of dispatched DER active power to total available DER active power. Since the DER dispatch may vary across geographic areas or in particular regulatory environments as well, providing the ability to adjust this ratio by Area, Zone, Owner, etc. would also be useful.

However, care must be taken when adjusting DER active power output globally. Non-PV DERs, such as distributed wind, may have active power outputs that should not be adjusted based on the time of day. In this case, it might be necessary to track PV DERs separately from non-PV DERs, and only adjust the PV DER active generation setpoints. Utilities and software vendors should collaborate to establish the appropriate parameters for the provision of this functionality.

Key Takeaways

- Power flow software should provide minimum and maximum active power generation fields within DER models that enforce limits on the active power output of DER devices.
- The combined active power setpoints and the combined maximum active power of all DER in a particular Area, Zone, etc. should be easily viewable in a tabular format in order to provide a measure of "headroom" between existing DER dispatch and maximum potential dispatch.
- Functionality should be added to power flow software to easily adjust the ratio of dispatched DER active power to total available DER active power. This functionality should be available to apply to the entire base case or a particular Area, Zone, Owner, etc.
- Care must be taken when providing global DER adjustments as it may not be appropriate to adjust non-PV DER.

Transient Modeling

When adjustments are made to DER active power setpoints, they may require corresponding changes to the DER dynamic modeling parameters. For instance, the NERC Modeling Notification, *Dispatching DER Off of Maximum Power during Study Case Creation,*[20] describes how to set parameters of the DER_A model (specifically *Freq_flag*, *Ddn*, and *Dup*) in cases where DERs are dispatched at off-peak output levels.

A major concern is the possible disconnect between the power flow and dynamic models since modeling maintenance or updates might not occur if data needs to be updated in both the power flow model and the dynamic model. For many planners, tracking and changing dynamic model parameters in each scenario is more challenging than changing power flow data.

This is especially true when an engineer has to adjust a large set of data for individual models and may not have enough detail to determine if their DER can be dispatchable or not for a given scenario. In general, planners adjust their own DER model parameters but are hesitant to make changes to neighboring systems.

One way to prevent these issues would be to flag dynamics data that does not agree with steady state parameters. As an example, PSS/E automatically highlights some of the parameters that are outside typical ranges in both power flow and dynamic cases for conventional power system elements. It would be helpful if such capability can be added for DER modeling.

For example (see **Figure 11**), the V_{max} and V_{min} fields are highlighted by PSS/E in the power flow. This is due to the fact their values are greater than 1.5 per unit (default maximum number). There is also a warning message when loading the power flow case as shown in **Figure 12** which is logged in a file or the program output for ease of view to the user.

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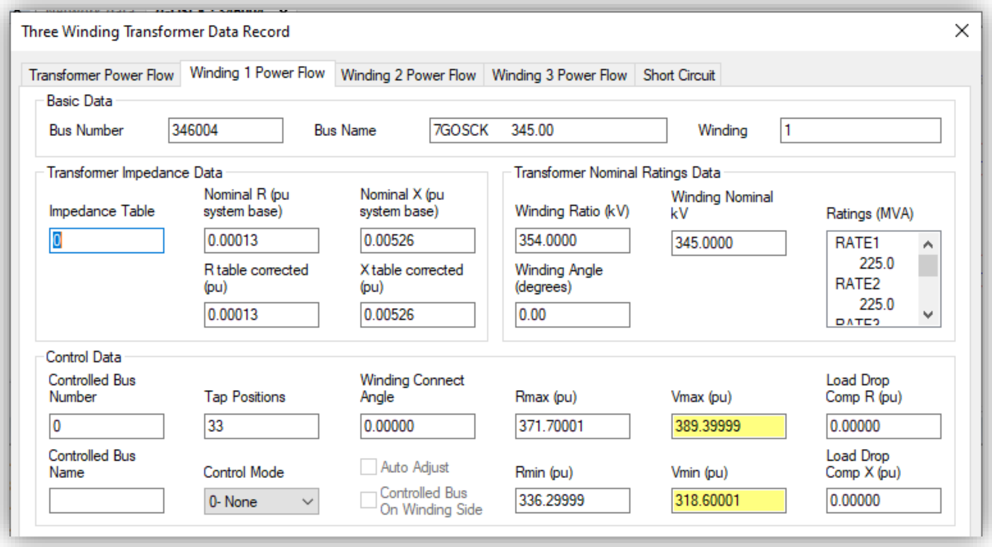
[20] NERC, "Dispatching DER Off of Maximum Power during Study Case Creation." Available here: https://www.nerc.com/comm/PC/NERCModelingNotifications/Dispatching_DER_Off_of_Maximum_Power_during_Study_Case_Creation1.pdf



Three Winding Transformer Data Record

Basic Data

Bus Number: 346004
Bus Name: 7GOSCK 345.00
Winding: 1

Transformer Impedance Data

Impedance Table: 0
Nominal R (pu system base): 0.00013
Nominal X (pu system base): 0.00526
R table corrected (pu): 0.00013
X table corrected (pu): 0.00526

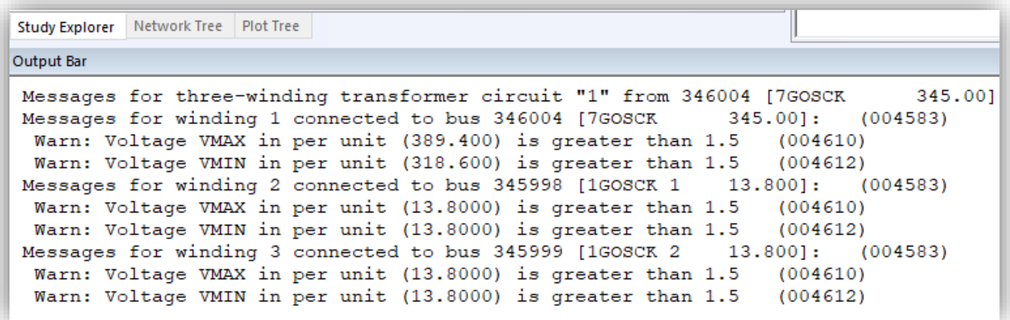
Transformer Nominal Ratings Data

Winding Ratio (kV): 354.0000
Winding Nominal kV: 345.0000
Winding Angle (degrees): 0.00
Ratings (MVA): RATE1 225.0, RATE2 225.0

Control Data

Controlled Bus Number: 0
Tap Positions: 33
Winding Connect Angle: 0.00000
Rmax (pu): 371.70001
Vmax (pu): 389.39999
Load Drop Comp R (pu): 0.00000
Controlled Bus Name:
Control Mode: 0- None
☐ Auto Adjust
☐ Controlled Bus On Winding Side
Rmin (pu): 336.29999
Vmin (pu): 318.60001
Load Drop Comp X (pu): 0.00000

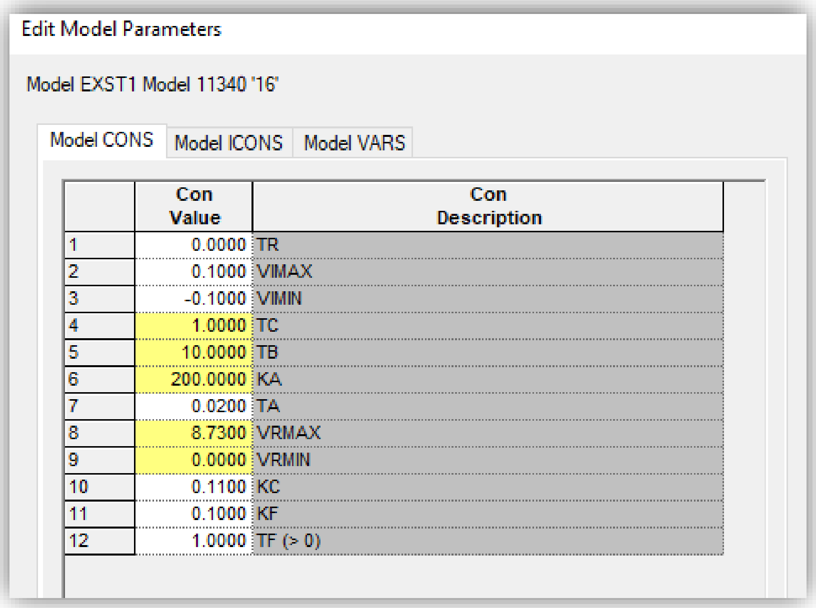
Figure 11: Potential Out-Of-Range Vmax and Vmin Parameters [Source: Siemens PSS/E]



```
Messages for three-winding transformer circuit "1" from 346004 [7GOSCK      345.00]
Messages for winding 1 connected to bus 346004 [7GOSCK      345.00]:   (004583)
 Warn: Voltage VMAX in per unit (389.400) is greater than 1.5   (004610)
 Warn: Voltage VMIN in per unit (318.600) is greater than 1.5   (004612)
Messages for winding 2 connected to bus 345998 [1GOSCK 1    13.800]:   (004583)
 Warn: Voltage VMAX in per unit (13.8000) is greater than 1.5   (004610)
 Warn: Voltage VMIN in per unit (13.8000) is greater than 1.5   (004612)
Messages for winding 3 connected to bus 345999 [1GOSCK 2    13.800]:   (004583)
 Warn: Voltage VMAX in per unit (13.8000) is greater than 1.5   (004610)
 Warn: Voltage VMIN in per unit (13.8000) is greater than 1.5   (004612)
```

Figure 12: Log Output of Potential Out-Of-Range Parameters [Source: Siemens PSS/E]

Similar capability exists when working with dynamic models. Figure 13 shows an example of the EXST1 model with parameters outside typical ranges being highlighted.



Model EXST1 Model 11340 '16'

	Con Value	Con Description
1	0.0000	TR
2	0.1000	VIMAX
3	-0.1000	VIMIN
4	1.0000	TC
5	10.0000	TB
6	200.0000	KA
7	0.0200	TA
8	8.7300	VRMAX
9	0.0000	VRMIN
10	0.1100	KC
11	0.1000	KF
12	1.0000	TF (> 0)

Figure 13: Flagged Dynamics Parameters for Potential Out-Of-Range Data [Source: Siemens PSS/E]

The most likely parameter to be misaligned between power flow and dynamic studies is the DER MVA base value for DER modeled as standalone U-DER generators. It will be particularly important to flag when there is a discrepancy between this value in the power flow and dynamic models.

Another potential solution to this issue may be to automatically adjust certain dynamic modeling parameters as the steady state values are changed. For any automated adjustments, the user should be made aware via the program log that a change to the data has been conducted.

Automating such a process requires a detailed understanding of the DER dynamics models and how they should be parameterized. Sources like the NERC *Reliability Guideline: Parameterizing the DER_A Model*[21] provide information to planning engineers regarding how best to determine the DER_A parameters. These references may also be of interest to power system software vendors to provide guidance on automatically adjusting certain DER_A dynamic model parameters in order to match steady-state DER dispatch modeling data.

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[21] https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_DER_A_Parameterization.pdf

Key Takeaways

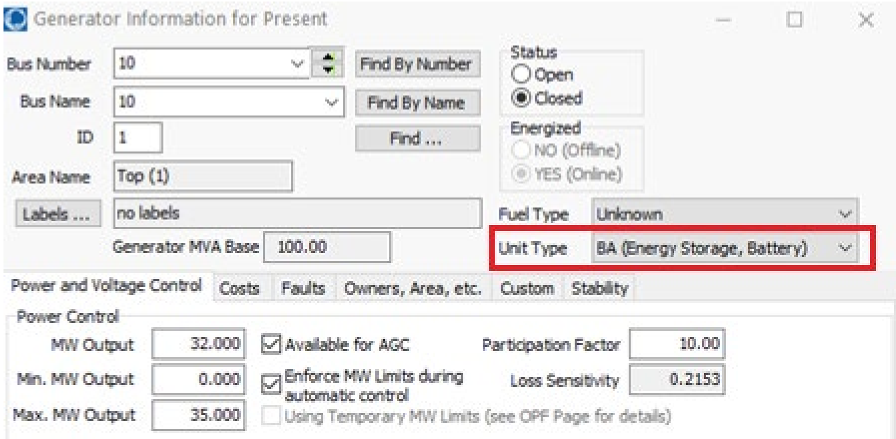
- Adjustments to certain DER power flow parameters will necessitate corresponding changes to the associated DER dynamics model per NERC documentation.
- Given the large amount of DER information likely to be present in future base case models, it will not be feasible for planning engineers to adjust all of the DER dynamics data after DER power flow adjustment have been made.
- Power flow and dynamics models should visually flag and report parameters that are suspected of being out-of-range via the log.
- When a DER is modeled as a standalone U-DER generator, particular care should be taken to flag or otherwise communicate when there is a discrepancy between the power flow and dynamic model MVA Base parameter.
- It may be beneficial to consider automating certain DER dynamics modeling parameter adjustments as the DER steady state values are changed while providing feedback to the user that this is occurring.

Battery Energy Storage System Modeling

U-DER Energy Storage Models

Modeling approaches for larger U-DER energy storage resources will depend on recommendations from other groups, including the NERC SPIDERWG and industry and regional planning organizations. In general, it is recommended that power system software provide the ability to model energy storage resources as independent generators with the ability to output a negative load.

From a power flow perspective, this representation is an acceptable modeling approach. However, in the absence of an identifying field, it may make it difficult for planners to observe power system base cases and determine which generation resources offer the flexibility of energy storage resources, so using the Energy Storage tag in the Unit Type or Turbine Type field for generators that represent energy storage resources is recommended (see **Figure 14**).



Generator Information for Present

Bus Number: 10

Bus Name: 10

ID: 1

Area Name: Top (1)

Labels ...: no labels

Generator MVA Base: 100.00

Status: ○ Open ● Closed

Energized: ○ NO (Offline) ● YES (Online)

Fuel Type: Unknown

Unit Type: BA (Energy Storage, Battery)

Power Control

MW Output: 32.000

Min. MW Output: 0.000

Max. MW Output: 35.000

☑ Available for AGC

☑ Enforce MW Limits during automatic control

☐ Using Temporary MW Limits (see OPF Page for details)

Participation Factor: 10.00

Loss Sensitivity: 0.2153

Figure 14: **Example Generator Dialog Box with "Unit Type" Highlighted. [Source: Powerworld]**

Additionally, a separate energy storage symbol on the one line diagrams could potentially make the distinction between these resources and traditional generators or loads more apparent. Current modeling tools do not have a unique symbol to indicate if the generation record depicted has energy storage capability (see **Figure 15**).

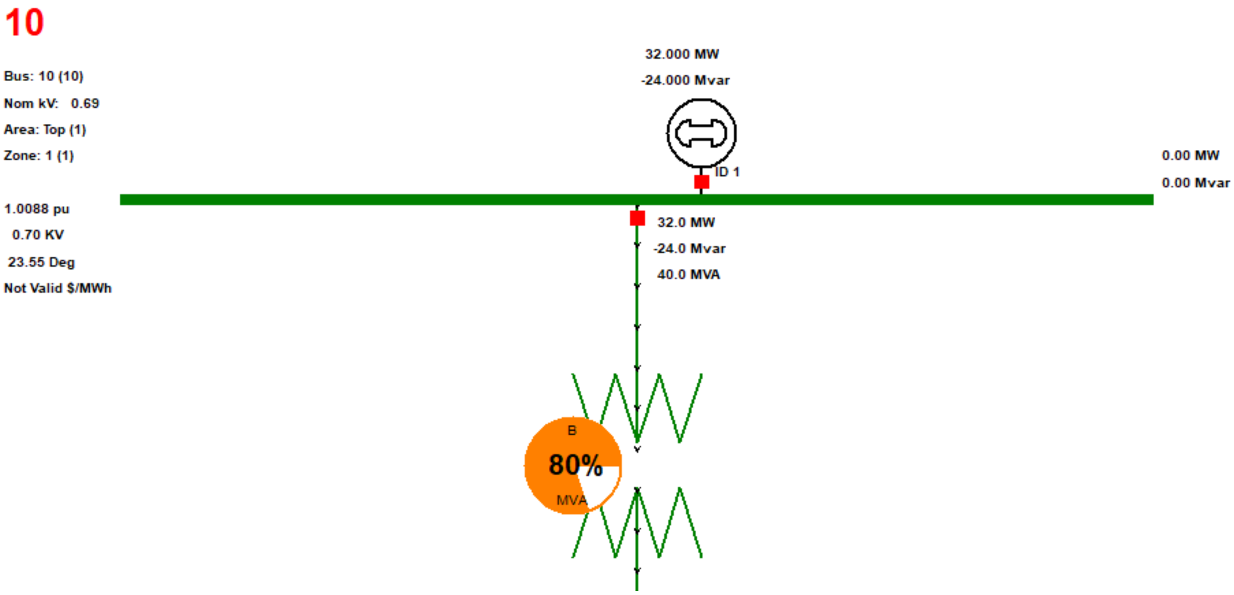


Figure 15: Example Unclear Generator "Unit Type" One-Line. [Source: PowerWorld]

R-DER Energy Storage Models

R-DER energy storage resources represent a difficult modeling challenge that system planners are still in the process of grappling with. In general, DER storage devices may be deployed alone along a distribution feeder or collocated with generating DER devices on the same feeder. Best practices are still under development for tracking energy storage separately on the same feeder and determining whether the energy storage devices should be dispatched in the power flow case.

This white paper recommends that future distributed generator submodels within the load model provide the ability to divide the distributed generation into multiple "turbine types" or "unit types" in order to account for the feeders that contain both energy storage and generating resources. This will allow planners to better track which resources should be deployed depending on the scenario.

Key Takeaways

- Distributed generation models should include the ability to separate resources into multiple "turbine types" or "unit types" in order to track energy storage resources separately from generation resources.

PART III: Seams between Power System Studies

The prevalence of DERs will stress the "seams" that exist between various types of power system studies. For instance, DER active power injection will affect distribution voltage and current dynamics while also changing power flows at the bulk transmission level. It will be necessary to quantify the impacts that DERs have in both distribution and transmission models either by creating data structures that can be easily ported between distribution and transmission software programs or by developing co-simulation platforms that can capture the behavior of the combined systems.

Part III highlights some of the known seams between power system studies and discusses how both interoperability between software programs and development of new co-simulation platforms will aid future planning efforts.

Transmission vs. Distribution Studies

For a number of reasons, transmission and distribution planners have traditionally run separate studies for their portions of the power system. With DERs, this is making the needs of both systems require a coordination and balance as illustrated in **Figure 16**.

Transmission planners' deal with a highly interconnected grid where the magnitude and direction of flow over transmission lines can change significantly based on the season and system conditions. They are often beholden to numerous federal and state requirements on how the transmission system should be planned. NERC Standard TPL-001[22] specifies the single- and multiple-element contingencies that must be studied by using power flow analysis to determine whether specified thermal and voltage criteria are met. Since transmission systems are relatively balanced across all three phases, positive-sequence programs that ignore phase imbalance are the tool of choice.

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[22] NERC Standard TPL-001-4 – Transmission System Planning Performance Requirements, NERC.

The TPL-001 standard also requires that transient stability analysis is used to determine whether the transmission system will maintain stability during specified faults and outages. This involves choosing the applicable industry-standard mathematical dynamic model for each system component (generator, exciter, stabilizer, etc.) and parameterizing it based on testing methods specified in NERC Reliability Standards MOD-25,[23] - 26,[24] and -27.[25] These block diagram models provide the differential equations that drive the transient behavior within dynamic simulations. The same positive-sequence transmission planning models are used in transient analysis in order to determine the voltage and current profiles within the network at each time step of the simulation.

In contrast, distribution planners deal with a radial network topology where phases can no longer be assumed to be balanced. Distribution networks also tend to change much more rapidly than transmission with daily reconfiguration not uncommon to mitigate outage impacts or offload customers to other feeders. While distribution planners also employ thermal and voltage analysis, it is not typical to study transients at the distribution level, so software tools used by distribution planners can accurately model phase imbalance and handle reconfiguration seamlessly. However, these tools typically are less robust at handling meshed networks and do not typically provide transient analysis capabilities.

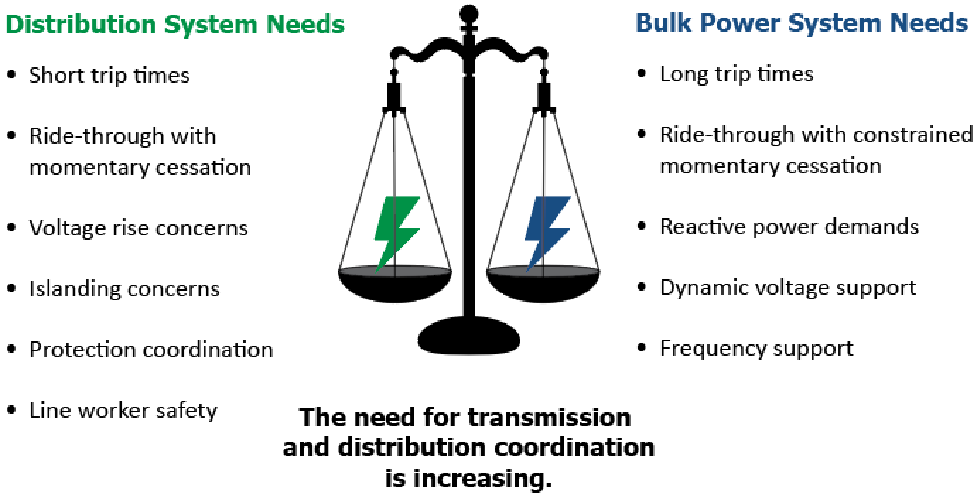

Figure 16: Bulk Power System and Distribution System Needs—Drivers for Coordination [Source: Adapted from EPRI]

As described throughout this white paper, DERs are blurring the lines between transmission and distribution analysis that requires a shift in how the power system is planned. The dynamics of distribution system operation, now more than ever, have to be carefully considered within the context of their impacts on BPS reliability.

Tools like the DER_A model provide a positive-sequence approximation of DER tripping behavior; this is a useful model for describing aggregate DER behavior. As DERs proliferate, further tools will be required to

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[23] NERC Standard MOD-25-2 – Verification and Data Reporting of Generator Real and Reactive Power Capability and Synchronous Condenser Reactive Power Capability

[24] NERC Standard MOD-26 – Verification of Models and Data for Generator Excitation Control System or Plant Volt/Var Control Functions

[25] NERC Standard MOD-27 – Verification of Models and Data for Turbine/Governor and Load Control or Active Power/Frequency Control Functions

provide higher-fidelity models that accurately capture the minutia of distribution operations. **Table 1** below lists several types of planning studies that must consider both transmission and distribution impacts.

Table 1: Overlapping Transmission and Distribution Planning Studies Related to DERs

Focus of Study	Distribution Impacts	Bulk System Impacts
Steady-state injection of DER real and reactive power	Voltage rise/drop concerns Developing data management strategies to separate net and gross system load Feeder and service transformer upgrades may be required	Large-scale changes to bulk system power flow that may defy traditionally observed patterns
DER trip settings	Coordination with other protection devices on the feeder Preventing DER energization of feeders during maintenance/outage work Adherence to applicable standards such as IEEE 1547-2018	Tripping behavior of DERs during faulted system conditions affects transient stability analysis
Distribution Automation and Recloser Operation	Coordination with downstream protection devices Continuity of electrical service for impacted customers	Distribution automation dynamics may alter distributed generator output and load profiles in turn affecting bulk system transient stability analysis
Under-frequency and Under-voltage load shed schemes[26]	Excluding critical loads from UFLS/UVLS enabled feeders	Determining an adequate amount of load shed in order to maintain system voltage and frequency stability while accounting for distributed generation losses at UFLS/UVLS enabled feeders

The studies listed in **Table 1** may be difficult to analyze with a single software tool. Planners will increasingly rely on collaboration between existing tools (e.g., running full three-phase unbalanced analysis on a distribution platform) and then importing the salient information from the distribution system into a transmission planning tool. In this environment, the more that separate industry tools can interact with each other the better off the resulting studies will be.

Furthermore, there is increasing interest in the development of new software platforms that can model both distribution and transmission systems on one unified software setting. Such tools would provide

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[26] NERC *Reliability Guideline – Recommended Approaches for Developing Underfrequency Load Shedding Programs With Increasing DER Penetration*. System Planning Impacts of Distributed Energy Resources Working Group. Available: https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Recommended_Approaches_for_UFLS_Program_Design_with_Increasing_Penetrations_of_DERs.pdf

planners with comprehensive tools to describe the full behavior of the system although most appear to be in the earlier development stages. For a full discussion of transmission and distribution co-simulation tools and techniques the NERC SPIDERWG is working on a technical reference document that will be available at the Reliability and Security Technical Committee (RSTC) website on approval[27].

Key Takeaways

- To provide the ability to import data between transmission and distribution software tools will be increasingly important to power system planners.
- Co-simulation tools are in development. NERC SPIDERWG stresses that these tools will fulfill a critical role in future planning studies. The NERC white paper, *Beyond Positive Sequence*, provides a deeper inspection of this topic.

Positive-Sequence Power Flow vs. Electromagnetic Transient Studies

DERs, and inverter-based resources in general, are also stressing the need for increased use of electromagnetic transient (EMT) analysis in planning studies. Fast timescale interactions between power electronics, switching devices, and electromechanical generator elements drive transients that positive-sequence software cannot accurately capture.

Engineers are increasingly relying on both positive-sequence and full EMT analysis when performing planning studies with data from one platform often having to be reproduced in the other. It would greatly aid planners if this data exchange was ironed out. For instance, it should be possible to identify a portion of the transmission system in a positive-sequence environment and create a corresponding transmission model in an EMT environment. Additionally, this should be while automatically calculating the Thevenin-equivalent parameters at the boundaries of the system and auto-populating the initial power flow in the EMT simulation. Such integration provides planners with a faster and more accessible way to run EMT and positive-sequence studies.

Key Takeaways

- Planning engineers use EMT analysis now more than ever, but it is not always a smooth process to import load flow and transmission modeling data from positive-sequence programs into EMT tools. It would be helpful if a portion of the transmission system could be identified in positive-sequence software and the information on Thevenin-equivalent boundaries of the selected system, as well as the initialized power flow information, could be easily imported into an EMT environment

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[27] RSTC approved document page is available here: https://www.nerc.com/comm/Pages/Reliability-and-Security-Guidelines.aspx

Contributors

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