Battery Energy Storage and Multiple Types of Distributed Energy Resource Modeling

December 2022

Executive Summary

The NERC System Planning Impacts from Distributed Energy Resources Working Group (SPIDERWG) investigated the potential modeling challenges associated with new technology types being rapidly integrated into the distribution system. SPIDERWG weighed updating or altering the recommended modeling framework and found that previous modeling guidance held in the face of two or more dominant technology types of distributed energy resources (DER) at a T–D Interface. Furthermore, SPIDERWG determined that control behavior rather than fuel sources is more appropriate for transient dynamic parameterization. This does not prevent the separation of DERs into two or more sets of dynamic transient models based on fuel source as necessary for a particular study application.[1] SPIDERWG also provided a set of sanity checks for Transmission Planners (TP) or Planning Coordinators (PC) to use two or more aggregate dynamic models to capture the totality of DERs behind a T–D interface. SPIDERWG developed recommendations when modeling more than one dominant control type behind a T–D interface (see **Recommendations**).

Purpose

The landscape of the power grid is constantly evolving due to the rapidly changing technologies and regulatory policies. This white paper highlights the importance of the ability to adequately model distributed battery energy storage systems (BESS) and other forms of distributed energy storage in conjunction with the currently prevailing solar photovoltaic (PV) systems of current DER installations. The higher deployment of DERs across the country has recently increased the application of distribution-connected BESSs as they can complement DERs that are limited, non-dispatchable, variable, and intermittent in nature. BESSs are also applied to distribution systems for other objectives, such as reducing customer demand charges, managing time-of-use rates, customer backup power, and participation in energy and ancillary service markets. BESSs, applied either in conjunction with variable DERs or as stand-alone storage applications, can improve system operation, planning, and efficiency and can act as reliable as well as vital source for emergency preparedness.

This white paper shares industry experience with DER BESSs and other forms of distributed energy storage modeling to highlight industry best practices, discuss lessons learned from studies performed with DER BESSs, and highlight model applications and parameterization within industry software and tools. The white paper also provides potential modeling practices to parameterize differing technology types under the SPIDERWG recommended modeling framework.

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[1] Study assumptions, such as nighttime conditions (and thus no Solar PV available) or batteries charging, require the disaggregation by fuel type in order to properly set up the case.

Background

SPIDERWG has published documentation on the recommended DER modeling framework to capture the distribution-connected resources that exist on the grid. While those documents have been published with the knowledge that the dominant technology type of DER is solar PV, they are helpful and can be adapted to discuss nuances associated with battery storage or other storage devices. Furthermore, when modeling solar PV and one of the available storage technologies, the previously published guidance is informative to produce the models. This section highlights the major points of the previous modeling guidance of SPIDERWG materials.[2]

DER_A Model Application

> **Key Takeaway**
>
> The DER_A model can represent distributed BESSs in dynamic transient software with proper adjustment of parameters.

The dynamic effects of the DER units on the transmission systems are conventionally studied with the DER_A dynamic load model either as a stand-alone or incorporated with the composite load model; the DER_A model was originally proposed for inverter-based solar and wind power generation. This model is appropriate for most applications[3] since the effect of distribution unbalanced loads on transmission voltage are not significant for a TP's simulations.[4] When used with BESSs, the active power command must be altered to a negative value for power absorption to represent the charging mode of energy storage.

The DER_A model uses a reduced set of parameters to represent the aggregation of a large number of inverter-interfaced DERs. The DER_A model can be used to represent both utility-scale distributed energy resources (U-DERs) and retail-scale distributed energy resources (R-DERs) in the simulation.[5,6] The DER_A model includes constant power factor and constant reactive power control modes; active power-frequency control with droop; dynamic voltage control; a representation of a fraction of resources tripping, restoring, or entering momentary cessation; active power ramp rate limits; and active-reactive current priority. Thus, the DER_A model is an appropriate model to use for both charging and discharging battery energy storage.

Currently, it is not anticipated that there are control interaction impacts for the DER_A model due to many Distribution Providers disabling the local voltage and frequency control blocks for the DERs that interconnect to the distribution system. In general, there may be greater attention to implementing bulk

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[2] All of the past SPIDERWG modeling related reliability guidelines can be found here: https://www.nerc.com/comm/Pages/Reliability-and-Security-Guidelines.aspx. Further information on SPIDERWG can be found on their website: https://www.nerc.com/comm/RSTC/Pages/SPIDERWG.aspx

[3] SPIDERWG has also identified applications where a single aggregate positive sequence dynamic model (i.e., DER_A model) would not fit in this generalization titled *Technical Report: Beyond Positive Sequence* available: Report (nerc.com)

[4] TPs primarily use Positive Sequence models to represent both the transmission and distribution system, and the DER_A model is a positive sequence dynamic transient model. This statement indicates that no new model is required to represent distribution-connected BESS in the TP's set of models.

[5] U-DERs and R-DERs are modeling designations to break up the DERs into two distinct categories. For more information, see the published SPIDERWG Guidance: (merged SPIDERWG RG from Tranche 2, if approved Dec RSTC)

[6] There is a need to adequately parameterize the DER_A model embedded in the composite load model to reflect the DER at that location on the feeder. This may involve adapting the model framework to allow for accurate parameterization of the load components of the composite load model and the DER components.

grid support functionality, such as frequency regulation, in areas where the DER penetration is high. However, the greater factor is the level of understanding of these issues by the distribution entities and their opinions on how implementing these functions balance with their own system's needs. Decisions regarding local voltage regulation implementation are most frequently based on the potential benefits and adverse consequences at the distribution level without any consideration of bulk system implications.[7] For these instances, some control interaction may exist between the various protection, voltage regulation, and frequency regulation schemes that are more important to capture rather than the fuel mix of the resources. Return-to-service, ride-through, and anti-island settings complicate the mix and can cause DER power disruption. The DER_A model has the capability to model the critical set of these equipment settings, and SPIDERWG does not propose developing a new model to capture all of the settings. Rather, SPIDERWG recommends TPs and PCs use other models in the software (e.g., protection models) in order to capture the remainder of the behavior rather than developing a larger integrated generator model.

Application to Co-simulation Algorithms

The DER_A model can be used to represent active and reactive current injection/absorption of standalone/aggregated single-phase DER units, including BESSs, in three-phase distribution simulators. The distribution simulator can then be coupled with a transmission simulator in a co-simulation environment through exchange of powers and voltages at the T–D coupling points. In these instances, the equipment being modeled in the DER_A model is for one point of interconnection at the distribution interface with an explicit representation of distribution feeders and other shunt equipment on the distribution system based on the local distribution requirements to serve load in that area. The transmission system is simulated separately from the distribution system, so the aggregate model instead is at the distribution point of interconnection rather than at the T–D interface and is an adaptation of the positive sequence modeling framework to use co-simulation. In short, batteries do not alter the general guidance of DER-related work in the co-simulation area.

Distributed Energy Storage FERC Order No. 2222 Implications

On September 17, 2020, the Federal Energy Regulatory Commission (FERC) approved Order 2222, enabling DER aggregators to compete in all regional organized wholesale electric markets. FERC defined DERs in Order 2222 as follows: "These resources may include, but are not limited to, resources that are in front of and behind the customer meter, [electric storage resources], intermittent generation, distributed generation, demand response, energy efficiency, thermal storage, and electric vehicles and their supply equipment – as long as such a resource is located on the distribution system, any subsystem thereof or behind a customer meter." [Emphasis added]

The final rule enables these aggregations of a DER to participate in the regional organized wholesale capacity, energy, and ancillary services markets alongside traditional resources. Multiple DERs may aggregate to satisfy the minimum size requirement that is specified in Order 2222 of 100 kW along with any necessary performance requirements that they might not meet individually. It is anticipated that Order 2222 will bring many different technology types of DERs into the market and the system. While Solar PV

[7] Voltage regulation provided by DERs at the distribution level rarely has any steady-state benefit to regulation of the transmission voltage due to the decoupling effect of on-load tap changers and voltage regulators in the distribution system.

still is the largest share of DERs in the system, it is anticipated that BESSs will rise to an appreciable penetration, meaning that the modeling framework proposed by SPIDERWG may need adaption to account for two significant lump sums of equipment potentially having differing operational characteristics. This white paper describes those considerations; however, the impacts of a DER aggregator are greater than modeling efforts for two or more technology types in an aggregated generation resource (akin to a virtual power plant with many fuel types). SPIDERWG's *White Paper: BPS Reliability Perspectives on the DER Aggregator*[8] contains a discussion on the various aspects of interfacing with the DER aggregator and has ongoing work to address various aspects of the issue.

Modeling of Distribution-Connected BESS

So far, SPIDERWG has investigated a few modeling aspects of BESSs. They have compared the electrical response of the BESS equipment in the positive sequence model versus a more explicit representation of the charge, discharge, and state of charge in an electromagnetic transient software. The comparison showed that the DER_ A model captured the large disturbance behavior of the resource, and there were not many times when the electromagnetic transient software model showed a more accurate representation than the positive sequence model. Furthermore, these differences are not unique to battery storage, so they were not used for drawing conclusions on modeling of battery storage.

Key Takeaway

Tracking of state of charge is not a critical component to modeling distribution-connected BESS in transmission transient dynamic studies. The DER_A model is sufficient.

While the exploratory simulation has shown that the modeling framework in the other SPIDERWG reliability guidelines is sufficient, there are a few discussion points to consider when accounting for BESS on the distribution system. These batteries can vary between a 7 kW wall-mounted pack to a 1–2 MW shipping container sized battery system that can integrate into community solar farms or interconnect at the distribution system at a separate point of interconnection as a standalone energy storage facility. The guidance in the reliability guidelines covers the different technology types for DERs; however, when a TP builds a distribution equivalent behind the T–D Interface to explicitly build out the SPIDERWG modeling framework,[9] then the TP can begin to place what was originally at the head of the equivalent feeder in the framework throughout the now non-equivalent represented distribution system. Furthermore, there is a real interest for larger U-DER modeled facilities to add large batteries to their installation post-commissioning process. These modify the voltage and frequency response of the plant and require some information to be sent to the Distribution Provider to finish the interconnection as well as to the TP so that proper adjustments are made to align the transmission planning study

Key Takeaway

The modeling framework in SPIDERWG documents accounts for distribution-connected battery storage, yet batteries are being interconnected in a way that can modify wide-area study assumptions. This indicates an increase of data to model appropriately.

[8] Available here : https://www.nerc.com/comm/RSTC_Reliability_Guidelines/SPIDERWG_White_Paper_-_BPS_Persepectives_on_DER_Aggregator_docx.pdf

[9] This is opposed to having the composite load model representation perform this function for the TP. Most major software has an automated and manual capability to add in the distribution equivalent.

assumptions.[10] These modifications to the facility capabilities underscore the sheer amount of study work and coordination of relevant information to ensure bulk system reliability. As other SPIDERWG documents and industry stakeholders have identified, good modeling data is already hard to obtain to populate these power system models so they represent aggregate equipment. Batteries, their various control schemes, and their potential for multiple operational profiles of the distribution-connected resources will only complicate the development of models.[11]

Modeling of Two or More Dominant DER Technology Types at a T–D Interface

In the past SPIDERWG documents, the proposed DER modeling framework had two electrical locations for a generator record specified to account for U-DERs and R-DERs. The framework is reproduced for reference in **Figure 1**. When using this framework, it was typical to have each individual DER above the defined individual modeling threshold to be at the head of the feeder as well as exceptions placed behind the feeder impedance should the feeder impedance be a factor[12] in determining the impact to the T–D interface for those larger utility-scale installations. This framework does not change for modeling the impacts of DER BESSs, and it is only adapted when more than one dominant technology type impacts the operational profile at the T–D Interface. SPIDERWG recommends that the modeling framework here be adapted to account for the control types and parameters for the equipment represented, including representing larger scale installations further away from the head of the feeder if that is more representative.

[10] Primarily around dispatch and whether these batteries will be injecting or absorbing current

[11] The NERC Standards Project 2022-02 is working through a portion of the modeling information and wide-area planning studies for all of DER. The Project webpage is available here: https://www.nerc.com/pa/Stand/Pages/Project2022-02ModificationstoTPL-001-5-1andMOD-032-1.aspx.

[12] In these cases, this would indicate that a shift to more explicit modeling of the distribution system of which the recommended DER modeling framework does not cover. The DER modeling framework is appropriate for instances where specific information (e.g., DER location throughout the system, distribution voltage regulation equipment settings) is not available or desired to be explicitly represented by the TP.

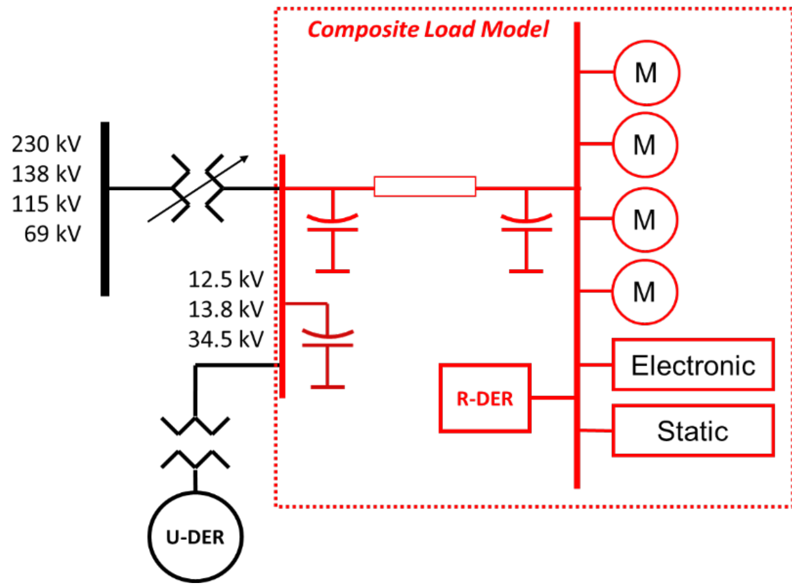

Figure 1: Recommended DER Modeling Framework

Battery Energy Storage Systems with the DER Modeling Framework

Typically, for bulk-connected BESSs, the transient dynamic model[13] representing the equipment accounts for the state of charge and outputs its value to a plotting tool for dynamic simulations in order for the study team to track the energy capability of the battery. The DER_A model lacks the ability to track or initialize the BESS's state of charge and has no loop to deplete the energy of the battery for output. This would mean that with various discharge time constants and levels of charge in an aggregation, there exists no method to accurately describe the tracking of aggregate state of charge, maximum state of charge in relationship to total aggregation capacity, or other various parameters that describe a single facility's operational behavior. In the SPIDERWG investigation, however, this complexity was not seen as a need for use in transient dynamic studies. Rather, the set of study assumptions can be informed by assumed availability of charge for the resources and accounted for by dispatch assumptions for transient dynamic modeling and other transmission planning functions.[14] Thus, the modeling framework can be directly used for capturing the impact of distribution-connected batteries.

In summary, the SPIDERWG modeling framework and the DER_A model are a convenient and recommended approach for capturing the impact of distribution-connected BESSs. No current issues exist with controllers and the state of dynamic transient models that allow for both power absorption and discharge from the equipment. There are various reasons why an aggregate model should be disaggregated, such as primarily the control behavior of the represented devices.[15] SPIDERWG recommends "fuel type" for BESSs be readily available for scenario development.

[13] This is typically the second generation renewable model reec_c.

[14] The Resource Planner, however, may need some different modeling assumptions when performing their analysis. However, this is outside the scope of this paper and the scope of changes is likely to mirror separation of fuel types rather than detailed modeling parameters.

[15] This is typically captured by the "vintage" of IEEE 1547 (e.g., 1547-2003, 1547-2014, etc.) as that dictates the trip behavior. With 1547-2018, some of these behaviors have an allowable range of settings, which can play into a TPs decision to disaggregate on such control behavior. UL 1741 SA or UL 1741 SB certification also can play a factor in deciding to dissaggregate.

Adaption of the Modeling Framework for Two or more Dominant Technology Types

Key Takeaway

When modeling two or more dominant technology types, the modeling framework is sufficient. Control logic on voltage or frequency is more important than technology types. Study assumptions may also dictate when to lump them into two aggregations. A prominent example is an instance of battery charging while solar PV is injecting active power to the system.

SPIDERWG has performed various simulations to show the potential coincident impact of different technology types in this and in the *Technical Report: Beyond Positive Sequence* document that describes potential indicators for a more detailed representation of the distribution system and DER.[16] Many of the findings in that report were based on one technology, solar PV, with various equipment settings based on what version of IEEE 1547 the equipment was certified to. The potential to require two different dynamic models to capture the expected large disturbance behavior seen at the T–D Interface was based on the difference in settings coded into the equipment and various functions enabled or disabled. This serves as the basis for the SPIDERWG recommendations for modeling more than one dominant technology type at a T–D Interface. In practical investigation, however, SPIDERWG members noted that the technology or fuel type is not as important as the inverter settings for most studies. At this time, technology type (e.g., battery storage, solar PV, super capacitors) is less important opposed to the various "smart features" that inverter manufacturers are adding to their equipment. In particular, the frequency and voltage controls. Two aggregations may be needed in order to model these controls.

Taking BESSs as an example, the need for careful parameterization of the DER models is highlighted when BESSs charge while solar PV DERs at the T–D Interface are producing power. In this scenario, not all DER locations have both a BESS and a solar PV system, but the T-D Interface in aggregate is affected motor loads, electronic loads, BESS charging characteristics, solar PV generation output, and a variety of other impacts. When lumping solar PV generation and BESS charging, the need to carefully parameterize the transient dynamic model of the lumped solar PV and BESS is enhanced in order to ensure the current commands and limits are appropriate for such a scenario. In particular, the frequency response settings of the aggregation should be checked by the TP for accuracy.

One complicating factor for using the present modeling framework is that distribution planners typically have feeder plans to ensure the feeder remains within 0.95 and 1.05 p.u. voltage per the ANSII requirements at end-user feeds. The present composite load model automatically adjusts the feeder impedance to ensure the end of the modeled equivalent feeder is within those boundaries. Thus, the transmission planner would need to include this adjustment in their planning practices if the TP is modeling the T–D interface explicitly to account for the electrical distance to head of feeder for the control of multiple aggregations of DERs. SPIDERWG does not consider this a deviation of the framework as it simply transitions from an automated process in the composite load model into something the TP parameterizes manually.

While the industry transitions between one dominant technology type to a future two or more dominant technology types (in terms of penetration at the T–D Interface), the modeling framework does not need to

[16] Available here: https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Beyond_Positive_Sequence_Technical_Report.pdf

be adjusted; however, there are parameters that would need to be tracked and adjusted during the transition. For example, a 1 MVA non-frequency-regulating aggregation coupled with a 0.1 MVA of 5% droop characteristic is a 1.1 MVA aggregation with a 55% droop bound by 1 MVA min and 1.1 MVA max.[17] In a practical modeling application, the above is awkward in present load modeling builds with only one input for generation as it requires aggregation of the "smart features" to be done for each applicable interconnection requirements of the resources. In future load models, there are plans for multiple generation components that would make the above calculation step moot[18] for building one aggregation out of the various control features.

Recommendations

SPIDERWG recommends that TPs and PCs use the recommended modeling framework in **Figure 1** to model multiple separate DER control aggregations behind a T–D Interface. To determine when a TP or PC can separate aggregate DERs into two or more smaller DER aggregations, SPIDERWG recommends ensuring that the following have been accomplished prior to investing the time and resources to maintain two or more aggregate models behind a T–D interface:

- The state of dynamic load modeling for that T–D interface should be of the same or higher model quality than the DER modeling component.
- The new models should be of higher quality when separated from the existing aggregation and provide more information at the T–D interface separated. (e.g., tracking of frequency responsive DERs).
- The percent penetration of the control to be separated should be significant at the T–D interface.
- The case assumptions should be aligned with the need to separate the existing aggregation into multiple.

Furthermore, if the T–D interface is selected for using a method in the *Beyond Positive Sequence* technical report,[19] SPIDERWG recommends to walk through the following:[20]

- TPs should understand the distribution composition, distribution model, load characteristics, and voltage/frequency control logic in order to capture the scope of distribution model buildout for their study.

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[17] Note that the higher percentage droop the larger speed (frequency) different to move the total MVA of the unit. Thus, for a 5% speed change at 55% droop, this 1.1 MVA aggregation will move 9.09% of its nameplate or 0.1 MVA, confirming that the aggregation is parameterized appropriately.

[18] As the planner can simply place each separately parameterized aggregation in the model, and it automatically handles the reflection of the aggregate at the T–D Interface.

[19] Whenever the TP moves to a more explicit model representation there is a need for increased computation power and data management. This is largely understood by most TPs, but it is worthwhile to note that the methods in this report require more explicit model representation than the recommended model framework outside of the listed recommendations.

[20] This is not a recommendation for or against using tools outside of positive sequence, but a list of high level determinations in order to ensure a smoother study plan.

- TPs should compare distribution voltage and frequency response characteristics to local transmission system characteristics and constraints to gather required data flags and information to exchange in the simulation platforms.
- TPs should determine the setup convenience to build the model and interface between the distribution solver and transmission solver and note areas of long setup times.