NERC
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WECC Base Case Review: Inverter-Based Resources

NERC-WECC Joint Report

August 2020

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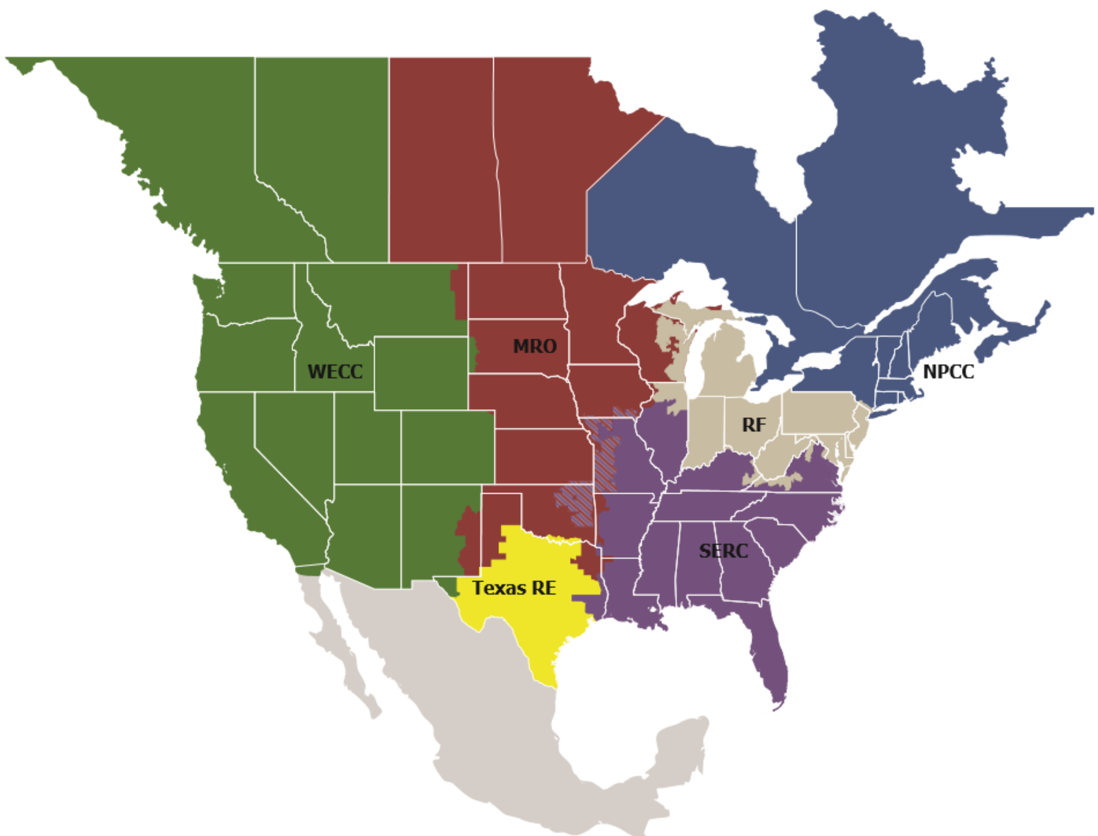
Preface

Electricity is a key component of the fabric of modern society and the Electric Reliability Organization (ERO) Enterprise serves to strengthen that fabric. The vision for the ERO Enterprise, which is comprised of the North American Electric Reliability Corporation (NERC) and the six Regional Entities (REs), is a highly reliable and secure North American bulk power system (BPS). Our mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid.

Reliability | Resilience | Security
Because nearly 400 million citizens in North America are counting on us

The North American BPS is divided into six RE boundaries as shown in the map and corresponding table below. The multicolored area denotes overlap as some load-serving entities participate in one RE while associated Transmission Owners (TOs)/Operators participate in another.



MRO	Midwest Reliability Organization
NPCC	Northeast Power Coordinating Council
RF	ReliabilityFirst
SERC	SERC Reliability Corporation
Texas RE	Texas Reliability Entity
WECC	WECC

Executive Summary

NERC issued alerts following the Blue Cut Fire and Canyon 2 Fire disturbances to gather data to understand the extent of possible inverter tripping or momentary cessation (MC) during fault events and to recommend mitigating actions to address potential reliability issues related to inverter-based resource performance.[1] The NERC alert following the Canyon 2 Fire disturbance focused primarily on modeling issues, recommending industry actions to update models for existing equipment, and proposing updated models for improved performance from bulk electric system (BES) solar photovoltaic (PV) resources. Based on the information from the NERC alert and subsequent follow-up activities, NERC documented several critical takeaways about the extent of modeling issues for solar PV resources in the NERC *Technical Report: BPS-Connected Inverter-Based Resource Modeling and Studies*.[2] These issues were predominantly observed in the Western Interconnection, where a large concentration of BPS-connected solar PV resources exist.

To continue efforts by the ERO Enterprise in this area, NERC and WECC convened a meeting of the majority of Transmission Planners (TPs) and Planning Coordinators (PCs) in the Western Interconnection and shared recommended practices for modeling BPS-connected solar PV resources. During the meeting, the group determined that a concerted effort was needed to address systemic modeling issues for existing solar PV resources and for newly interconnecting solar PV resources. The WECC Solar Modeling Advisory Group (SMAG), consisting of Western Interconnection TPs and PCs, formed following the meeting to facilitate modeling discussions and modeling improvements. The group met regularly for about a year, but made little progress addressing issues with Interconnection-wide base case quality related to solar PV modeling errors.

In Q2 2020, NERC and WECC determined that they would conduct an objective review of a recent WECC base case using the latest dynamics data submitted from registered entities and facilitate modeling discussions for SMAG. This technical report shows the findings and recommendations from that analysis. The WECC 2020 HS3 base case was used with the latest available WECC Master Dynamics File (MDF) dynamics models. The goal of this report is to document issues identified during the review of base case quality, highlight how this analysis was performed, and give recommendations to industry on the next steps to address modeling issues related to inverter-based resources.

Overall Key Findings and Recommendations

This report documents many different findings and takeaways on modeling issues identified in the steady-state power flow base case and associated dynamics data records. WECC and its members should review this report in its entirety to address each of the issues. However, NERC and WECC have identified the highest priority modeling issues that are considered systemic within the WECC base case that need to be addressed immediately. **Table ES.1** shows those findings and recommendations.

[1] https://www.nerc.com/pa/rrm/bpsa/Pages/Alerts.aspx

[2] https://www.nerc.com/comm/PC/InverterBased%20Resource%20Performance%20Task%20Force%20IRPT/IRPTF_IBR_Modeling_and_Studies_Report.pdf

Table ES.1: Key Findings and Recommendations from Wind Plant Model Review		
#	**Modeling Issue**	**Recommendations**
1	Type 3 and Type 4 wind plants and solar PV plants are represented using the first-generation dynamic models (i.e., wt3g, wt4g). See **Chapter 3** and **Chapter 4**.	Generator Owners (GOs) should update their first-generation generic wind and solar PV models to the second-generation models at the earliest possible time due to modeling limitations and simplifications within the first-generation renewable energy models. This may require additional verification testing to ensure accurate parameterization of the dynamic models.
2	Wind and solar PV plants above the modeling threshold established in the WECC *Data Preparation Manual* (i.e., 20 MVA) are represented with either no dynamic model or an incorrect dynamic model (e.g., synchronous generator model). See **Chapter 3** and **Chapter 4**.	GOs should develop appropriate dynamic models for their wind facilities that meet the specifications set in the WECC *Data Preparation Manual* and should use the latest recommended dynamic models (i.e., the second-generation renewable energy models). These models should be provided to the respective TP and PC at the earliest possible time.
3	Wind and solar PV plant models are likely parameterized by using generic values that do not reflect as-built settings of equipment installed in the field. TPs and PCs performing verification of dynamic models for wind and solar PV plants are not capturing modeling errors. See **Chapter 3** and **Chapter 4**.	GOs should ensure that the dynamic models for their respective facilities are parameterized to reflect the actual installed equipment at each specific site and should not include generic parameter values. GOs should coordinate with their TPs and PCs if they have any questions regarding how to parameterize their dynamic models. TPs and PCs should verify[3] the dynamic model parameters provided by GOs to ensure that they match the as-built controls, settings, and configuration of the equipment installed in the field. This verification should occur for all generator models provided and should occur prior to TPs and PCs providing these models to WECC for inclusion in the Interconnection-wide base case.
4	Several modeling errors were identified during the review of case quality. See **Chapter 1**.	GOs should ensure that all data fields are reported correctly per the WECC *Data Preparation Manual*. TPs and PCs should verify that the data fields are submitted correctly. WECC should ensure that data quality checks are being performed on all incoming data from TPs and PCs for their areas. WECC should place additional scrutiny during case review processes to ensure errors are being corrected. Change management processes should be implemented to ensure updates are reflected in the current release of WECC base cases in a timely manner: in particular, generator turbine type, dynamics models for resources above the modeling size thresholds, distributed energy resource (DER) modeling practices, handling retired units, matching power flow and dynamics data, modeling battery energy storage systems (BESSs), interoperability between software vendors, and modeling dynamic reactive devices all should be a primary modeling improvement for WECC and its stakeholder groups.

[3] This should include reviewing appropriate documentation provided by the GO—such as factory test reports, specification sheets, inverter control settings, plant controller settings, etc.

Introduction

Following the Blue Cut Fire[4] and Canyon 2 Fire[5] disturbances, NERC issued alerts[6] to gather data to understand the possible extent of inverter tripping or MC during fault events and to recommend mitigating actions to address potential reliability issues related to inverter-based resource performance. In particular, the NERC alert[7] following the Canyon 2 Fire disturbance focused primarily on modeling issues. Specifically, the NERC alert provided recommendations to accurately model the expected behavior of existing solar PV resources as well as seeking updates to inverter controls for potential changes to eliminate MC (and accompanying modeling updates).

Based on the information obtained from the NERC alert and subsequent follow-up activities, NERC identified several critical takeaways regarding the extent of modeling issues for solar PV resources. These issues were predominantly identified in the Western Interconnection where a large concentration of BPS-connected solar PV resources exist. The key findings and recommendations were documented in NERC *Technical Report: BPS-Connected Inverter-Based Resource Modeling and Studies*.[8]

To continue industry efforts to address the identified modeling issues, NERC convened a meeting of most of the TPs and PCs in the Western Interconnection and shared recommended practices for modeling BPS-connected solar PV resources. One of the key outcomes of this meeting, after hearing feedback from industry stakeholders, was that much more focused effort was needed to address systemic modeling issues for existing solar PV resources as well as newly interconnecting solar PV resources. Building off this meeting and other industry activities, the NERC Inverter-Based Resource Performance Task Force (IRPTF) published NERC *Reliability Guideline: Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources* to support industry develop clear modeling requirements that can be implemented for newly interconnecting solar PV resources.[9]

The WECC SMAG was formed following the meeting with Western Interconnection TPs and PCs to facilitate modeling discussions and modeling improvements. The group met for about a year and made little progress on addressing issues with Interconnection-wide base case quality related to solar PV modeling errors. In Q2 2020, NERC and WECC determined that in addition to facilitating modeling discussions for SMAG that they would conduct an objective review of a recent WECC base case using the latest dynamics data submitted from registered entities.

This report documents the review of the WECC 2020 HS3 base with the latest available WECC MDF dynamics models. Data is being updated and provided to WECC constantly, so it is likely that updates to models have been made even in the time duration between analysis and publication of this report. The goal of this report is to further document some of the issues identified during the cursory review of base case quality, highlight how this analysis was performed, and provide key findings and recommendations for industry next steps to address the modeling issues.

[4] https://www.nerc.com/pa/rrm/ea/Pages/1200-MW-Fault-Induced-Solar-Photovoltaic-Resource-Interruption-Disturbance-Report.aspx
[5] https://www.nerc.com/pa/rrm/ea/Pages/October-9-2017-Canyon-2-Fire-Disturbance-Report.aspx
[6] https://www.nerc.com/pa/rrm/bpsa/Pages/Alerts.aspx
[7] https://www.nerc.com/pa/rrm/bpsa/Alerts%20DL/NERC_Alert_Loss_of_Solar_Resources_during_Transmission_Disturbance-II_2018.pdf
[8] https://www.nerc.com/comm/PC/InverterBased%20Resource%20Performance%20Task%20Force%20IRPT/IRPTF_IBR_Modeling_and_Studies_Report.pdf
[9] https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf

Chapter 1: Review of WECC Summer Peak Base Case

The first step in characterizing the WECC base case and its dynamic models was to identify the different types of units and their associated power flow and dynamics models. The goal was to use the turbine types and generator dynamics models to identify the various types of generators across the WECC system. However, this proved to be challenging, so NERC and WECC performed a more comprehensive review of the WECC 2020 HS3 base case and documented those findings here.

Review of the WECC 2020 HS3 base case involved using the posted WECC power flow base case posted on the WECC website that provides the root steady-state power flow data. The 2020 HS3 base case was selected as the case for analysis since the analysis was being performed during Q1 2020 prior to that upcoming operating season. It was noted that the dynamics data may have been updated from the time that this 2020 HS3 case was created, so WECC pulled the latest WECC MDF data for all applicable units in early May 2020. This provided the most up-to-date dynamics data available that was more current than the posted materials on the WECC website.

NERC and WECC engaged with system planning engineers throughout the Western Interconnection to coordinate verification of the turbine types in the base case. As noted below, turbine types were widely inaccurate in all areas of the WECC base case and required the TPs and PCs to confirm turbine types that were provided or update turbine types that were not provided. Most entities provided a fully completed list of updated turbine types, and a couple of entities stated that they were not able to acquire turbine type information for many of their units. These will be denoted in **Chapter 2**.

The next sub-section documents the observations made by NERC and WECC during the analysis of the 2020 HS3 base case and dynamics data.[10]

Key Findings and Recommendations from Case Review

The following issues were identified during review of the 2020 HS3 base case:

- **Observation:** Many generating units modeled in the power flow base case did not have a turbine type identified. This made tracking types of generation extremely challenging and required NERC and WECC to engage with TPs and PCs to verify the correct turbine types for each generating resource. The WECC *Data Preparation Manual*[11] identifies turbine type as a required data field for generating units in the Interconnection-wide base case. The turbine type field was added in June 2012, and additional turbine type identifiers have been added over the years. NERC and WECC engaged all TPs and PCs to gather accurate turbine types for the 2020 HS3 base case, which was a labor-intensive process requiring significant rework.
    - **Recommendation:** WECC and its stakeholders should ensure that all generating units have turbine types correctly represented in Interconnection-wide base cases as this is a required field in the WECC *Data Preparation Manual*.
    - **Recommendation:** NERC should include a turbine types check in its case quality metrics assessments. WECC should also apply a turbine type check as a condition of modeling in the Interconnection-wide base cases. WECC should place additional emphasis on turbine type data being corrected during case creation and case review processes.
- **Observation:** Many wind generating resources had a turbine type equal to 20, which denotes an “unknown” type of wind turbine generator. This was particularly a practice employed in Area 40.

[10] Focusing primarily on steady-state data and its link to the dynamics data, rather than on the dynamics data parameterization itself.
[11] https://www.wecc.org/Reliability/2020%20WECC%20Data%20Preparation%20Manual.pdf

- **Recommendation:** WECC and its stakeholders should ensure that all wind generating units have a correctly identified turbine type for the type(s) of turbine(s) within the facility (i.e., turbine types 21–24 for wind turbine Types 1–4, respectively).
- **Recommendation:** For any units where the turbine type is not known, TPs and PCs should coordinate with the respective GO to determine the correct type of wind turbine(s) within the facility. This should be accounted for in both the turbine type and the dynamic models.
- **Recommendation:** The WECC *Data Preparation Manual* should eliminate turbine type 20 as an acceptable entry, and WECC should ensure that all wind plants have a correct turbine type associated with them (i.e., types 21–24).[12]

- **Observation:** Many generating units do not have dynamics data associated with the generator record in the base case. This was identified for units both above and below the 10 MVA threshold. Not only does this make it difficult to corroborate turbine types with generating units, but load-netting generation also causes inaccuracies in simulation results.
- **Recommendation:** WECC and its stakeholders should ensure that all units are modeled appropriately based on the following criteria specified in the *WECC Data Preparation Manual*: individual generating units with capacity greater than 10 MVA and connected to the BPS at 60 kV or higher as well as aggregated generating units[13] with capacity greater than 20 MVA connected at 60 kV or higher should submit steady-state data and dynamics data for each generator
- **Observation:** Some DERs are modeled in the power flow base case; however, DERs are not widely included in WECC base cases, posing a risk for the creation of a reasonable starting case for entities neighboring those with notable DER penetrations. Furthermore, there is no clear way to differentiate DERs from other BPS-connected generating units, particularly when modeled at the BPS bus in the power flow base case.
  - **Recommendation:** WECC and its stakeholders should ensure clear and consistent modeling of DERs in the Interconnection-wide base cases for all TP and PC footprints as defined in the WECC *Data Preparation Manual*.[14]
  - **Recommendation:** WECC should ensure that the *WECC Data Preparation Manual* is clear regarding how DERs should be dispatched in the base cases, including time of day, season, and any other relevant assumptions that would affect dispatch of DERs and other BPS-connected variable energy resources. If these topics are covered in overall base case descriptors, they should simply be linked to the DER elements as well.
  - **Recommendation:** WECC and its stakeholders should identify an effective means of tracking which generating units in the base case are DERs and which are BPS-connected units. Tracking could simply include adding additional turbine types for units that are representative of individual or aggregate DERs. Multiple turbine types could be used to capture different types of DERs. For example, "DER-solar photovoltaic" or "DER-battery energy storage" turbine types could be used to track utility-scale DERs (U-DERs) modeled as generators in the power flow base case.
- **Observation:** Multiple TPs represented retired units in the power flow base case with no standardized distinction of which units are retired and which are still in-service. The *WECC Data Preparation Manual* states in Table 2 that "retired units shall be deleted rather than having status set to zero." Therefore, data is being submitted to WECC and entering the WECC base case that does not conform to the *WECC Data Preparation*

[12] Turbine Type 0 or a blank field should not be used as a workaround; this will be identified in the case quality metrics assessments as an unacceptable modeling practice.
[13] Wind, solar PV, and BESSs are examples of aggregated resources with collector system-based generation facilities.
[14] This includes both U-DER modeling in the generator section and R-DER modeling in the loads section of the manual.

Manual. Furthermore, units were denoted as "not operational yet" but were added to the base case with no dynamic models.

- **Recommendation:** WECC and its stakeholders should ensure that the WECC *Data Preparation Manual* is clear regarding consideration of handling retired units and that the specifications in the manual are adhered to during the annual case creation process.
- **Recommendation:** WECC and its stakeholders should ensure that units being added to the Interconnection-wide base cases conform to a standardized set of rules consistent across TPs and PCs. Units being modeled in near-term planning base cases should have both steady-state and dynamics data associated with them.

- **Observation:** In some cases, the unit ID in the power flow base case did not match the unit ID in the dynamics data (.dyd file). This can lead to units being unexpectedly load-netted since they do not have a corresponding dynamics data record assigned to them. This issue was identified in the power flow base case and .dyd file posted to the WECC web page.
  - **Recommendation:** TPs and PCs should ensure that the power flow base case and dynamics data submitted to WECC matches for each base case created. Furthermore, WECC should ensure that units with a submitted dynamics data record are modeled appropriately (i.e., linked to their respective dynamics data). This may include improvements to the WECC MDF process for linking updates to dynamics data with updates to power flow base case information.
- **Observation:** Multiple BESS facilities were modeled with a turbine type of 50; however, a turbine type of 50 is not a defined turbine type in the WECC *Data Preparation Manual*. A turbine type of 50 is the default turbine type for BESS in the PSLF manual. Multiple TPs stated that using turbine type 50 was correct because it was in the General Electric PSLF manual.[15]
  - **Recommendation:** TPs and PCs should be submitting data to WECC that conforms to the WECC *Data Preparation Manual*, not the PSLF manual. WECC should not accept any unit with a turbine type that is not listed in the WECC *Data Preparation Manual*. Furthermore, WECC should add a data quality check to flag any incorrect Turbine Types, including those marked as 50.
- **Observation:** The Interconnection-wide base cases are developed in PSLF; however, some TPs and PCs in the Western Interconnection use Siemens PTI PSS®E as their primary simulation platform. The version of PSS®E that is currently used by industry members does not have the capability to represent a turbine type. This is proving to be a common source of bad data for TPs and PCs who use PSS®E.[16] Case creation requires additional steps to add in the turbine type once the data has been converted to PSS®E, and it appears this is not occurring consistently.
  - **Recommendation:** WECC and its stakeholders should confirm with Siemens PTI PSS®E that a turbine type field has been added and develop plans to support industry efforts to move to that version of PSS®E to align with other software capabilities and existing industry practices. Not having the ability to track different types of units makes understanding the types and mix of generation in a base case challenging.
- **Observation:** The WECC Interconnection-wide base cases include turbine types for "motor/pump"; however, it is not clear which units these refer to or if they may be the same as "energy storage – reversible hydraulic turbine."
  - **Recommendation:** WECC and its stakeholders should explore possible consolidation or clarification of this turbine type to determine if "motor/pump" and "energy storage–reversible hydraulic turbine" types

[15] https://www.geenergyconsulting.com/practice-area/software-products/pslf

[16] Furthermore, PSS®E also does not have the capability to represent a load record "Long ID," which enables the tracking of different load types used for dynamic load modeling. This was also noted as a software limitation with PSS®E by at least one user.

are both referring to pumped hydro resources. Possibly these could be separated out or combined into a clearer turbine type representation.

- **Observation:** Multiple STATCOMs and other dynamic reactive resources are modeled as generators in the base case rather than using SVS[17] models per industry-recommended modeling practices. Representation as a generator (i.e., a voltage source) may overestimate the reactive capability from these resources, particularly during abnormal voltage conditions since there is no modeled dependence on voltage. Use of the SVS/shunt models will allow for more accurate representation of voltage dependence and align with industry recommended practices.
  - **Recommendation:** WECC should consider working with TPs and PCs to adapt existing dynamic reactive resources models from generator records to the proper shunt/SVS models.

The recommendations listed above should be acted upon promptly for all future base case creations in the Western Interconnection. In addition, the observations and recommendations show that continuous review of existing and additional base case quality checks is needed to ensure modeling improvements are being made.

[17] Such as svsmo1, svsmo2, or svsmo3.

Chapter 2: Composition of Generation in the WECC Base Case

This chapter describes the composition of generation in the WECC 2020 HS3 base case to illustrate the extent of inverter-based generation in the base case and to find trends in data and modeling issues. Characterizing the composition of generation in the WECC base case will lead into the discussion regarding specific modeling challenges covered in **Chapter 3** and **Chapter 4**.

Generation Composition Overview

The 2020 WECC 2023 HS3 base case with updated turbine types verified by TPs and PCs to the greatest possible extent includes the generation mix shown in **Figure 2.1** and **Table 2.1**. Wind and solar PV make up about 17% of the installed capacity; synchronous fossil fuel-based generation constitutes about 54%; hydro about 27%; and the remaining is a mix of geothermal, energy storage, and other types.

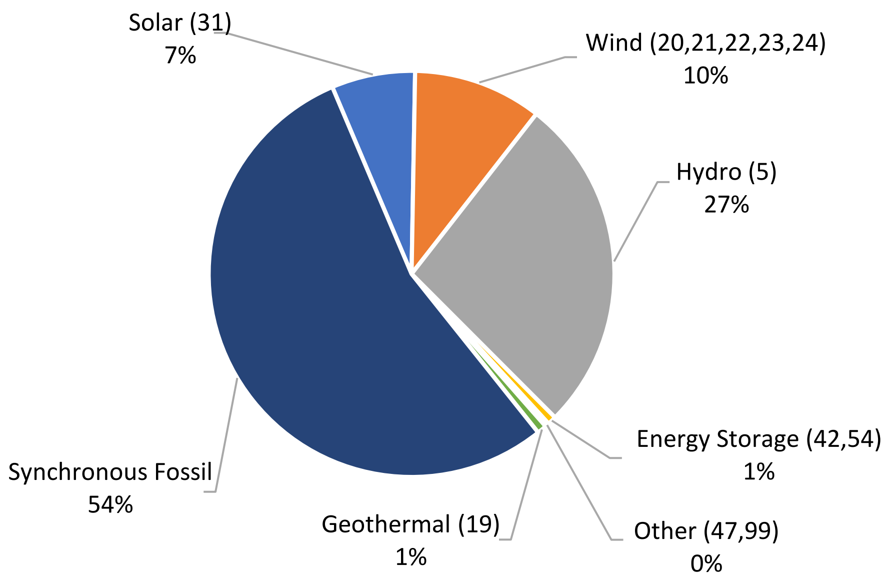


Figure 2.1: Overview of Generation Capacity in WECC 2020 HS3 Base Case

Table 2.1: Overview of Generation Capacity in WECC 2020 HS3 Base Case

Generation Type	# Units	Total MW	% MW Capacity
Solar (31)	414	18,180	7%
Wind (20, 21, 22, 23, 24)	424	27,995	10%
Hydro (5)	1,329	73,456	27%
Energy Storage (42, 54)	34	1,911	1%
Other (47, 99)	22	861	0%
Geothermal (19)	66	2,064	1%
Synchronous Fossil	1,932	148,123	54%

Figure 2.2 shows the breakdown of generation mix by base case area; Table 2.2 shows the legend for area numbers in the WECC base case. Over 20% of the installed generation capacity in Areas 21, 22, and 24 is solar PV. Note that these numbers generally do not consider DERs. Figure 2.3 shows the same information in absolute values rather than percentages.

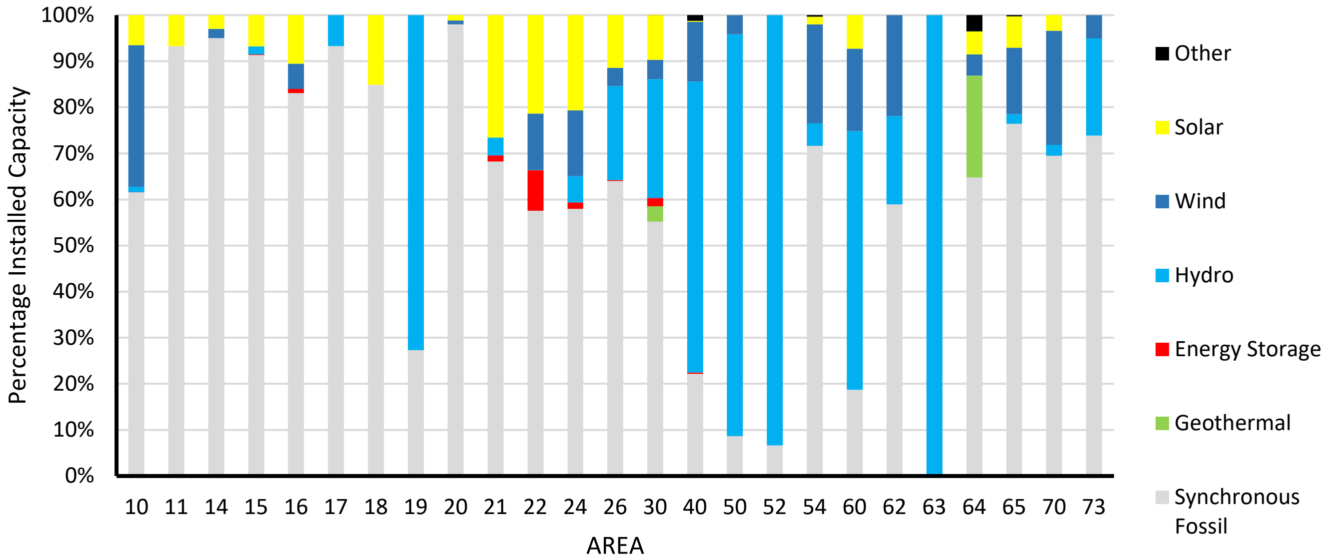


Figure 2.2: Percentage of Installed Generation Capacity by Area

Table 2.2: Mapping of WECC Base Case Area Numbers

Area Number	Area Name	Area Number	Area Name
10	Public Service of New Mexico	30	Pacific Gas and Electric
11	El Paso	40	Pacific Northwest
14	Arizona Public Service	50	BC Hydro
15	Salt River Project	52	Fortis BC
16	Tucson Electric Power	54	Alberta
17	Arizona Electric Power Co.	60	Idaho
18	Nevada Power	62	Montana
19	WAPA Lower Colorado	63	WAPA Upper Great Plains
20	Mexico CFE	64	Sierra
21	Imperial Irrigation District	65	PacifiCorp East
22	San Diego Gas and Electric	70	Public Service of Colorado
24	Southern California Edison	73	WAPA Rocky Mountain
26	L.A. Dept. Water and Power		

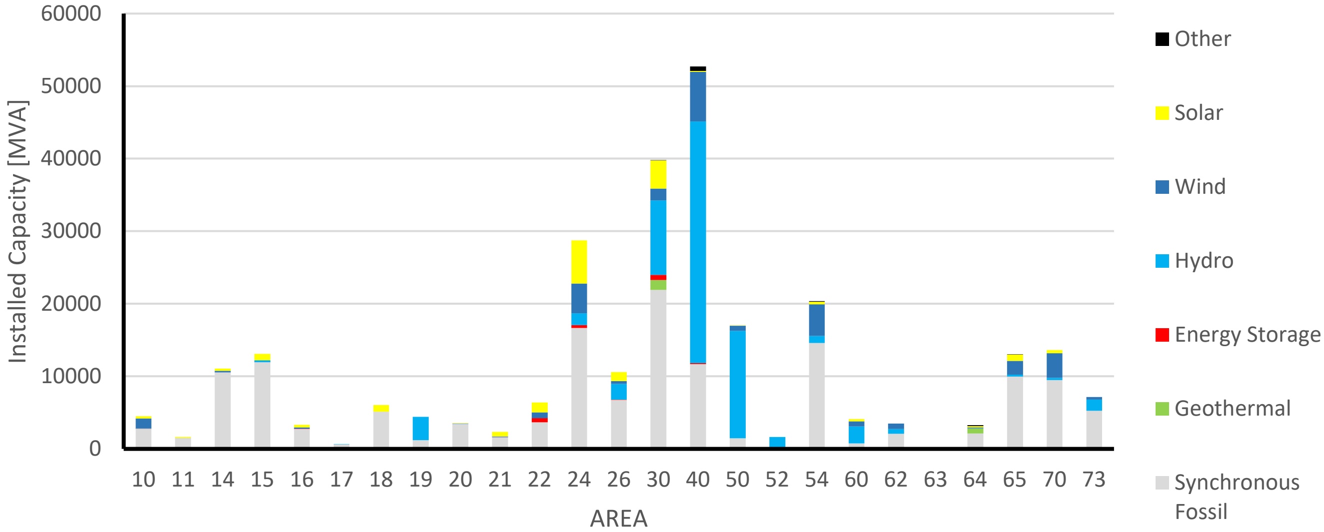


Figure 2.3: Total Capacity of Installed Generation Capacity by Area

Wind Generation

Figure 2.4 shows the total installed capacity of wind generation in the WECC base case (about 28 GW) and a breakdown of turbine types. About half of the installed capacity of wind turbines in WECC are Type 3 doubly-fed induction generator wind turbines. About one-quarter of the installed wind turbines are Type 4 fully-interfaced power electronic devices. Of the remaining quarter, about half are Type 1 squirrel cage induction generator turbines, about half are Type 2 wound-rotor induction generator turbines with external resistance control, and a small fraction have unknown types. Area 40, Northwest, has a notable penetration (over 40% of installed capacity) of legacy Type 1 and Type 2 wind power plant. All other areas have predominantly Type 3 and Type 4 inverter-based wind power plants.

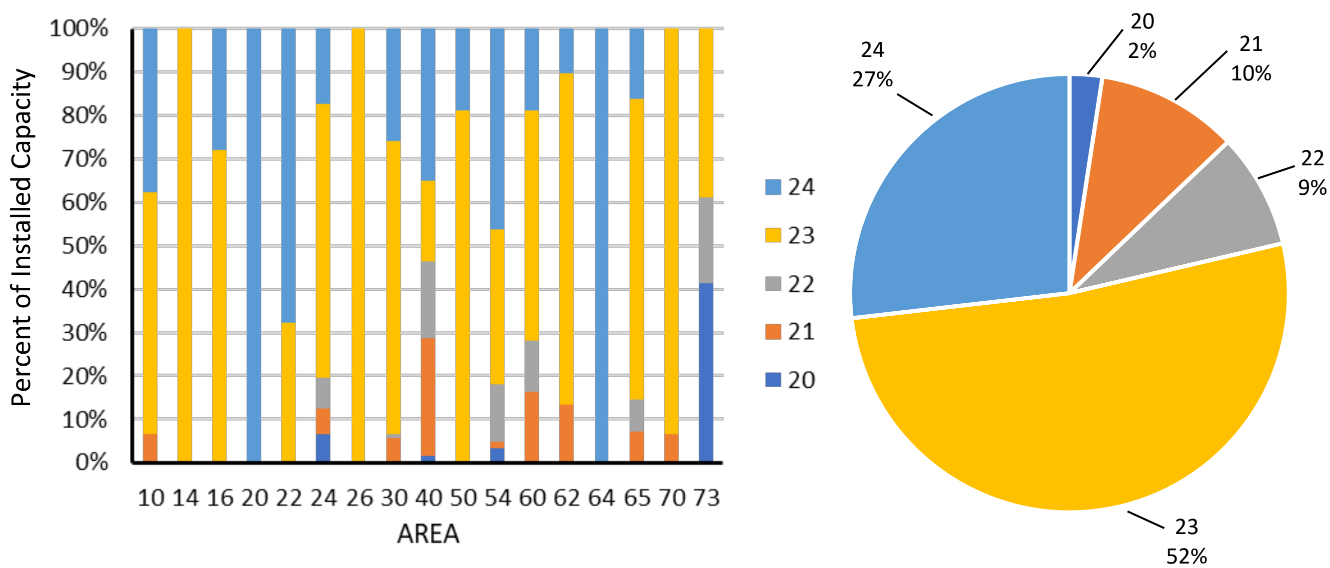


Figure 2.4: Overview of Wind Power Plants in the WECC Base Case

Table 2.3: Wind Turbine Types in WECC

Wind Turbine Type	WECC Turbine Type	# Units	MW Capacity
Type Unknown	20	12	676
Type 1	21	48	2,928
Type 2	22	31	2,372
Type 3	23	229	14,509
Type 4	24	104	7,509
	Total	**424**	**27,995**

During the verification steps in which NERC and WECC coordinated with industry stakeholders, some areas were not able to identify which type of wind generator types each plant consisted of. Area 73 was unable to identify over 40% of its wind plant capacity by turbine type. Follow-up discussions with engineers from Area 73 highlighted that the primary cause of this issue was that the software tool they use for simulations, Siemens PTI PSS®E, does not include a turbine type field whereas the Interconnection-wide base cases are created using GE PSLF simulation tools. This is leading to mismatched data and inconsistency between case submittals and should be improved for future annual case creation processes.

Solar PV Generation

Figure 2.5 and Table 2.4 show the total installed solar PV capacity in the WECC base case (about 18 GW), separated by WECC area number. As the Table 2.4 shows, the majority of solar PV capacity is in the California region (mostly in areas 22, 24, 26, and 30).

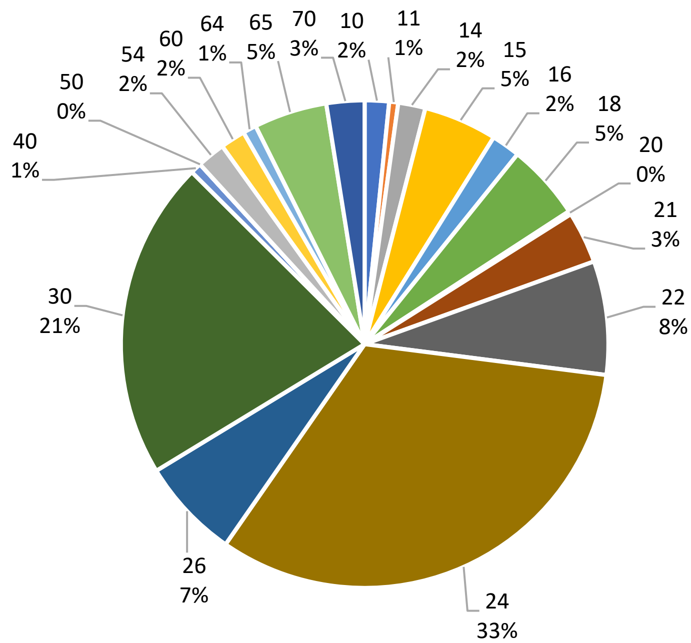


Figure 2.5: Percentage Installed Capacity of Solar PV by Area

Table 2.4: Solar PV Capacity by WECC Area						
Area Number	Total MW	% Total MW Capacity		Area Number	Total MW	% Total MW Capacity
10	293	1.61%		26	1,208	6.64%
11	109	0.60%		30	3,846	21.16%
14	328	1.80%		40	134	0.74%
15	886	4.87%		50	1	0%
16	347	1.91%		54	341	1.87%
18	915	5.03%		60	300	1.65%
20	41	0.23%		64	163	0.90%
21	626	3.44%		65	883	4.85%
22	1,369	7.53%		70	458	2.52%
24	5,933	32.64%		**Total**	**18,180**	

Battery Energy Storage Systems

As BESSs continue to fill a large fraction of transmission service providers' interconnection queues, WECC is seeing an increase in the number of these resources modeled in the Interconnection-wide base cases. Figure 2.6 and Table 2.5 show some statistics about the total capacity of these resources in the 2020 HS3 base case and the types of models used to represent these resources. There are currently around 1,700 MW of BESSs in the base case with about 60% of those resources having no dynamic model and 40% modeled using the second-generation renewable models.

Figure 2.6: Overview of Battery Energy Storage in the WECC Base Case

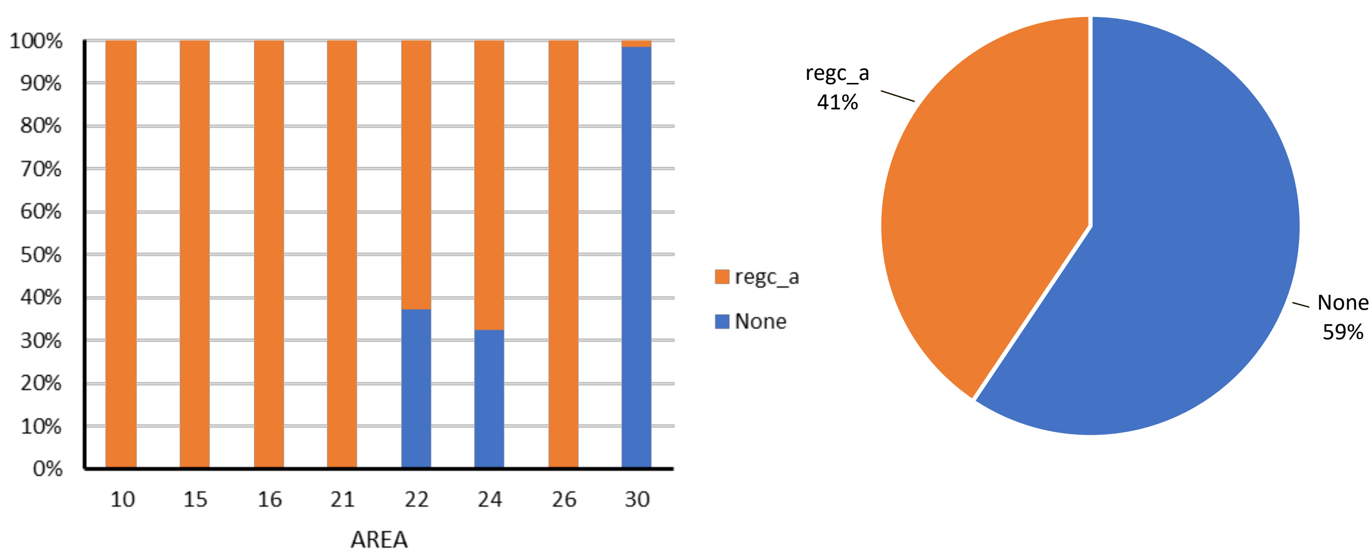


Table 2.5: Battery Energy Storage in WECC Base Case		
Dynamics Record	# of Units	MW Capacity

None	11	1,031
regc_a	18	704
Total	29	1,735

Observations and Recommendations

The Western Interconnection includes about 273,000 MW of installed capacity in the 2020 HS3 base case. Of that total capacity, about 10% (28,000 MW) is wind generation and 7% (18,000 MW) is solar generation. About half of the installed wind capacity in the Western Interconnection consists of Type 3 doubly-fed induction generators, about one quarter consists of Type 4 full-converter generators, and the remaining one quarter is legacy Type 1 and Type 2 turbines with a small fraction of types unknown. Most areas in the Western Interconnection are also beginning to integrate solar PV resources to the BPS; however, some areas are already experiencing a notable penetration level. Of the installed BPS-connected solar PV generation the Western Interconnection, California has over 50% with neighboring desert southwest states also experiencing increasing solar PV penetrations.

While only constituting 17% of the installed capacity today, the instantaneous penetration of BPS-connected wind and solar PV in some Balancing Authority areas is already exceeding 50% or greater (i.e., California Independent System Operator (CAISO)). Areas within the CAISO footprint are experiencing an increasing installed capacity of wind and solar PV, presenting rapid changes to the power flow and dynamics models as well as presenting new challenges for TPs and PCs to ensure these models are reasonable and accurate.

Chapter 3: Wind Modeling Focus

This chapter gives a cursory review of wind models and some modeling parameterization issues shown in the WECC 2020 HS3 base case. The goal is to highlight identified issues needing attention by industry through the WECC case creation process.

Figure 3.1 and **Table 3.1** provide an overview of the wind resources in the 2020 HS3 base case and the dynamic models associated with those resources. The following salient points are observations made during the analysis (percentage based on model rated power):

- About 37% of wind plants are modeled using the latest second-generation renewable models (i.e., *regc_a*).
- About 35% of wind plants are modeled using the first-generation renewable models (i.e., *wtXg*).
- About 12% of wind plants are modeled using synchronous generator models (e.g., *genrou*).
- About 10% of wind plants do not have a dynamic model.
- The remaining 6% of wind plants are modeled using other dynamic models.

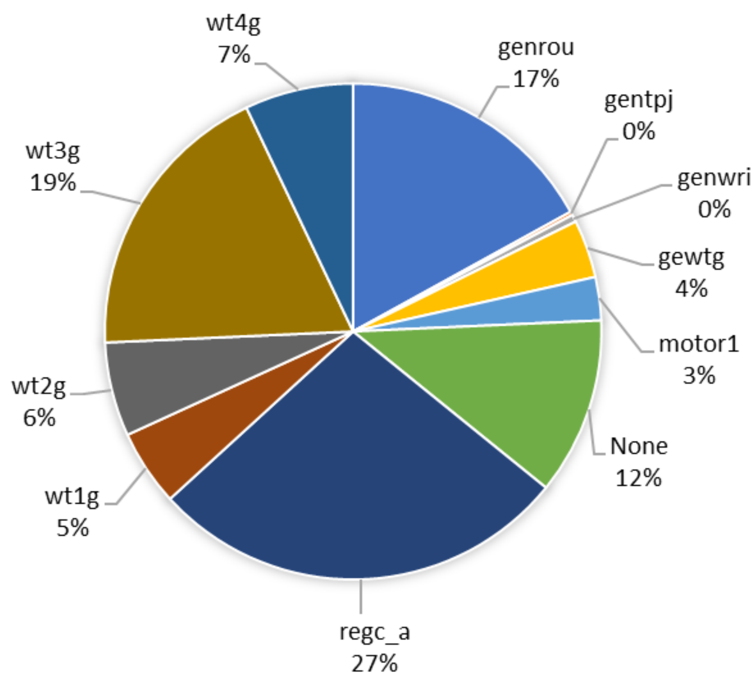


Figure 3.1: Overview of Dynamic Models for Wind Power Plants

Table 3.1: Overview of Dynamic Models for Wind Power Plants			
Dynamic Model	**# Units**	**Total MW Capacity**	**% MW Capacity**
genrou	72	3,108	11.10%
gentpj	1	76	0.27%
genwri	2	191	0.68%
gewtg	16	1,604	5.73%
motor1	12	243	0.87%

Table 3.1: Overview of Dynamic Models for Wind Power Plants

Dynamic Model	# Units	Total MW Capacity	% MW Capacity
No Dynamic Model	49	2,700	9.65%
regc_a	116	10,283	36.73%
wt1g	21	1,141	4.08%
wt2g	26	1,907	6.81%
wt3g	79	4,385	15.67%
wt4g	30	2,355	8.41%
Total	**424**	**27,995**	

Units with No Dynamic Model Included

About 2,700 MW of wind plant capacity (49 wind power plants) are modeled with no dynamic model and are therefore "load netted" out in the dynamic simulations (see **Figure 3.2** and **Table 3.2**). Load netting refers to converting the generating resource to a negative load and ignoring any dynamic response from the resource in dynamic simulations, an unacceptable dynamic modeling practice. The WECC *Data Preparation Manual* states that individual generating units greater than 10 MVA connected at 60 kV or higher and aggregated generating units greater than 20 MVA connected at 60 kV or higher should have an accurate dynamic model associated with their facility.

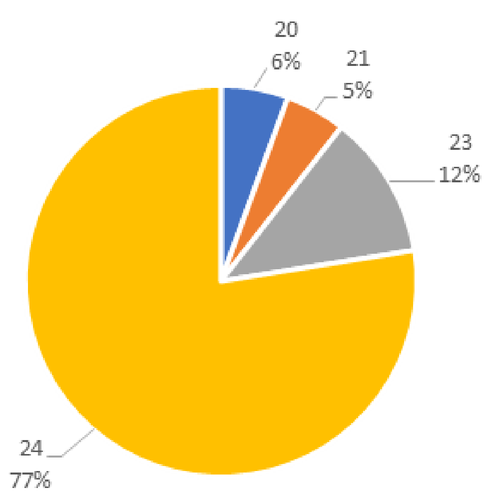


Figure 3.2: Wind Plants with No Dynamic Model

Table 3.2: Wind Plants with No Dynamic Model

Plant Turbine Types	Turbine Type	# Units	MW Capacity
Unknown	20	1	150
Type 1	21	8	135
Type 2	22	0	0
Type 3	23	13	322
Type 4	24	27	2,093
	Total	**49**	**2,700**

Figure 3.3 shows a histogram of the size of the resources with no dynamic model. As the plot shows, the units with no dynamic model are a mixture of smaller units subject to the Small Generator Interconnection Process and larger units subject to the Large Generator Interconnection Process. Furthermore, about 15 units are likely BES generators and still have no dynamic model in the Interconnection-wide base case.

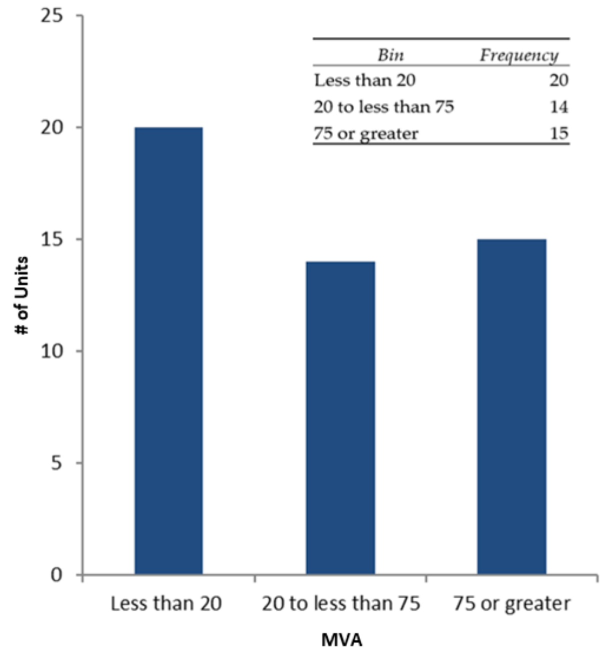


Figure 3.3: Histogram of Wind Plants with No Dynamic Model

Units with Round Rotor Synchronous Machine Model

Over 3,100 MW (~11%) of wind plant capacity (72 wind power plants) are modeled using the *genrou* dynamic model, which is used to represent round rotor synchronous machines (see **Figure 3.4** and **Table 3.3**). This is not the proper model for a wind power plant and should not be used in Interconnection-wide base cases. The majority of these are Type 3 doubly-fed induction generator facilities, which are inverter-based resources.

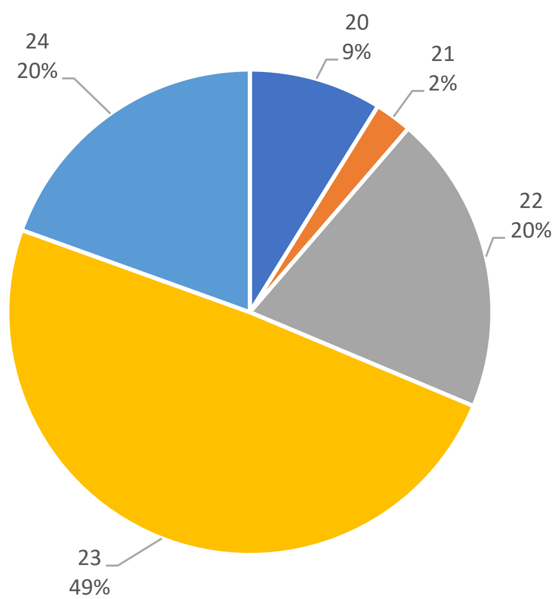


Figure 3.4: Wind Plants Modeled Using GENROU

Table 3.3: Wind Plants Modeled using GENROU

Plant Turbine Types	Turbine Type	# Units	MW Capacity
Unknown	20	9	275
Type 1	21	5	77
Type 2	22	7	621
Type 3	23	36	1,529
Type 4	24	15	606
	Total	**72**	**3,108**

Units with MOTOR1 Induction Machine Model

About 240 MW of wind plant capacity (12 wind power plants) are modeled using the *motor1* dynamic model to represent induction machines. This may have been a modeling practice for legacy Type 1 or Type 2 wind plants before the release of the first-generation wind models; however, using this model now is not an acceptable modeling practice. **Figure 3.5** and **Table 3.4** show that two of the facilities are Type 1, and 10 of the remaining facilities are Type 3 inverter-based resources.

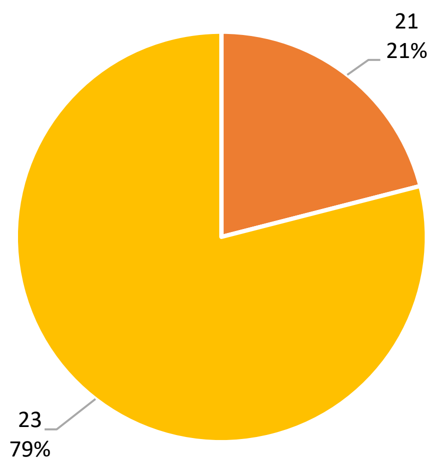


Figure 3.5: Wind Plants Modeled Using MOTOR1

Table 3.4: Wind Plants Modeled using MOTOR1

Plant Turbine Types	Turbine Type	# Units	MW Capacity
Unknown	20	0	0
Type 1	21	2	51
Type 2	22	0	0
Type 3	23	10	192
Type 4	24	0	0
	Total	**12**	**243**

Use of First-Generation Generic Wind Plant Models

As shown in **Table 3.1**, over one-third of the wind plants modeled in the WECC base case use the first-generation renewable energy models (i.e., wt1g, wt2g, wt3g, wt4g). **Figures 3.6–3.9** and **Tables 3.5–3.8** show the breakdown of the number of plants and the installed capacity for each type of dynamic models. Use of wt1g and wt2g is the correct modeling approach for Type 1 and Type 2 wind power plants, respectively. However, Type 3 and Type 4 wind plants should be modeled with second-generation renewable models now. Notable observations of wind plants and their respective models include the following:

- One 30 MW Type 3 wind power plant is modeled incorrectly with the wt1g model.
- Two Type 1 wind power plants totaling around 150 MW are modeled incorrectly with the wt2g model.
- Four Type 1 wind power plants totaling around 420 MW are modeled incorrectly with the wt3g model.
- Two Type 1 wind power plants totaling around 400 MW are modeled incorrectly with the wt4g model.

This cursory review of dynamic models compared to the turbine types that are verified by the respective TPs and PCs shows that around 1,000 MW of wind generation in the WECC case is modeled incorrectly. Furthermore, the second-generation renewable models (e.g., *regc_a*, *reec_a*, and *repc_a*) are the recommended dynamic models for inverter-based Type 3 and Type 4 wind plants currently; over 100 units totaling 6,700 MW (~24%) of installed capacity are modeled with obsolete models.

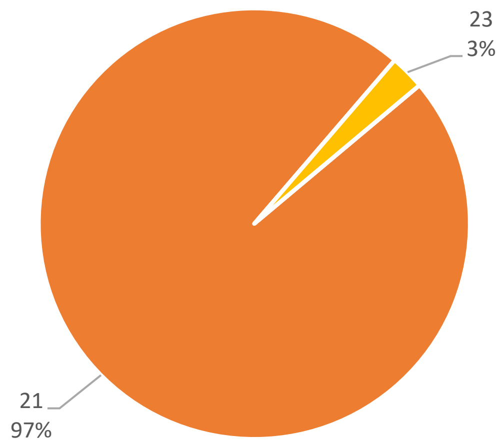


Figure 3.6: Wind Plants Modeled Using WT1G

Table 3.5: Wind Plants Modeled using WT1G			
Plant Turbine Types	Turbine Type	# Units	MW Capacity
Unknown	20	0	0
Type 1	21	20	1,111
Type 2	22	0	0
Type 3	23	1	30
Type 4	24	0	0
	Total	**21**	**1,141**

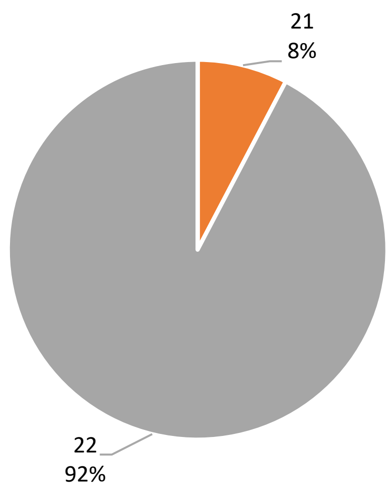


Figure 3.7: Wind Plants Modeled Using WT2G

Table 3.6: Wind Plants Modeled using WT2G			
Plant Turbine Types	Turbine Type	# Units	MW Capacity
Unknown	20	0	0
Type 1	21	2	156
Type 2	22	24	1,751
Type 3	23	0	0
Type 4	24	0	0
	Total	**26**	**1,907**

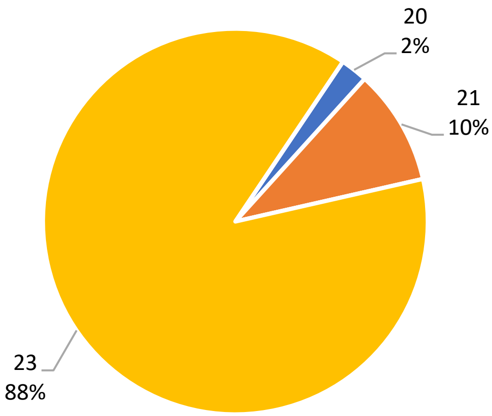


Figure 3.8: Wind Plants Modeled Using WT3G

Table 3.7: Wind Plants Modeled using WT3G			
Plant Turbine Types	**Turbine Type**	**# Units**	**MW Capacity**
Unknown	20	1	101
Type 1	21	4	426
Type 2	22	0	
Type 3	23	74	3,859
Type 4	24	0	0
	Total	**79**	**4,386**

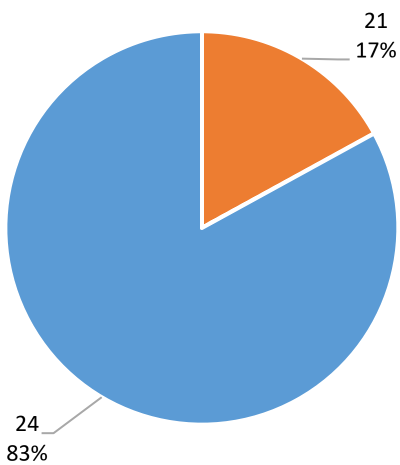


Figure 3.9: Wind Plants Modeled Using WT4G

Table 3.8: Wind Plants Modeled using WT4G			
Plant Turbine Types	**Turbine Type**	**# Units**	**MW Capacity**
Unknown	20	0	0
Type 1	21	2	401
Type 2	22	0	0
Type 3	23	0	0
Type 4	24	28	1,954
	Total	**30**	**2,355**

Upon review of the Type 3 first-generation wind models, it was noted that every wt3e dynamic model has matching parameter values that are nearly identical to the software user manual default values; there are two sets of wt3g dynamic model parameters. Both points highlight the fact that there is likely little to no variation for capturing site-specific settings or controls for any of these plants. The values are most likely defaults provided by the equipment manufacturers and likely not tuned upon commissioning.

Upon review of the Type 4 first-generation wind models, it was noted that the vast majority of *wt4g* dynamic models are using software manual default parameter values. There are only two sets of parameter values for the *wt4e* dynamic models (14 of 63 models use default values from the software manual; the remaining 49 of 63 models have matching parameters yet not the default parameters from the software manual). This further supports the fact that these models are likely not parameterized for each specific installation and likely represent a generic set of parameters. Lastly, there were three plants with only a wt4g generator dynamic model with no *wt4e* electrical controls model.

Second-Generation Model Parameterization

As shown in **Figure 3.1** and **Table 3.1**, about 37% of the wind plants modeled in the 2020 HS3 base case are using the second-generation renewable models, namely *regc_a*. **Table 3.9** shows some interesting statistics about the wind plant modeling using the second-generation models. Wind plants that use the second-generation renewable models are represented in three ways:

- *regc_a* generator model, *reec_a* electrical controls model, and no plant-level controller model
- *regc_a* generator model, *reec_a* electrical controls model, *repc_a* plant-level controller model
- *regc_a* generator model, *reec_a* electrical controls model, *repc_b* plant-level controller model

Table 3.8: Wind Plant Modeling Practices

Plant Type	# Units	MVA Capacity
regc_a, reec_a, no plant model	33	2166
regc_a, reec_a, repc_a	88	8242
regc_a, reec_a, repc_b	5	640
Total	**126**	**11,048**

Upon reviewing the second-generation renewable models for wind plants, a few potential modeling issues were identified as listed here:

- **Frequency Controls:** There are 16 wind units with the frequency control flag enabled; of those 16 units, 12 have settings that override the flag settings (e.g., droop gains set to 0, very large deadbands, very large droop settings). Four units have frequency response enabled in both directions and will provide primary frequency response if not dispatched at maximum turbine capability. WECC and its stakeholders should check these units to ensure an appropriate modeling practice based on local grid requirements and operational characteristics; these parameter values seem suspect based on current market and interconnection rules.
- **REGC_A Parameterization:** A few units have the low-voltage power logic switch (*lvplsw*) and the breakpoint (*brkpt*) value not aligned with one another; two units have a large voltage measurement time constant at 1 second. Both appear suspect and should be reviewed for accuracy.
- **REEC_A Parameterization:** Some units have default settings for the voltage-dependent current logic (i.e., the VDL tables) that match the software user manuals. This may or may not be incorrect but should be investigated more closely by WECC and its stakeholders.

Key Findings and Recommendations for Wind Power Plant Review

Table 3.9 provides the key findings and recommendations from review of the wind power plant dynamic models in the 2020 HS3 base case. Each of the recommendations set forth should be acted upon by the respective entities; WECC should help facilitate improvements to these models while working closely with its stakeholders.

Table 3.9: Key Findings and Recommendations from Wind Plant Model Review

#	Modeling Issue	Recommendations
1	Type 3 and Type 4 wind plants are represented using the first-generation dynamic models (i.e., wt3g and wt4g).	GOs should update their first-generation generic wind models to the second-generation models at the earliest possible time due to modeling limitations and simplifications within the first-generation models.
2	Wind plants above the modeling threshold established in the WECC *Data Preparation Manual* are represented with either no dynamic model or a synchronous generator model	GOs should develop proper dynamic models for their wind facilities meeting the specifications set in the WECC *Data Preparation Manual* and should use the latest recommended dynamic models (i.e., the second-generation renewable energy models). These models should be given to the respective TP and PC at the earliest possible time.
3	Wind plant models are likely parameterized using generic values that do not reflect as-built settings of equipment installed in the field.	GOs should ensure that the dynamic models for their respective facilities are parameterized to reflect the actual installed equipment at each specific site and should not include generic parameter values. GOs should coordinate with their TPs and PCs if they have any questions about how to parameterize their dynamic models.
4	Based on the breadth of modeling issues and parameterization concerns, TPs and PCs performing verification of the dynamic models for wind plants are not capturing modeling errors	TPs and PCs should verify[18] the dynamic model parameters provided by GOs to ensure they match the as-built controls, settings, and configuration of the equipment installed in the field. This verification should occur for all generator models provided and should occur prior to TPs and PCs providing these models to WECC for inclusion in the Interconnection-wide base case.

[18] This should include reviewing appropriate documentation provided by the GO, such as factory test reports, specification sheets, inverter control settings, plant controller settings, etc.

Chapter 4: Solar PV Modeling Focus

The overview provided in Chapter 2 highlights the rapid increase in solar PV across the Western Interconnection. This chapter will explore some of the solar PV modeling practices employed by industry with the latest dynamics data submitted to WECC and the 2020 HS3 base case. **Figure 4.1** and **Table 4.1** show the types of dynamic models used for solar PV resources, including the total capacity, number of units in the case, and a breakdown by area. Important observations from this data include the following:

- About 82% of the capacity of solar PV resources are modeled with second-generation renewable models, notably the *regc_a* generator model. This aligns with the latest guidance provided by the WECC REMTF in terms of the vintage of dynamic models used by industry. However, 90% of the facilities using the *regc_a* model are not using the recommended electrical controls model and are instead using a model that is not recommended for use (i.e., *reec_b*).
- About 12% of the capacity of solar PV resources have no dynamic model associated with them and are load-netted in dynamic simulations.
- About 4% of the capacity of solar PV resources are using the *wt4g* dynamic model, which is first-generation renewable model applied for solar PV prior to the release of the second-generation renewable models. These units are either equipment installed prior to the release of the second-generation renewable models that have not updated their models to the latest available or are newer units that use obsolete modeling practices.
- Similarly, about 2% of the capacity of solar PV units are using the *gewtg* dynamic model, which is a legacy wind plant model used to specifically represent GE wind power plants. This is an obsolete model and not the proper representation of a solar PV plant.
- Less than 1% of the capacity of solar PV units are modeled with synchronous generator models *genrou*, *gentpf*, and *gentpj*. This is an obsolete model and not the proper representation of a solar PV plant.

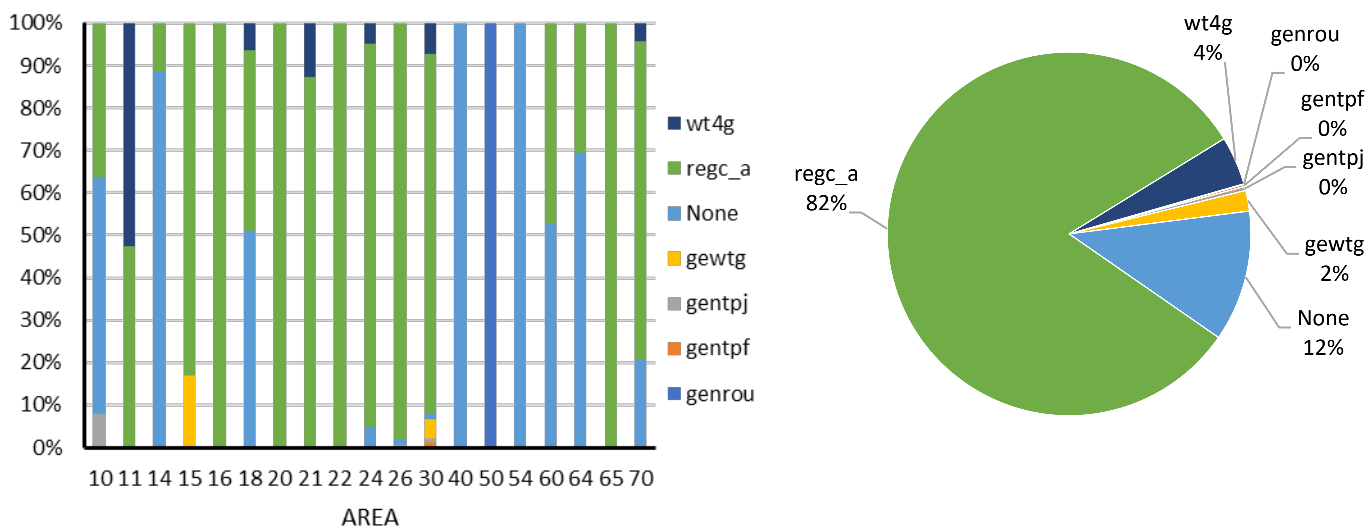


Figure 4.1: Breakdown of Dynamic Models for Solar PV Plants in the WECC Base Case

Table 4.1: Overview of Dynamic Models for Solar PV			
Generator DYD Record	**# of Units**	**MW Capacity**	**% of Total MW Capacity**
genrou	3	10	0.05%
gentpf	3	35	0.19%
gentpj	6	66	0.36%
gewtg	11	333	1.83%
None	83	2,119	11.66%
regc_a	274	14,833	81.59%
wt4g	34	785	4.32%
Total	**414**	**18,180**	

Over 80% of the solar PV resources are using the second-generation renewable models (i.e., *regc_a*). However, recent work by the NERC IRPTF has highlighted that using the appropriate electrical controls models in conjunction with the *regc_a* model is critical for accurately modeling solar PV resources. All major inverter manufacturers contributing to IRPTF activities have stated that they do not recommend the use of the reec_b dynamic model originally created by the WECC REMTF as a simplified representation of solar PV resources. Unfortunately, this model was the de facto model used for solar PV resources and recommended by WECC for several years. In June 2019, the WECC REMTF published a white paper that described steps and clear recommendations to convert *reec_b* dynamic models to *reec_a*.[19]

Table 4.2 and **Figure 4.2** show the different electrical control models used by solar PV resources with the second-generation *regc_a* dynamic model. A total of 11 (820 MW) of the 274 solar PV resources that use the *regc_a* model are using the *reec_a* electrical controls dynamic model (i.e., the appropriate modeling practice), 260 (13,778 MW) resources are using the *reec_b* model, and the remaining are incorrectly modeled. Very few dynamic models have been updated following the published guidance released in June 2019. Outreach to the GOs of solar PV facilities is needed by TPs, PCs, and the ERO Enterprise to ensure they make these changes and that they accurately capture the large disturbance dynamic behavior of solar PV resources for planning assessments.

[19] https://www.wecc.org/Reliability/Converting%20REEC_B%20to%20REEC_A%20for%20Solar%20PV%20Generators.pdf

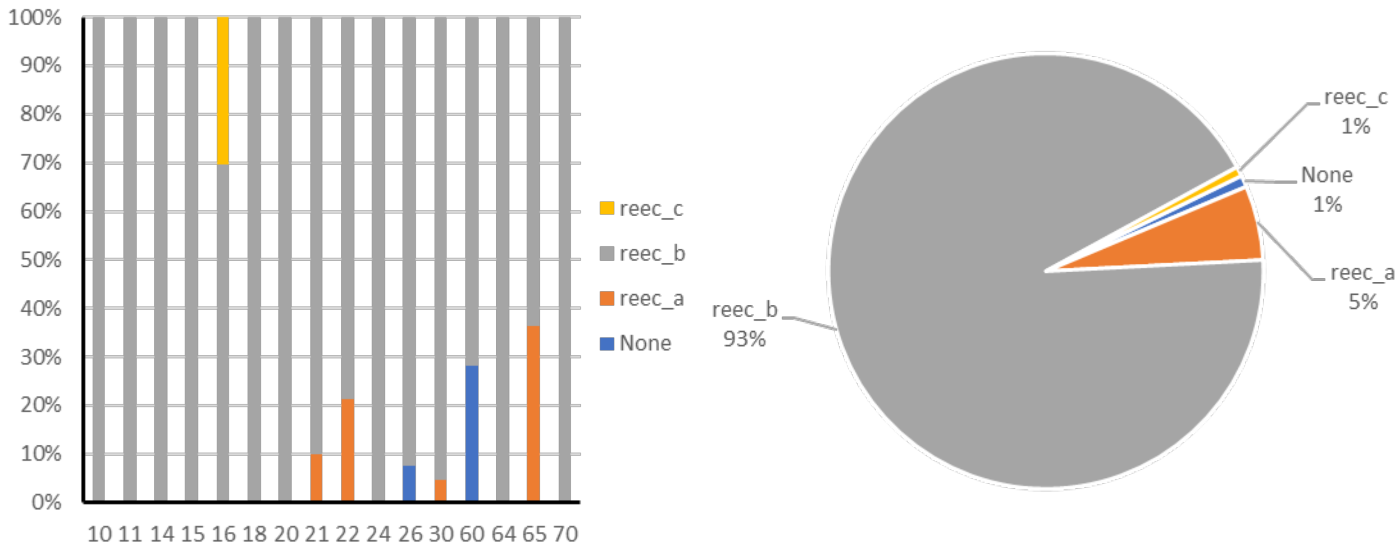


Figure 4.2: Breakdown of Dynamic Models for Solar PV Plants in the WECC Base Case

Table 4.2: Electrical Controls Models for Solar PV Modeled with REGC_A			
Generator DYD Record	**# of Units**	**MW Capacity**	**% of Total MW Capacity**
None	2	130	0.88%
reec_a	11	820	5.53%
reec_b	260	13,778	92.89%
reec_c	1	105	0.71%
Total	**274**	**14,833**	

Review of Large Solar PV Resource Dynamic Models

Resources with turbine type 31 (i.e., solar PV) and maximum active power rating of 75 MW or higher were reviewed against the 2018 NERC alert data provided following the Canyon 2 Fire disturbance.[20] The goal of this comparison was to determine the quality of the dynamic models provided by these resource owners. **Appendix A** contains the detailed review of models. In general, the models fall into these categories:

- **Correct Modeling and Parameterization of Select Solar PV Resources:** A small handful of solar PV plants are represented with the correct dynamic models and appear to be correctly parameterized. An example of this is a 550 MW plant that has matching EIA-860 capacity with the maximum capacity modeled in the steady-state power flow. Furthermore, the plant uses one type of inverter that uses MC during large voltage deviations, and the settings are correctly parameterized with the *regc_a* and *reec_a* dynamic models. As

[20] The 75 MW threshold was used as a general proxy for BES solar PV resources; however, it is understood that this may not match identically to NERC Registration. This approach was deemed sufficient for the purposes of this review.

stated, only a small handful of plants are modeled appropriately; only one of the top five largest solar PV plants are modeled correctly.

- **Incorrect Solar PV Models and Parameters:** The majority of solar PV resources are not modeled using practices that conform to the requirements set forth in the WECC *Data Preparation Manual* or the WECC acceptable model list.[21] Four of the top five largest solar PV resources fall into this category. An example of this is one of the largest plants in the Western Interconnection that is modeled with no dynamic models, so it is netted in dynamic simulations. This is either attributed to the GO not providing a model to the TP and PC or the model getting lost in the process between the GO, TP, PC, and WECC.

The following sub-sections highlight some of the identified issues.

Incorrect Parameterization of Momentary Cessation

A handful of units that use the reec_b dynamic model were compared to the NERC alert data on MC settings used by those facilities. This included reviewing the dynamic model voltage-dependent current logic table (i.e., voltage-dependent current logic tables) and other associated model parameter values with the NERC alert data provided by the entities. While the data is a bit outdated, NERC and WECC analysis teams were looking for similarities or differences that may be considered systemic issues. Upon inspection, it was clear that most dynamic models did not match the NERC alert data provided. In most cases, the NERC alert data showed the use of MC while the dynamic model did not account for MC or used MC settings that were different from those reported. While updates may have occurred since the release of the NERC alert, it is clear WECC and its stakeholders should conduct follow-up activities to ensure all solar PV resources above the dynamic modeling thresholds are appropriately modeled in the WECC base cases.

Mismatch between Energy Information Agency (EIA) Capacity and Modeled Capacity

Several solar PV resources modeled in the WECC base case had discrepancies between the EIA summer capacity and the modeled maximum capacity in the steady-state power flow case. In almost all cases, the modeled capacity in the base case is less than the EIA summer capacity. This is a concern because the plant can produce a greater capacity of energy than modeled in the case. Correct modeling approach will depend on TP and PC modeling practices as well as any contractual requirements between the GO and the transmission service provider. It is critical that the maximum capacity be correctly modeled to ensure that any transmission overloads are identified for normal and emergency operating conditions. Some plants are modeled with multiple generator records, and some EIA records are split. This makes it more difficult to match up capacities; however, the capacities should be relatively close. WECC and its stakeholders should follow up with GOs to ensure that their EIA-860 and contractual obligations are correctly modeled in the power flow base case.

Application of the REEC_B Electrical Controls Model

The WECC REMTF initially developed the *reec_b* model as a simplified version of the *reec_a* model to represent solar PV facilities. However, the NERC IRPTF highlighted limitations with the *reec_b* model to represent MC. Furthermore, inverter manufacturers stated that the *reec_b* model is not suitable to represent the dynamic response of solar PV facilities even if MC is not used. Therefore, the current recommendation is for solar PV resources to be represented with the *reec_a* dynamic model or other more recently dynamic models that are on the WECC list of acceptable models.

Many of the solar PV resources in the WECC base case use *reec_b* for their electrical controls model. Due to the limitations of the *reec_b* model to accurately reflect MC and its inability to capture the voltage-dependent current

21 https://www.wecc.org/_layouts/15/WopiFrame.aspx?sourcedoc=/Reliability/Approved%20Dynamic%20Models%20January%202020.pdf&action=default&DefaultItemOpen=1

logic during large disturbance current injection, the *reec_a* model is recommended. These models need to be updated to the *reec_a* model and correctly parameterized for their specific installed settings and capabilities.

Modeling Solar with First-Generation Models

Solar PV resources modeled with the first-generation models are likely to be updated gradually with second-generation dynamic models; however, two modeling issues raised concern for prompt replacement as listed here:

- **GEWTG Model:** The *gewtg* dynamic model is a legacy GE dynamic model that was used to represent Type 3 or Type 4 wind power plants. This model can be used to represent a simplistic control structure for solar PV resources if a supplemental electrical controller model is included. Of the 11 solar PV facilities using the *gewtg* model, only 6 include the supplemental model. Of the remaining 5, only 3 use a Type 3 wind electrical controls model and 2 do not include any electrical controls model. Both methods are an incorrect use of the *gewtg* model, which is an obsolete model for solar PV. While all units modeled with *gewtg* models should be converted to the second-generation models, these facilities stood out as significant modeling errors that should not be accepted by the TP and PC in their review or by WECC in its case quality metrics.
- **WT4G Model:** The *wt4g* model has been used in the past to represent solar PV resources, since Type 4 wind turbines and solar PV inverters are full-converter resources. However, this model is a legacy model and should be converted to the second-generation generic models. Regardless, there are 34 instances of this model for solar PV resources in the base case. Furthermore, this model cannot accurately represent MC, and upon inspection of the models, the reviewers found many instances of generic model parameters with default values found in the software manuals for controller settings. Use of generic parameters is strongly discouraged. These models need to be updated to the latest generic models and parameterized according to each specific installation's settings and controls. **Figure 4.3** shows a histogram of the number of units less than 20 MVA, between 20 MVA and 75 MVA, and greater than 75 MVA. Most of the units are greater than 20 MVA but less than 75 MVA (i.e., subject to the Large Generator Interconnection Process but not Bulk Electric System resources).

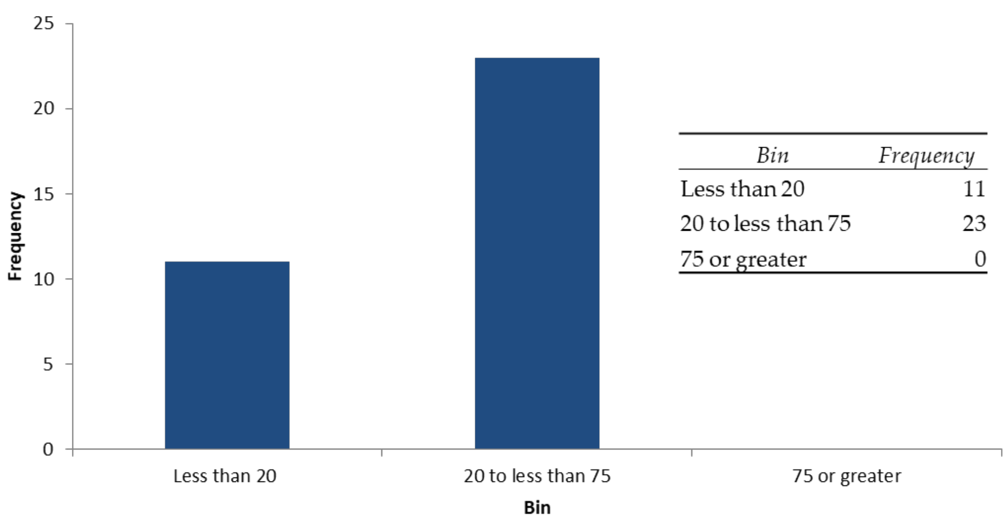


Figure 4.3: Number of Solar PV Plants Modeled using WT4G First-Generation Model

Units with No Dynamic Model or Synchronous Model

According to the WECC *Data Preparation Manual*, aggregated generating resources greater than 20 MVA should have a dynamic model associated with the facility in the Interconnection-wide base case. There are 83 (2,119 MW) solar PV resources that do not have a dynamic model associated to them. **Figure 4.4** shows a histogram of the number of units less than 20 MVA, between 20 MVA and 75 MVA, and greater than 75 MVA. A total of 51 units are less than 20 MVA (following the specification in the WECC *Data Preparation Manual*), 27 units are between 20 MVA and 75 MVA (subject to the Large Generator Interconnection Process but not BES resources), and 5 units are greater than 75 MVA (likely BES resources). One of the units greater than 75 MVA has a capacity exceeding 300 MW and is one of the top five largest solar PV plants in the Western Interconnection. As stated, this plant has no dynamic model in the 2020 HS3 base case and is load netted (i.e., exhibits no dynamic response in simulations). This a significant modeling error that should be addressed immediately.

There are also 12 (111 MW) units that use a synchronous generator model, which is an incorrect representation of a full-electronic inverter-based resource. Both modeling issues should be addressed for units above the size thresholds specified in the WECC *Data Preparation Manual*.

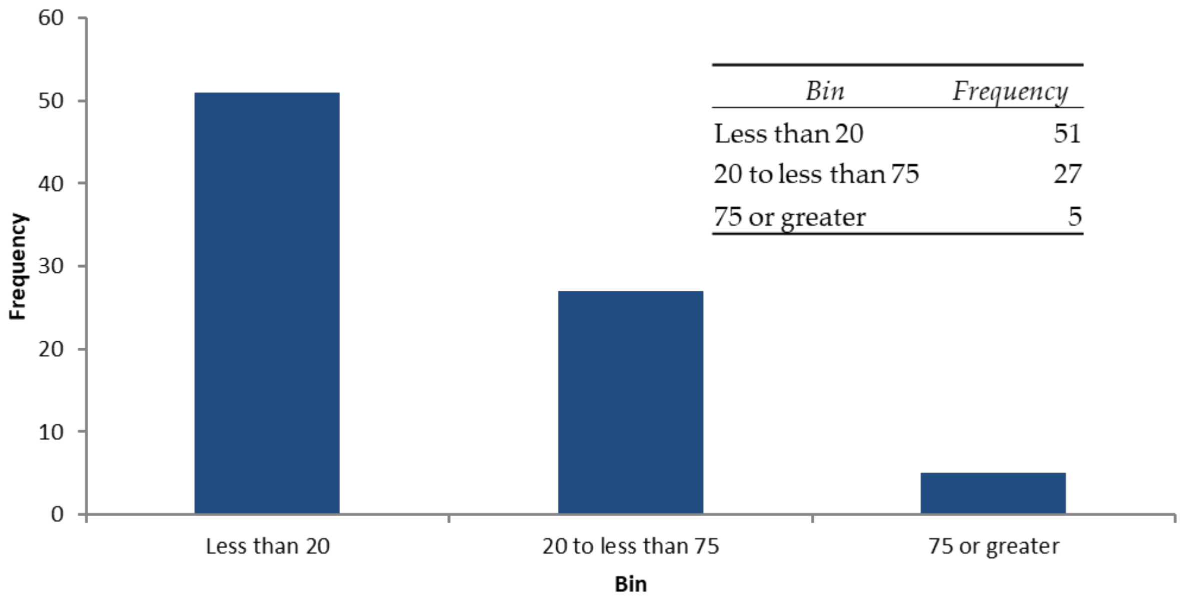


Figure 4.4: Number of Solar PV Plants with No Dynamic Model

Key Findings and Recommendations for Solar PV Power Plant Review

Table 4.3 provides the findings and recommendations from review of BPS-connected solar PV plant dynamic models in the 2020 HS3 base case. Each of the recommendations set forth should be acted upon by the respective entities; WECC should help encourage improvements to these models while working closely with its stakeholders.

Table 4.3: Key Findings and Recommendations from Solar PV Plant Model Review		
#	Modeling Issue	Recommendations
1	Some solar PV facilities are represented with the first-generation renewable models, with no dynamic model, or with other dynamic models not appropriate for solar PV facilities.	GOs for facilities meeting the size criteria in the WECC Data Preparation Manual (i.e., 20 MVA) should update their dynamic models to the latest recommended models set forth by WECC (i.e., the second-generation renewable energy models). These models should be provided to the respective TP and PC at the earliest possible time.
2	Most solar PV models are represented using the *reec_b* electrical controls models, which has been deemed an unacceptable model by WECC and all major solar PV inverter equipment manufacturers.	GOs should convert the *reec_b* dynamic model to the *reec_a* dynamic model following the guidance provided by WECC.[22] These models should be provided to the respective TP and PC at the earliest possible time. GOs should consult with their equipment manufacturers and with their TPs and PCs to ensure the correct dynamic models and parameters are used.
3	Solar PV plant models are likely parameterized with generic values that do not reflect as-built settings of equipment installed in the field.	GOs should ensure that the dynamic models for their respective facilities are parameterized to reflect the actual installed equipment at each specific site (i.e., considering MC or other large disturbance behavior of the facility) and should not include generic parameter values. GOs should coordinate with their TPs and PCs if they have any questions about how to parameterize their dynamic models.
4	Based on the breadth of modeling issues and parameterization concerns, TPs and PCs performing verification of the dynamic models for solar plants are not capturing modeling errors	TPs and PCs should verify[23] the dynamic model parameters provided by GOs to ensure they match the as-built controls, settings and configuration of the equipment installed in the field. This verification should occur for all generator models provided and should occur prior to TPs and PCs providing these models to WECC for inclusion in the Interconnection-wide base case.

[22] https://www.wecc.org/Reliability/Converting%20REEC_B%20to%20REEC_A%20for%20Solar%20PV%20Generators.pdf

[23] This should include reviewing appropriate documentation provided by the GO, such as factory test reports, specification sheets, inverter control settings, plant controller settings, etc.

Chapter 5: Current Industry Efforts and Industry Feedback

This chapter documents some of the current industry efforts and feedback received from TPs and PCs in the Western Interconnection on model review and modeling discussions.

Current Industry Efforts

There are activities underway at WECC that address some of the issues identified in the previous chapters. The following list provides a brief update on each of these groups and their key activities in this area:

- **WECC Modeling and Validation Subcommittee (MVS):** The MVS is composed of industry, consultants, national labs, and other experts in the creation of dynamic models. This group develops model structures and maintains the list of acceptable models for use in the Western Interconnection. To help industry move toward the latest and most accurate versions of models developed, the MVS has developed guidelines and performed workshops to provide information to industry. Currently MVS is reviewing the data in the WECC base cases and reaching out to entities still using the phase one models to help them in getting the models moved to the more current phase 2 models. This group has also developed some typical data that can be used for future units where the specifics are not known.
- **WECC Renewable Energy Modeling Work Group (REMWG):** The REMWG is a work group under the MVS that focuses on renewable energy models. The REMWG has been the group behind development of the generic models for both wind and solar. These models have been developed in phases; as more renewable energy has been deployed and technology evolves, this group has worked with the product vendors to ensure the that generic models can adequately represent the equipment for Interconnection-wide studies. The group continues to review and refine the models and produce white papers and other instructional materials for converting between new and old models.
- **WECC System Review Subcommittee (SRS):** In the Western Interconnection, the group that oversees the schedule and data requirements for the power flow and dynamic base cases is the SRS. As part of their duties, the SRS develops data checks and reviews the results of these data checks. SRS holds monthly webinars to focus on a specific data check to aid the data submitters in correcting the identified issues. The SRS has collaborated on how to roll out new models and set timelines for the retirement of models that have been superseded by newer models. One current initiative is trending the amount of inertia represented in the base cases; this effort is being implemented to track how quickly the change is occurring. This effort relies on accurate models specifically for renewable energy.
- **WECC Energy Storage Task Force**: WECC has established a task force to look at the operation, modeling, and commercial issues associated with energy storage. This effort is currently underway and will address issues associated with energy storage.

There are also some industry efforts that focus on modeling improvements of BPS-connected inverter-based resources. For example, the CAISO has been on the forefront of the shift to renewable energy. CAISO, as the market operator, is committed to using forward-looking approaches to ensure its planning models are accurate and to encourage the sharing of accurate model information. Commensurate with this commitment, the CAISO recently revised its *Business Practice Manual for the Transmission Planning Process*[24] to address CAISO's requirement that accurate and up-to-date generator modeling data is provided through its generator interconnection process. Specifically, in Section 10 of version 21 of the manual, there is a discussion of the CAISO Tariff Section 24.8.2, which documents the specific requirements of the data being requested along with a schedule by which the data must be provided. Commensurate with its authority, the CAISO instituted a sanction of $500/day for late submission of any

24 https://bpmcm.caiso.com/BPM%20Document%20Library/Transmission%20Planning%20Process/Transmission_Planning_Process_BPM_Version_21.docx

required information or data. Finally, as described in the business practice manual, the schedule requires full compliance by October 1, 2023, at which time accurate models of all participating generator equipment in service as of January 1, 2018 will be provided. New units are required to meet the data submission requirements during the interconnection process.

Feedback from SMAG Members

During WECC SMAG discussions, industry members were asked several questions about the challenges that TPs and PCs are facing with respect to collecting accurate and verified modeling data to be used in planning assessments. Most members did not respond to questions posed by NERC staff; however, a small handful of individuals provided responses. Some of the key takeaways include the following:

- GOs commonly ignore email requests from TPs and PCs about follow-up on modeling-related issues. Multiple follow-up emails are needed to get a response from the GO, and the process for any modeling revision requires many months to complete.
- GOs are not providing requested reporting information that should accompany the model/data to verify that the information provided is correct. In many cases, GOs are using generic data provided by the inverter or equipment manufacturers.
- The feedback loops developed in MOD-032-1 are not being used by TPs and PCs to correct modeling issues, nor are TPs and PCs being proactive to address identified issues on a widespread basis. TPs and PCs blame the fact that modeling-related issues are a "check the box" type of task for GOs and that GOs provide little attention to these matters.
- TPs and PCs receiving this generic modeling data use it at face value so long as it initializes, shows positive damping, and does not cause any numerical issues during simulations. This information is then passed to WECC for incorporation into the MDF.
- TPs and PCs have provided updated models to WECC once received by GOs but are not sure that the models have correctly been incorporated into the MDF as they receive little or no confirmation that these have been incorporated. Confirmation of successful integration into the MDF should be a critical step in the data submittal or update process. WECC provides confirmation to GOs, TPs, and PCs on data submitted via generator test report submission process. However, for all other data, WECC expects that individual entities review the base cases to ensure the submitted data have been incorporated.
- Entities have said that they are adhering to the WECC *Data Preparation Manual* to the best of their knowledge and that they do not receive feedback from WECC of any issues. WECC creates a steady-state and dynamics data dashboard on the WECC System Review Subcommittee (SRS) webpage for each base case that is published, which includes model data quality metrics. WECC expects the entities to review the dashboard results and fix issues.
- Interactions between the Phase 2 composite load model (including motor stalling) and inverter-based resource dynamic models has resulted in some unexpected simulation results, such as resource tripping that has not been verified in real-world events. The behavior of the composite load model is not widely trusted regarding delayed voltage recovery, and near-term effort is needed to address steps that should be taken when simulations present potential tripping issues; however, these types of concerns have not been observed in actual grid events or other types of testing.
- TPs and PCs stated that for units larger than 75 MVA they rely solely on the MOD-026-1 and MOD-027-1 test reports for receiving "verified" data.[25] For smaller units, TPs have stated that they have little authority or

[25] The NERC IRPTF has identified that these test reports often do not consider the large disturbance behavior of inverter-based resources and therefore do not verify the dynamic model parameters for large disturbance events.

capability to request accurate data. TPs are seeking PMU installations to have better monitoring; however, this is unrelated to the modeling issues in this report.

- TPs have said that the lack of expertise and experience working with dynamic models for inverter-based resources has likely been a significant contributing factor to bad models in base cases. As engineering staff change, new engineers unfamiliar with these topics become responsible for data submittals. Furthermore, there are limited data quality checks applied to the Interconnection-wide case creation process, and the data checks that are applied are not enforced in a meaningful way.
- WECC identifies data issues in the case creation process and informs the TPs and PCs of those errors. The TPs and PCs have limited ability and success getting those issues corrected and are not fully using MOD-032-1 Requirement R3 to its fullest extent due to concerns related to compliance. TPs and PCs often point at WECC as the responsible entity; however, MOD-032-1 does not enable the RE (i.e., the MOD-032 designee) to enforce data quality issues as a single point of contact. This issues needs to be addressed in the near-term.

Appendix A: Large Solar PV Resource Dynamic Model Review

This appendix includes a scorecard for model quality of solar PV plants 75 MW and above modeled in the WECC 2020 HS3 base case. Table A.1 shows a coloration legend, which is applied to each model review shown in Table A.2.

Table A.1: Coloration Legend

Color	Meaning
(dark green)	The model is consistent with NERC alert data, WECC modeling practices, and recommendations made by NERC/WECC.
(light green)	The model is consistent with most data but may require a few corrections such as a wrong bus number in dynamics data, turbine type correction, or other non-impactful data error.
(yellow)	The correct model used but is not consistent with NERC alert data or the model matches NERC alert but wrong model used.
(orange)	The model has dramatic differences between NERC alert data, is netted in the base case, or does not have a complete model set.
(red)	The model does not conform to WECC *Data Preparation Manual*, uses incorrect dynamics model, has significant quality issues, or has no model associated with the unit.
(gray)	A link to NERC alert data cannot be determined.

Table A.2: Model Review Table

Bus #	PSLF Gen Name	Gen ID	Area	Pmax	Gen DYD	EC DYD	Model Quality	Model Review Notes
			24	300	regc_a	reec_a	(dark green)	GO indicated study can be done to eliminate MC. WECC should follow up with respective TP on study results if done.
			14	290	None	None	(red)	No dynamics model found for large generator.
			30	254	regc_a	reec_b	(light green)	EIA capacity of 50 MW; needs review of capacity. Provided new model to TP to eliminate MC. Should ensure correct capacity does not use MC.
			24	250	regc_a	reec_a	(dark green)	GO indicated study can be done to eliminate MC. WECC should follow up with respective TP on study results if done.
			30	245	regc_a	reec_b	(red)	Incorrect modeling of electrical controls. Uses MC, but does not have *reec_a*. No new models provided with altered MC settings. Generator name does not match dyd file.
			24	235	None	None	(red)	No dynamics model found for large generator.
			24	235	regc_a	reec_b	(red)	EIA capacity of 20 MW, needs review of capacity. Plant uses MC but has *reec_b* model that cannot model MC properly.
			30	233	regc_a	reec_b	(red)	Model incorrectly models electrical controls. Uses MC but can eliminate based on NERC alert data. No new models were provided

Table A.2: Model Review Table								
Bus #	**PSLF Gen Name**	**Gen ID**	**Area**	**Pmax**	**Gen DYD**	**EC DYD**	**Model Quality**	**Model Review Notes**
								with altered MC settings, so MC settings cannot be verified. Generator name does not match dyd file.
			22	207	regc_a	reec_b		Dynamics file indicates model received updates in 2018. Cannot determine link to NERC alert data.
			30	202	regc_a	reec_b		Cannot determine link to NERC alert data.
			18	200	None	0		Model is netted at request of data submitter; however, this model should have information based on WECC *Data Preparation Manual*.
			30	200	regc_a	reec_b		Cannot determine link to NERC alert data.
			24	174	regc_a	reec_b		Cannot determine link to NERC alert data.
			26	165	regc_a	reec_b		Plant can eliminate MC, but current equipment uses MC. Incorrect model used.
			30	165	regc_a	reec_a		MW does not match between dynamics and power flow. Cannot determine link to NERC alert data.
			65	160	regc_a	reec_a		All capacity modeled. MC settings do not match reported NERC alert data.
			24	155	regc_a	reec_b		EIA capacity and power flow do not match. Can eliminate MC but model is of existing equipment using MC. Incorrect model used.
			30	155	regc_a	reec_b		Cannot eliminate MC and uses MC. Incorrect model used.
			15	154	regc_a	reec_b		Model newer than NERC alert data (2019) confirm usage of MC.
			24	152	regc_a	reec_b		Cannot determine link to NERC alert data.
			22	150	regc_a	reec_b		Cannot determine link to NERC alert data.
			15	150	gewtg	None		EIA capacity and power flow capacity different. Cannot eliminate MC and uses MC, no electrical model provided. GEWTG model in DFIG mode. Major model errors.
			24	148	regc_a	reec_b		Cannot determine link to NERC alert data.
			22	147	regc_a	reec_b		Cannot determine link to NERC alert data.
			24	144	regc_a	reec_b		Can eliminate MC, but model represents current equipment that does use MC. Certain capacities cannot eliminate MC. Incorrect model used.
			24	144	regc_a	reec_b		Can eliminate MC, but model represents current equipment that does use MC. Certain capacities cannot eliminate MC. Incorrect model used.

Table A.2: Model Review Table								
Bus #	PSLF Gen Name	Gen ID	Area	Pmax	Gen DYD	EC DYD	Model Quality	Model Review Notes
			24	136	regc_a	reec_b		Combined with Redacted. EIA capacity and power flow capacity slightly different. Can eliminate MC, but model represents current equipment that does use MC. Incorrect model used.
			30	134	regc_a	reec_a		MC setting differences between NERC alert reported data and base. case data. Plant indicated no changes can be made to MC settings.
			26	134	regc_a	reec_b		Unit combined with Redacted. Plant uses MC and indicated no changes can be made to MC settings. Incorrect model used.
			24	131	regc_a	reec_b		EIA capacity and power flow capacity different. Can eliminate MC, but model represents current equipment that does use MC. Certain capacities cannot eliminate MC. Incorrect model used.
			22	129	regc_a	reec_b		EIA capacity and power flow capacity different. Cannot eliminate MC and uses MC. Incorrect model used.
			24	125	regc_a	reec_b		Cannot determine link to NERC alert data.
			24	124	regc_a	reec_b		Unit combined with Redacted. EIA capacity and power flow capacity different. Can eliminate MC, but model represents current equipment that does use MC. Incorrect model used.
			26	124	regc_a	reec_b		Unit combined with Redacted. Plant uses MC and indicated no changes can be made to MC settings. Incorrect model used.
			24	123	regc_a	reec_b		Combined with Redacted. EIA capacity and power flow capacity slightly different. Can eliminate MC, but model represents current equipment that does use MC. Incorrect model used.
			26	122	regc_a	reec_a		Combined with Redacted. Does not use MC and model parameters fit with no MC.
			70	120	regc_a	reec_b		Cannot eliminate MC and uses MC. Incorrect model used.
			24	116	regc_a	reec_b		EIA capacity and power flow capacity different. Can eliminate MC, but model represents current equipment that does use MC. Certain capacities cannot eliminate MC. Incorrect model used.
			24	115	regc_a	reec_b		EIA capacity and power flow capacity different. Can update MC cannot eliminate MC. Incorrect model used.
			24	109	regc_a	reec_a		Cannot determine link to NERC alert data. Electrically close to Redacted.
			26	108	regc_a	reec_b		Plant can eliminate MC, but current equipment uses MC. Incorrect model used.

Table A.2: Model Review Table								
Bus #	**PSLF Gen Name**	**Gen ID**	**Area**	**Pmax**	**Gen DYD**	**EC DYD**	**Model Quality**	**Model Review Notes**
			30	108	regc_a	reec_b		Plant does not use MC and uses correct model.
			24	106	regc_a	reec_b		Unit combined with Redacted. EIA capacity and power flow capacity different. Can eliminate MC, but model represents current equipment that uses MC. Incorrect model used.
			22	105	regc_a	reec_b		Cannot determine link to NERC alert data.
			18	105	regc_a	reec_a		Cannot determine link to NERC alert data.
			16	105	regc_a	reec_c		Cannot determine link to NERC alert data.
			24	104	regc_a	reec_b		Cannot determine link to NERC alert data.
			24	104	regc_a	reec_a		EIA capacity and power flow capacity different. Unit uses MC and is consistent with settings.
			24	104	regc_a	reec_a		EIA capacity and power flow capacity different. Unit uses MC and is consistent with settings.
			30	103	regc_a	reec_b		Plant does not use MC, but uses *reec_b*. Needs updating.
			30	102	regc_a	reec_b		Can eliminate MC, but model represents current equipment that uses MC. Incorrect model used.
			26	102	regc_a	reec_a		Combined with Redacted. Uses MC and model parameters fit with NERC Alert Data.
			24	101	regc_a	reec_b		Cannot determine link to NERC alert data.
			18	100	regc_a	reec_b		Cannot determine link to NERC alert data.
			18	100	regc_a	reec_a		Cannot determine link to NERC alert data.
			18	100	None	0		Unit netted in power flow and dynamics and does not conform to WECC *Data Preparation Manual*.
			22	100	regc_a	reec_a		Cannot determine link to NERC alert data.
			18	99	regc_a	reec_b		Can eliminate MC, but model is of current equipment that does use MC. Model was not updated as proposed in NERC alert data. Incorrect model used.
			24	94	regc_a	reec_b		Plant uses MC and cannot eliminate MC. Incorrect model used.
			24	94	regc_a	reec_b		Can eliminate MC, but model is of current equipment that does use MC. Incorrect model used.
			24	92	regc_a	reec_b		EIA capacity and power flow capacity different. Plant uses MC and cannot eliminate MC. Incorrect model used.

Table A.2: Model Review Table								
Bus #	**PSLF Gen Name**	**Gen ID**	**Area**	**Pmax**	**Gen DYD**	**EC DYD**	**Model Quality**	**Model Review Notes**
			26	90	regc_a	None		Similar plant to Redacted; however, no unit data reported for PV3 in NERC alert data. Electrical controller causes errors in initialization, so commented out. Does not conform to WECC *Data Preparation Manual*.
			24	88	regc_a	reec_b		Plant combined with Redacted. Cannot determine link to NERC alert data.
			24	88	regc_a	reec_b		Plant combined with Redacted. Cannot determine link to NERC alert data.
			24	83	regc_a	reec_a		Plant combined with Redacted. EIA capacity and power flow capacity different. Plant does not use MC and settings are consistent.
			24	83	regc_a	reec_a		Plant combined with Redacted. EIA capacity and power flow capacity different. Plant does not use MC and settings are consistent.
			22	83	regc_a	reec_a		Cannot determine link to NERC alert data.
			65	82	regc_a	reec_b		Cannot determine link to NERC alert data.
			22	81	regc_a	reec_b		Cannot determine link to NERC alert data.
			24	80	regc_a	reec_b		Plant uses MC, but can eliminate MC. Plant indicated model of proposed changes to be sent; however, WECC MDF does not contain proposed model updates.
			65	80	regc_a	reec_a		Plant uses MC and cannot eliminate MC. Settings effectively eliminate MC in model.
			65	80	regc_a	reec_a		All capacity modeled. MC settings do not match reported NERC alert data.
			65	80	regc_a	reec_a		Plant uses MC and cannot eliminate MC. Settings effectively eliminate MC in model.
			65	80	regc_a	reec_a		Plant uses MC and cannot eliminate MC. Settings effectively eliminate MC in model.
			65	80	regc_a	reec_b		Plant uses MC and cannot eliminate MC. Incorrect model used.
			65	80	regc_a	reec_a		Cannot determine link to alert data.
			21	77	regc_a	reec_b		Cannot determine link to alert data.
			24	76	regc_a	reec_a		Plant combined with Redacted. EIA capacity and power flow capacity different. Parts of plant use MC; settings not consistent with alert data.

Table A.2: Model Review Table								
Bus #	PSLF Gen Name	Gen ID	Area	Pmax	Gen DYD	EC DYD	Model Quality	Model Review Notes
			24	76	regc_a	reec_a		Plant combined with Redacted. EIA capacity and power flow capacity different. Parts of plant use MC; settings not consistent with alert data.
			30	75	regc_a	reec_a		Plant combined with Redacted. Cannot determine link to alert data.
			30	75	regc_a	reec_a		Plant combined with Redacted. Cannot determine link to alert data.

Appendix B: Review Team

NERC gratefully acknowledges the contributions and assistance of the WECC SMAG in formulating this report and would like to acknowledge the technical discussions and contributions of the IRPTF.

The following individuals were involved in the analysis of the WECC base case and development of key findings and recommendations documented in this report.

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