WECC

Changes in Grid Strength Study Report

December 2023

https://www.wecc.org/Administrative/Changes%20in%20Grid%20Strength%20Overview.pdf

Executive Summary

As the resource mix continues its rapid evolution—with synchronous generation retiring and being replaced by inverter-based resources such as wind, solar, and battery storage—it is critical to understand the impact these new generators will have on protection systems of the bulk power system. This study examines how the system responds to transmission system faults and assesses the voltage profile of the electric grid to identify weak areas.

In 2021, WECC conducted the Changes in System Inertia (CSI) study, which found that a large generator outage during spring conditions with low system inertia could pose a risk to the Western Interconnection. The CSI study focused on inertia but recommended additional studies to understand how a reduction in synchronous resources might affect voltage stability.[1] A similar recommendation came from the 2018 NERC white paper Short-Circuit Modeling and System Strength.

No Western Interconnection-wide studies of this kind have ever been conducted. This is largely because manufacturers of inverter-based resources (IBR) have not shared data to help determine the fault current provided per unit by IBRs, arguing that it is proprietary information. Without this data, fault current modeling can only estimate the behavior of IBRs. In addition, and perhaps as a result, there is no standard short-circuit modeling approach for IBRs, and each model used today has flaws. Given the large number of planned IBRs over the next 10 years, these barriers need to be addressed to ensure the West can accurately measure and study the potential impacts of IBRs on system strength.

Despite these challenges, WECC determined an approach that allowed it to begin analyzing system strength. Using the short-circuit ratio (SCR) as a measure of voltage stability, this study compared a baseline case with existing resources to a change case where 20% of synchronous generation was replaced with IBRs. Given the lack of short-circuit modeling information for IBRs, WECC modified synchronous generators in existing models to behave like IBRs by limiting the fault current to 1.1 per unit. This is because IBRs have hardware and software current limiters to protect the inverter electronics.

The analysis showed only a small reduction in grid strength (measured by the SCR), which was localized to within roughly two buses closest to where new IBRs were located. Fault currents remained relatively stable in the change case. There was a decrease of less than 14% in fault current one bus away from the modified generation and less than 5% two buses away. This indicates the reliability of the system's protection and coordination system would likely not be significantly compromised with IBR penetration of an additional 20%. Overall, replacing 20% of synchronous generation with IBRs does not appear to have a significant effect on system strength. WECC will conduct additional analysis of higher IBR penetration levels.

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[1] WECC expanded its study of inertia in its Grid-forming Inverters Study, released in November 2023.

In addition to the results of this analysis, WECC gained valuable experience on how to model IBRs to analyze grid strength. The challenges and lessons from this analysis should be used to improve modeling of IBRs across the interconnection. To this end, WECC provides the following recommendations.

> **Recommendation:** The Short-circuit Modeling Subcommittee should continue working with the software vendors and industry to establish recommendations on how IBRs are represented in short-circuit models.

> **Recommendation:** Industry should impel inverter manufacturers to share modeling data to allow the creation of robust short-circuit models.

> **Recommendation:** WECC explored the use of the Converter Interfaced Resources (CIR) IBR model but was unable to get the model to run properly. Software vendors should continue to improve IBR modeling so the effects they have on the interconnection can be further evaluated.

Table of Contents

Background and Purpose

As Inverter-based Resources (IBR) replace synchronous generation, a fundamental shift in the operational characteristics of the bulk power system is occurring. There are many potential reliability implications to this shift. This study examines how the system responds to transmission system faults and assesses the voltage profile of the electric grid to identify weak areas.

In 2021, WECC conducted the Changes in System Inertia (CSI) study, which found that a large generator outage during spring conditions with low system inertia could pose a risk to the Western Interconnection. In that study, the frequency decreased to 59.5 Hz, passing the activation threshold for the underfrequency load shedding program. WECC concluded that operating the system with reduced inertia and without frequency support from IBRs could create a reliability risk. In addition, WECC concluded that additional studies were necessary to look beyond inertia to understand how a reduction in synchronous resources might affect voltage stability.[2]

A NERC whitepaper, Short-Circuit Modeling and System Strength, released in 2018, also identified the need for this type of study and showed that these nonsynchronous resources have unique short-circuit characteristics that have not been assessed. The lack of studies of system strength is largely because manufacturers of IBRs have not shared modeling data to help determine the fault current provided per unit by IBRs, arguing that it is proprietary information..

One measure of voltage stability is the short-circuit ratio (SCR). This is a metric that has traditionally been used to indicate the strength of the grid at individual locations, or buses. The ratio evaluates the system's ability to withstand and respond to a short circuit. An area with a lower SCR is considered weaker, and disturbances in areas with low SCRs can cascade, leading to load loss.

While the fault current and short-circuit behavior of synchronous generators is well understood, limited research has been done on the unique short-circuit characteristics of non-synchronous generators, such as IBRs. This study is WECC's first attempt to quantify the changes in grid strength caused by increasing penetration of IBRs by measuring changes to the SCR.

Approach

To study the effects of IBRs on system strength, WECC compared two simulations: one with the existing generation fleet (baseline simulation) and the other with 20% of the synchronous generation replaced by IBRs.

[2] Short-Circuit Modeling and System Strength, 2018.

Calculating the SCR

The SCR is the ratio of the short-circuit MVA capacity at the busbar in the existing network before the connection of a new resource to the rated megawatt value of the new resource. Each bus has a calculated SCR based on the potential fault current provided by the generation and transmission on the system.

Modeling the IBRs

The lack of a standard short-circuit modeling approach for IBRs, and the fact that many of the models used have flaws, presented a challenge in conducting this study. Ultimately, WECC created a study approach that worked around these limitations, using information currently available. WECC's approach was to limit fault current to 1.1 per unit, making the synchronous generator a current-limited device. "Per unit" is used to describe power-system quantities such as voltage, current, power, and impedance. It represents a percentage of a specified base value; in this assessment, a percentage of the base fault current. (See Equation 1).

Equation 1: Per-Unit Equation

$$per - unit\ quanity = \frac{actual\ quantity}{base\ value\ of\ quantity}$$

Using 1.1 per unit for IBR fault current limitation is an industry standard practice that attempts to simulate the unique behavior of IBRs during fault conditions. This value acknowledges that IBRs typically provide limited fault current compared to synchronous generators. Using this approach aligns with common modeling practices in the Western Interconnection; however, the approach is not ideal because it models non-synchronous generators as synchronous generators with a limited per-unit fault current output.

Data and Models

Data

For the baseline, WECC used 2023 operating short-circuit models from Tri-State G & T, Bonneville Power Administration (BPA), and PacifiCorp (PAC). These models contain existing generation resources. To create the change case, WECC replaced 20% of the synchronous generation in each model with IBRs.[3] The new IBRs were located at the site of the retiring generator. WECC used an equation to determine how much current to expect from the IBRs. The equation is based on the size of the generating unit in MVA and represents 100% of the current the generating unit provided to the system. (See Equation 2).

[3] WECC based the 20% change on expected retirements reported by entities for the next five to 10 years.

Equation 2: IBR Current Calculation

$$Amps\ (A) = \frac{MVA}{\sqrt{3} * Voltage}$$

The assessment examined three-phase faults only. Other than the IBR generator modification, no other changes were made to the models. The short-circuit software settings were maintained for each model.

WECC applied the 1.1 per-unit limitation to the new generators to mimic the expected output from IBRs. (See Table 2).

Table 1: Generators Replaced with IBRs in the Change Case

BPA		
Plant	Voltage (kV)	MVA
CENTRALIA P2	525	402
MOXEE	115	80
SPRING CREEK	230	100
MAUPIN	230	200
MAUPIN	69	20
FRANKLIN	230	1,200
	Total MVA Replaced	2,002
PAC		
BRIDGER1	230	295
BRIDGER2	230	295
BRIDGER3	230	295
BRIDGER4	230	295
DAVEJON1	115	66.8445
DAVEJON2	115	66.8445
DAVEJON3	115	127.5
DAVEJON4	115	200
NAUGT G1	230	96
NAUGT G2	230	128
NAUGT G3	230	192
WYODAK 1	230	201.15
	Total MVA Replaced	2,258.339
Tri-State		
Craig G1	345	150
Craig G3	345	150
	Total MVA Replaced	300

Modeling Software

To compare the baseline and change case, WECC ran a bus fault summary on each short-circuit model in each case using ASPEN OneLiner. The bus fault summary faults every bus in the network and provides for a range of data types, including fault current. The output from the summary provides information that WECC used to evaluate the difference in fault current and the difference in the SCR between the two cases.

Results

Based on the current state of IBR modeling, the impact of replacing 20% of synchronous generation with IBRs would be unlikely to have any significant impact on protection system setting, due to only minor changes in SCR and fault current levels.

Short-Circuit Ratio

When the synchronous generators were replaced with IBRs, the SCR decreased between 10% and 14% from the baseline at each faulted bus. The SCR decrease was less severe one bus away (half of the decrease at the faulted bus). Beyond two buses from the faulted bus, there was little to no effect. The addition of IBRs appears to have caused localized reductions in SCR but limited effects overall. On elements 345 kV and above, there was only a 1.3% decrease in the SCR.

Fault Current

Fault currents remained relatively stable after the introduction of IBRs. There was a decrease of less than 14% in fault current one bus away from the modified generation and less than 5% two buses away. Based on these results, it is not likely the reliability of system protection and coordination elements would be significantly compromised with an IBR penetration of an additional 20%. Figure 1 shows the fault current percentage difference between the baseline and change case by voltage. The plot shows results for 18,000 buses. Of those, only four buses at 100 kV and above show a difference in fault current above 5%. These four buses are the buses closest to the replaced generation.

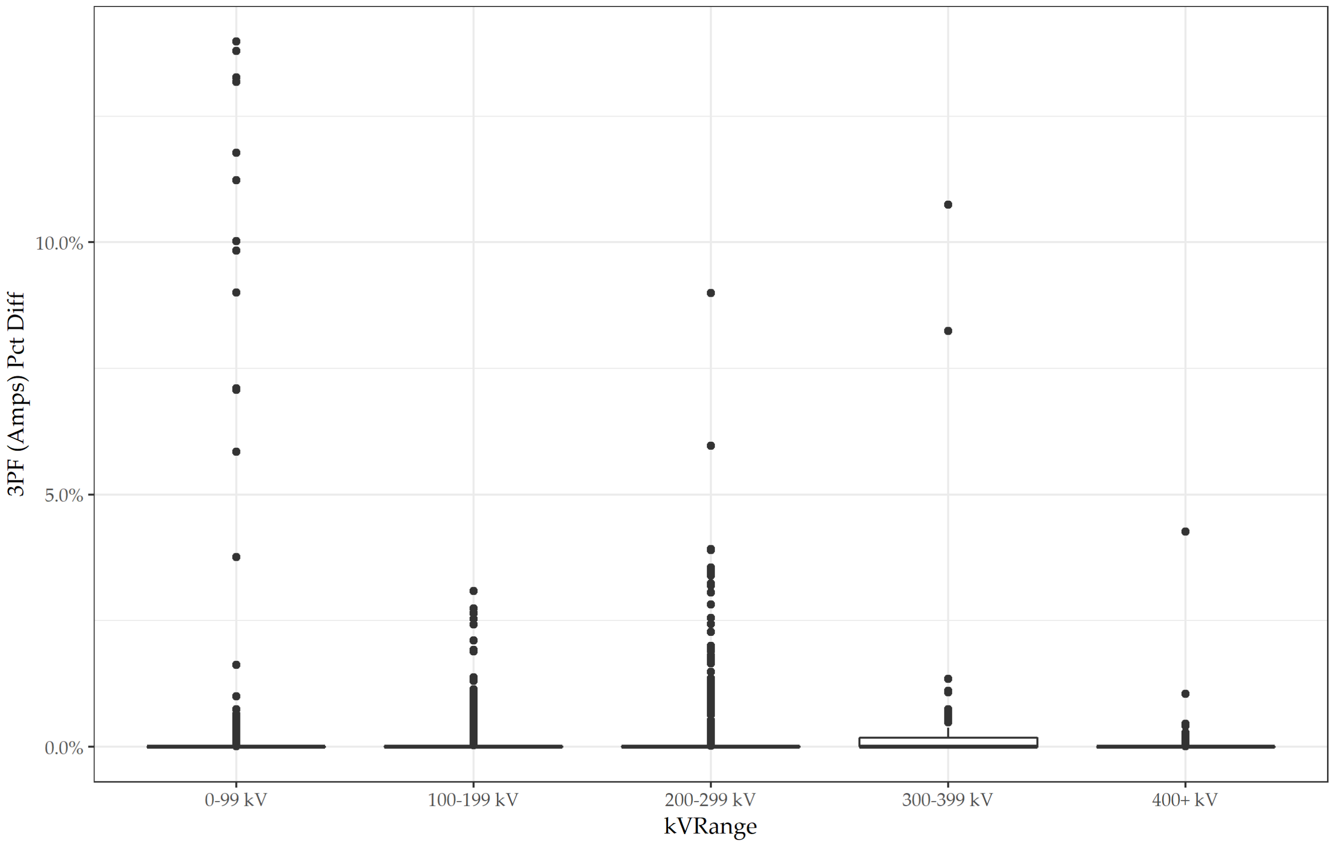
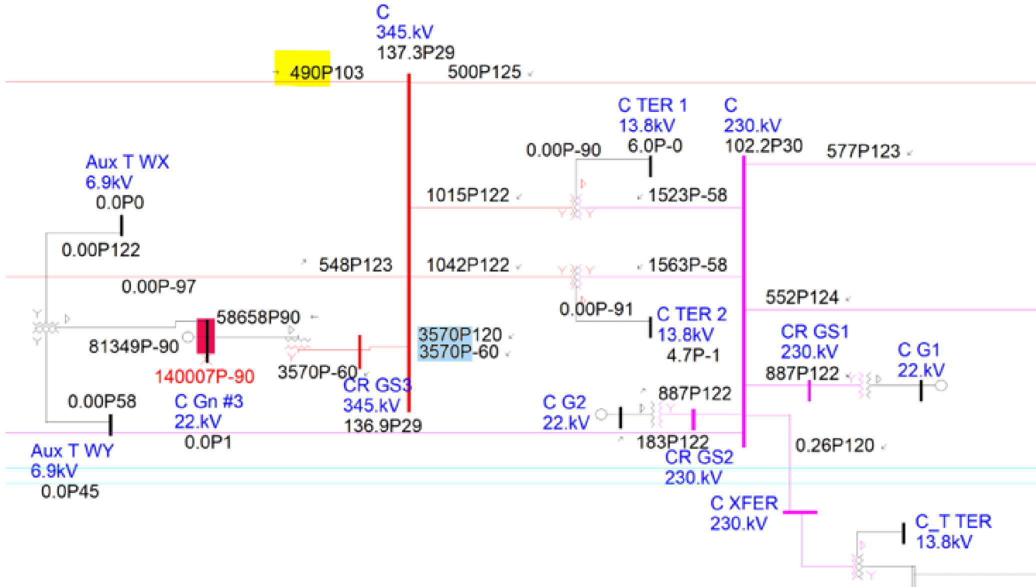


Figure 1: Three-Phase Fault Current % Difference

Figure 2 compares fault current results from the baseline case and change case, taken from the short-circuit software. The faulted bus is highlighted in red. Highlighted in yellow and blue are two examples of fault current along each of the branches. The first example to look at shows, highlighted in yellow, 490 amps flowing into bus C, and, highlighted in blue, 3,570 amps flowing out of bus C toward the faulted bus C Gn #3. Figure 3 is the modified model with the added current-limited IBR models. Looking at the yellow highlighted fault current, there is a slight increase of 8 amps now flowing into bus C; but, looking at the blue highlight, there are now 3,543 amps flowing from bus C toward the fault. There is little difference in fault currents looking just one to two buses away, when only 20% of the generation is replaced.



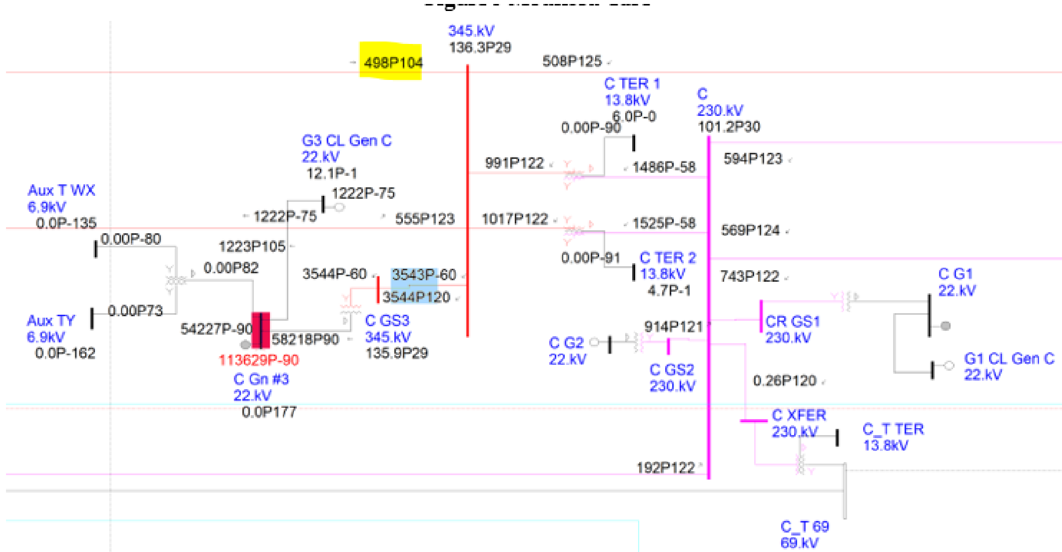


Figure 2: Changes in Fault Current between Baseline and Change Case

Findings and Conclusions

Higher IBR Penetration

To meet state and national clean energy goals, industry plans to add large amounts of IBRs. To understand the potential effects of higher levels of IBR adoption on protection settings, the industry should conduct additional studies at higher IBR penetration levels. The goal of future work could be to identify a point at which system strength is compromised and may be deemed unstable.

Modeling Accuracy

There were several instances in the model where generators appeared to be solar plants but were behaving like synchronous generation units, putting out 6 per-unit current. WECC believes these to be data errors in the model and encourages entities to periodically review the models to verify they are accurate, particularly for older generators. While the purpose of this assessment was not to verify the accuracy of how existing IBRs are modeled, the existing IBRs were used as a reference. An inaccurate representation of resources can significantly affect the results.

> **Recommendation:** The Short-circuit Modeling Subcommittee should continue working with the software vendors and industry to establish recommendations on how IBRs are represented in short-circuit models.

In addition, the lack of modeling data to help determine the fault current provided per unit by IBRs has created a situation in which the West cannot accurately model system strength. Given the large number of planned IBRs over the next 10 years, this barrier will need to be addressed to ensure the West can accurately measure and study the potential impacts of IBRs on system strength.

> **Recommendation**: Industry should impel inverter manufacturers to share modeling data to allow the creation of robust short-circuit models.

Modeling Tools

There is no standard short-circuit modeling approach for IBRs, and each model used today has flaws. This presented a challenge in conducting this study. WECC explored multiple modeling approaches to conduct this assessment and decided to use the new Converter Interfaced Resources (CIR) IBR model. However, when using ASPEN OneLiner software, WECC was unable to get the CIR type 4 model to run properly in the short-circuit models. WECC abandoned this approach and reported this result to the software vendor.

> **Recommendation:** Software vendors should continue to improve IBR modeling so that the effects of IBRs on the interconnection can be further evaluated.

Contributors

WECC thanks the following people and organizations for the hard work and time they invested in this project:

Role	Name	Affiliation
Staff Lead	Tyson Niemann	WECC
Project Manager	Dennis Doyle	WECC
Advisory Group Member	Bill Middaugh	Tri-State G & T
Advisory Group Member	Mohamed Osman	NERC
Advisory Group Member	Thomas McDermott	PNNL
Advisory Group Member	Jinho Kim	PNNL
Advisory Group Member	Xiaoyu Wang	ENEL
Advisory Group Member	Hari Singh	Xcel Energy
Advisory Group Member	Malati Chaudhary	PNM
Advisory Group Member	Matthew Truscott	GCPUD
Advisory Group Member	Amos Ang	SCE
Advisory Group Member	Kwami Sedzro	NREL
Advisory Group Member	Yilu Liu	UTK
Advisory Group Member	Song Wang	PGN
Advisory Group Member	Dhurian Vitoldas	Siemens Gamesa
Advisory Group Member	Eric Baran	WIRAB
Advisory Group Member	Will Parker	WECC