Developing a PSCAD Model of the Reduced 240-Bus WECC Test System

Preprint

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Developing a PSCAD Model of the Reduced 240-Bus WECC Test System

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***Abstract*—Fast-acting controls of inverter-based resources introduce unprecedented dynamics in bulk power systems and island power grids, especially high-frequency dynamics ranging from $>$ 5 Hz to hundreds of hertz. PSS/E, PSLF, Powerworld, and TSAT—because these tools and corresponding models typically don't have a fast enough time resolution. Instead, these fast dynamic problems are best studied in the electromagnetic transient (EMT) domain using corresponding EMT dynamic models. Instead, these problems should be studied in the electromagnetic transient (EMT) domain using proper EMT dynamic models. This paper documents the development and validation of a PSCAD model of the reduced 240-bus Western Electricity Coordinating Council test system. The PSCAD model will be released to the public, to be used by academia and power industry practitioners for studying fast dynamic problems, without requiring access to critical energy/electric infrastructure information.**

***Index Terms*—240-bus WECC test system, PSCAD, electromagnetic transient simulation, EMT, inverter-based resources, IBR, renewable energy**

I. INTRODUCTION

Power systems have been dominated by rotating machines, such as synchronous generators, for many decades. The inertia from rotating machines can prevent the system frequency from any sudden change, and rotating machines present only low-frequency oscillations as system-level stability concerns.[1] As inverter-based resources (IBRs) continue to increase in modern power grids, unprecedented dynamics, especially high-frequency dynamics ranging from $>$ 5 Hz to hundreds of hertz, are emerging. As shown in Fig. 1, there is a correlation between the number of worldwide high-frequency oscillation events and the worldwide growth of renewable energy generation since 2000.

- In the 2009 Texas oscillation event, multiple wind turbines and a series capacitor were significantly damaged. The post-event investigation found the cause to be subsynchronous control interactions. Mitigation actions were not established until two years later [1].
- In the 2009 Sayano-Shushenskaya power station accident, subsynchronous oscillations caused a hydro turbine failure, leading to the *death of 75 people*, plus the damage/destruction of nine turbines [2]. Although this event was caused by traditional subsynchronous oscillation issues, it illuminates the potential danger of such oscillations in contemporary power systems.
- During the Blue Cut Fire in 2016, 1200 MW of solar was tripped, partially due to some IBRs' phase locked loop (PLL) algorithms incorrectly measured a frequency of $<$ 57 Hz upon sudden voltage waveform distortions when the true frequency remained near 60 Hz [3].
- On August 24, 2021, the Great Britain power grid experienced severe 8-Hz oscillations for two, 20–25-second occasions when the IBR penetration was high. The root cause is unknown, and the investigation is ongoing [4].

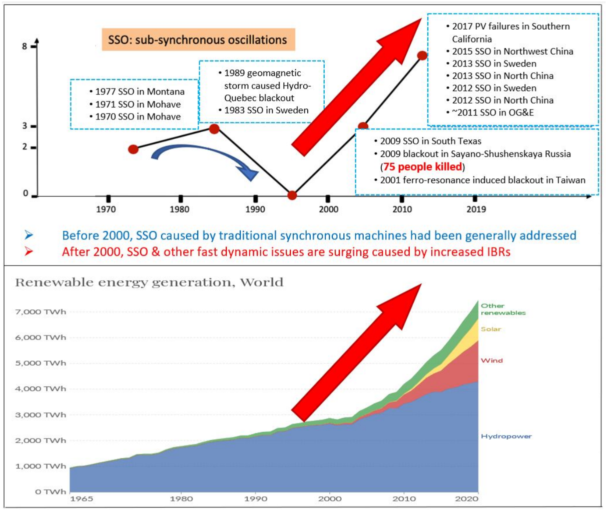

Fig. 1: Number of high-frequency oscillation events (top) [5] and renewable energy generation growth (bottom) [6].

A thorough investigation of each of these events requires a detailed study of the underlying system electromagnetic transient (EMT) model, which is accessible only to the members of the investigation team. Relevant studies in academia are usually performed on small-scale test systems, whereas more complex problems associated with large-scale grids might not be captured. Currently, there is a lack of open-source, large-scale test systems for studying fast IBR dynamics and their interactions with electrical grids. This paper aims to fill this gap by developing a power system computer-aided design

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[1] Subsynchronous oscillations having high frequencies are traditionally local dynamic problems, e.g., interactions between multi-mass or elastic turbine generator and power network, and have been generally addressed for historical operating conditions.

(PSCAD) model of the reduced 240-bus Western Electricity Coordinating Council (WECC) test system, which represents the highly simplified Western Interconnection of the United States.

The remainder of this paper is organized as follows: Section II briefly reviews the reduced 240-bus WECC test system. Section III presents the development of the 240-bus system in PSCAD. Section IV validates the PSCAD model. Section V concludes this work.

II. 240-BUS WECC TEST SYSTEM

To the best of the authors' knowledge, the reduced 240-bus WECC test system developed in [7] is the only open-source, interconnection-level test system with IBR dynamic models included in the dynamic data. This is the primary reason for selecting this test system for developing a PSCAD model in this work.

The original reduced 240-bus WECC test system in [8] has less than 5% IBR penetration. The IBR penetration level and resource mix there can only represent a pre-2011 system condition, whereas the actual WECC grid has experienced a significant change in the last decade [9], with instantaneous IBR penetrations exceeding 20% [10]. Reference [7] achieved a reduced 240-bus power flow base case representing the generation mix of the actual WECC system in the year 2018, and the authors developed a set of dynamic models for this reduced 240-bus WECC test system, including machine models with excitation and governor controls, and generic dynamic models for IBRs. The dynamic models were validated against three recorded real events in WECC, showing that the system-level frequency response and the dominant N-S oscillation mode were preserved. Power system stabilizer models were added at ten locations by [11] to convert the poorly damped local oscillation modes to having reasonable damping ratios.

A high-resolution one-line diagram of this 240-bus test system is shown in Fig. 2 [12] [13]. All previously mentioned versions of the reduced 240-bus WECC test system models including production cost models, PSSE models as well as the newly developed PSCAD models can be downloaded for free from NREL's Test Case Repository for High Renewable Study [12]. A summary of the system's basic information and dynamic models can be found in Table I and Table II.

TABLE I: Summary of 240-Bus WECC Test System

Elements	# of Instances/Total Capacity
Synchronous generator (SG)	104/220 GW
Synchronous condenser	5/0 GW
Distributed PV	59/10 GW
Utility-scale PV	45/28 GW
Wind	17/21 GW
Load	139/142.67 GW
Total generation	225/145.28 GW
Bus	243
Line	329
Transformer	122
Zones	14
Areas	4

TABLE II: Summary of Dynamic Models

Elements	PSS/E Model	# of Instances
SG-Generator	GENROU	109
SG-Exciter	SEXS	109
SG-Power System Stabilizer	IEEEST	10
SG-Governor	GAST	47
SG-Governor	HYGOV	25
SG-Governor	TGOV1	37
IBR-Generator	REGCA1	121
IBR-Electrical control	REECB1	121
IBR-Auxiliary control	REPCA1	121

This 240-bus phasor-domain test system model has been adopted in machine learning-based dynamic stability assessment [14], the development of an automated tool for obtaining AC power flow solutions [15], and the 2021 IEEE-NASPI Oscillation Source Location Contest [16], to name a few.

III. MODELING OF 240-BUS SYSTEM IN PSCAD

The realization of the 240-bus WECC test system in PSCAD consists of two main steps: (1) building the network with ideal voltage sources and constant power loads to verify the network topology implementation and (2) implementing each dynamic model in Table II.

In Step 1, as suggested by [17], PRSIM was used to convert the network from PSS/E to PSCAD. The network was partitioned into eight areas (called *namespaces* in PSCAD) connected by Bergeron transmission lines. Such a split allows for the use of multiple cores on a computer for the parallel computing of the model, leveraging the PSCAD Parallel Network Interface (PNI). These 8 areas are named by letters from A–H, as shown in Fig. 2 and Fig. 3. To balance the computational intensity among areas, each area contains roughly 25 generation sources. Note that although PRSIM was used in this work to create the network in PSCAD, it is not required to run the PSCAD simulations.

In Step 2, each dynamic model in Table II (except for the SG-Generator model, which directly uses the Synchronous Machine model in PSCAD) was built as a new component in PSCAD using basic components from the Master Library. The created library containing these new components is part of the open-source, 240-bus PSCAD model package. The impetus of this effort is to make the entire 240-bus PSCAD model stand-alone, such that the simulation is independent of any third-party libraries. The resulting new PSCAD components are shown in Fig. 4, whose diagrams can be found in [18]. Note that a few changes have been made on the REGCA1 model to cater for the EMT simulation, including (i) d- and q-axis currents representing the inverter output current are converted to three-phase currents using the angle tracked by the phase locked loop, (ii) an LCL filter is added between IBR and the grid, as shown in Fig. 5, whose parameters are taken from [19]. After building these components, each one was validated against PSS/E simulations on a small test system with a disturbance. As an example, Fig. 6 shows the validation of the TGOV1 governor model.

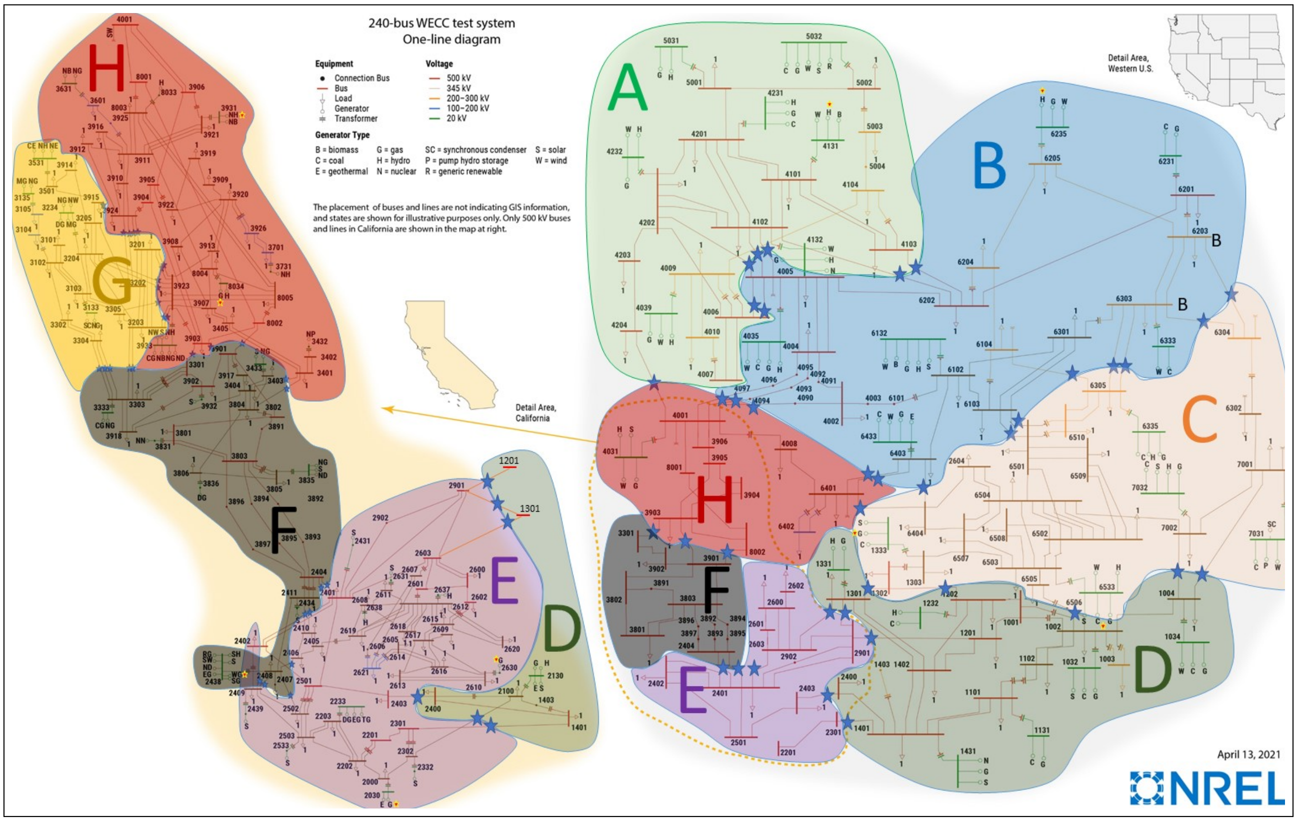

Fig. 2: One-line diagram of 240-bus WECC system.

The 1,364 output channels subsequently itemized have been included in the PSCAD model of the 240-bus system; additional channels can be added based on user interest. Python code developed to extract all these data and save as collated .csv files is included in the release package.

- Voltage root-mean-square magnitude and phase of all 243 buses
- MW and Mvar output of all 109 synchronous generators and 121 IBRs
- Rotor speed of all 109 synchronous generators
- Phase-locked loop frequency of all 121 IBRs
- MW and Mvar consumption of all 139 loads.

Python codes for automatically modifying load flow conditions will be available along with the release of the 240-bus PSCAD model at [12].

IV. VALIDATION OF PSCAD MODEL

In this section, the developed PSCAD model of the 240-bus test system was validated against the PSS/E model [7], [12] in terms of the steady-state condition and low-frequency dynamics. Designing interesting cases with fast dynamics using the developed PSCAD model that are not captured by phasor models and tools will be our future work.

A. Validation of Steady-State Condition

As detailed in [17], a PSCAD simulation starts from a de-energized state, and gradually different dynamical components are enabled in a manner to obtain the desired steady-state conditions. It is found that the system can be fully started and brought to steady state within a 10-second PSCAD simulation. The verification of steady-state conditions, including total MW/Mvar load and generation and bus voltage magnitudes and angles, is summarized in Table III, Fig. 7, and Fig. 8. Evidently, the largest errors in bus voltage magnitude and angle are <0.004 p.u. and <0.4 degrees, respectively, which shows a good agreement between PSS/E and PSCAD based on the acceptable errors presented in [17].

TABLE III: Steady-State Condition Comparison

Quantities	PSS/E	PSCAD
Total GW generation from SGs	118.093	117.973
Total Gvar generation from SGs	21.257	21.313
Total GW generation from IBRs	27.183	27.183
Total Gvar generation from IBRs	4.351	4.351
Total GW load	142.675	142.525
Total Gvar load	14.912	14.925

B. Validation of Dynamics

The PSS/E phasor model of the 240-bus test system was validated against real events in [7]. This subsection validates the slow dynamics of the PSCAD model against the PSS/E model over the loss of the largest generator (nuclear) at Palo Verde in Arizona. The loss of generation is 2.251 GW, i.e., 1.5% of the system's total online generation. Generator rotor speed, MW output, and bus voltage magnitude are compared

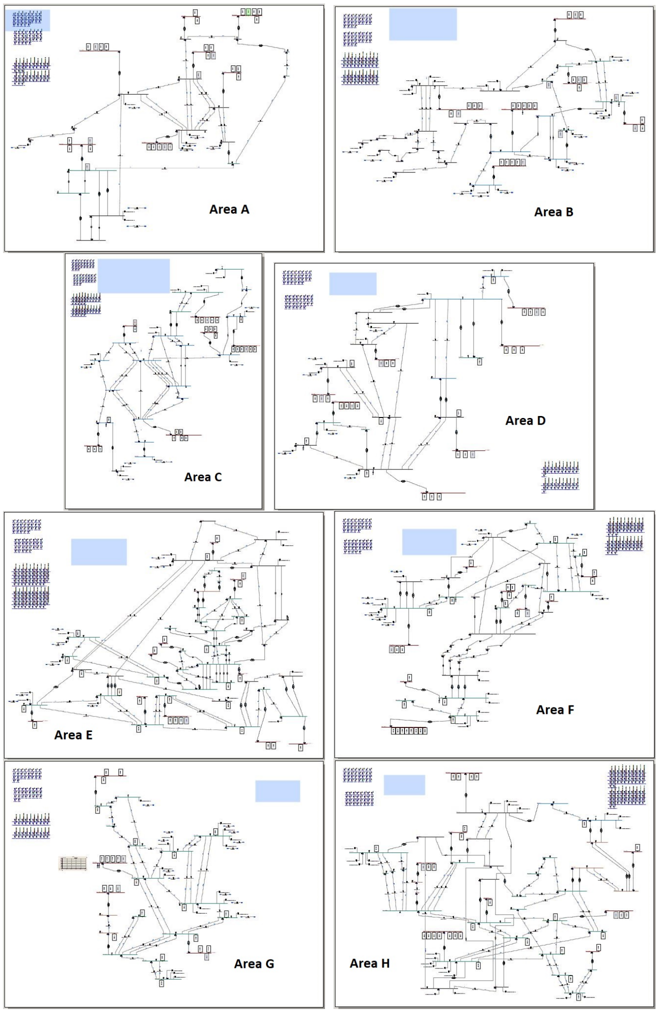

Fig. 3: Partitioned network as modeled in PSCAD.

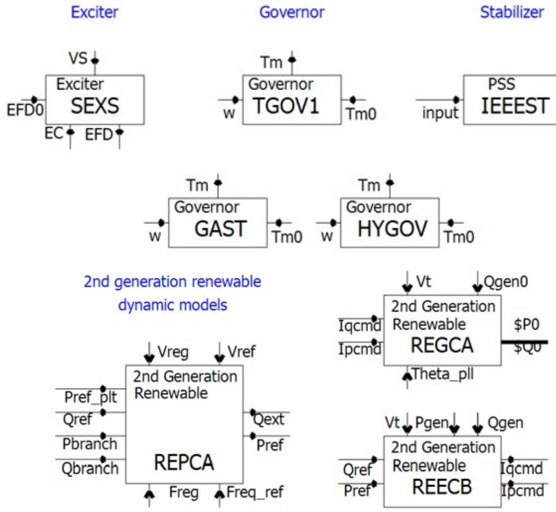

Fig. 4: Component modeling in PSCAD.

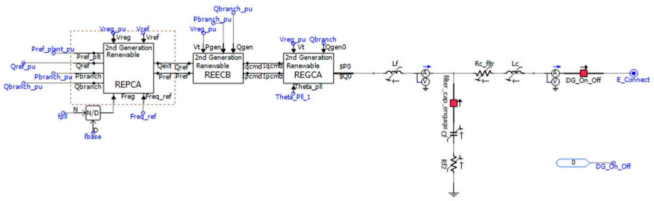

Fig. 5: IBR-grid interface.

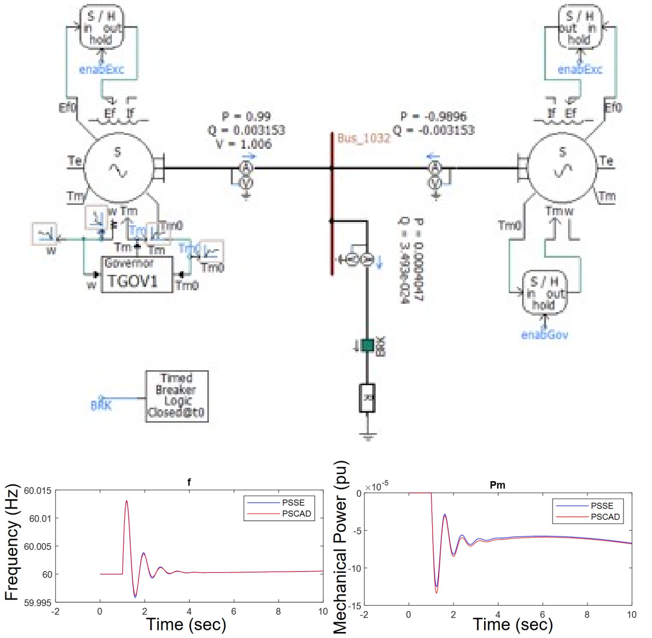

Fig. 6: Validating TGOV1 in a small two-machine system.

with those from the PSS/E simulation, as shown in Fig. 9. The results show that the PSCAD simulation is well aligned with PSS/E in terms of slow dynamics.

V. CONCLUSION

This work summarized the development and validation of the PSCAD model of the reduced 240-bus WECC test system. Future work will add more detailed IBR models, use this model to design interesting cases and study fast dynamics of IBRs and their interactions with the rest of the grid.

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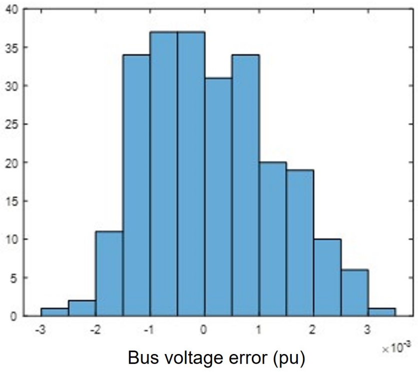

Fig. 7: Histogram of bus voltage error (PSCAD−PSS/E).

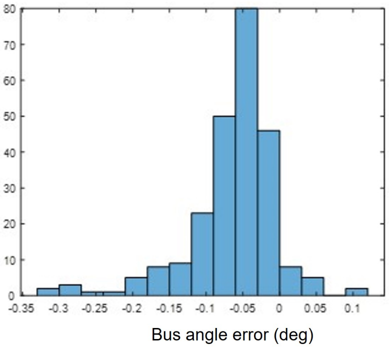

Fig. 8: Histogram of bus angle error (PSCAD−PSS/E).

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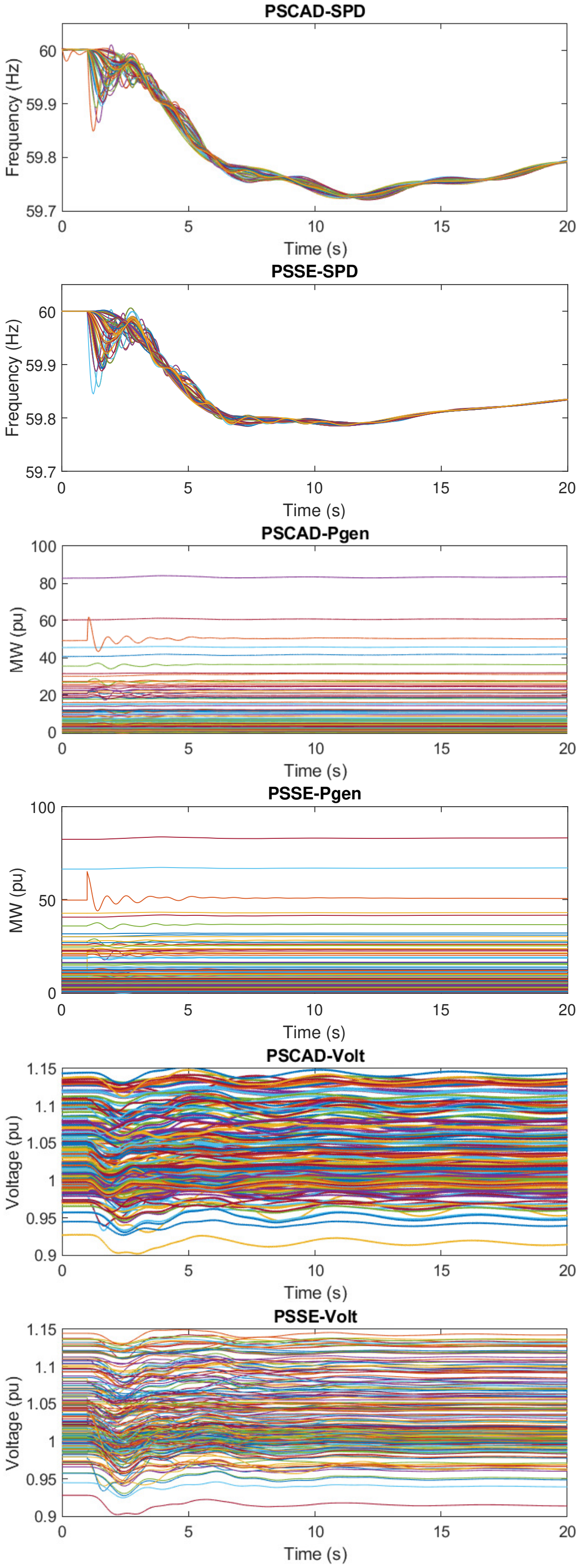
PSCAD-SPD

PSSE-SPD

PSCAD-Pgen

PSSE-Pgen

PSCAD-Volt

PSSE-Volt

Fig. 9: Validation of dynamics against PSSE.

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