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EPRI Grid Forming Inverter Models

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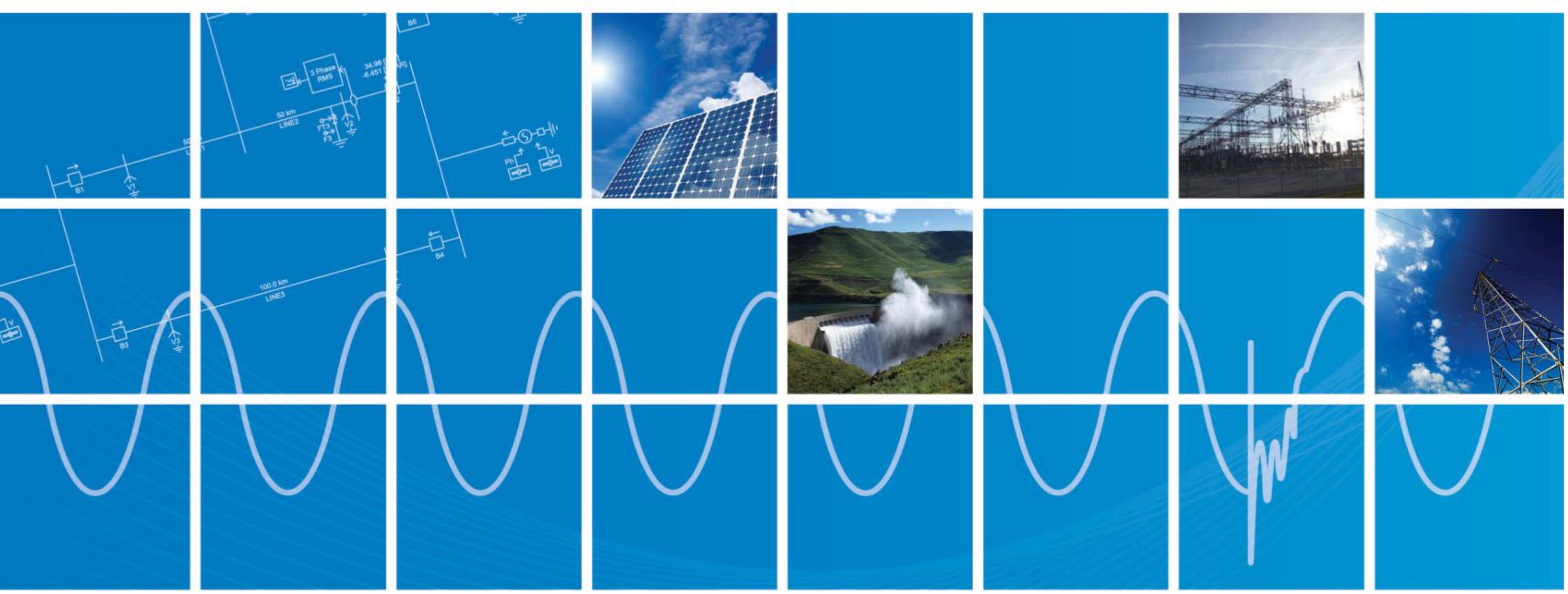

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1 Introduction

This report documents the high level of the Electric Power Research Institute (EPRI) EMT Models of PV Inverter Based Resource in Grid Following and Grid Forming Mode. These models were developed by EPRI in collaboration with University of Illinois Urbana Champaign (UIUC), University of Washington (UW), and University of Minnesota (UMN). EPRI has offered them for others' use.

Any comments/feedback on these models can be sent to their developer:
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A grid forming inverter is an inverter with the ability to start the grid or sustain the grid stability without relying on conventional generation. Traditionally inverters have been grid following, relying on the grid for the voltage and references to sustain power output, and disconnecting from the grid rather than contributing to recovery during large disturbances or outages. As the penetration of inverter based resources (IBRs) into grids increases, grid forming inverters allow IBRs to contribute to the grid stability during normal operation as well as stay online to assist the grid in recovering from disturbances. Grid forming inverters also allow for greater use of IBRs in small, isolated grids or microgrids.

The primary documentation of this PSCAD model is the EPRI technical update about this model [4] available for free online. The technical update covers the model set up, the control systems and the parameters used to configure the model as well as showing example results. This documentation covers a summary of the papers used to create the models in Section 2, and provides a high level overview of the model in Section 3.

Use of this EMT model for simulation studies is to be accompanied with cautions, not limited to:

1. The control structures and algorithms used are by no means the only way to achieve a stable operation. There are numerous other methods presently available and still more are continuously developed in research domain.
2. The use of these models for blackstart studies has not yet been tested.
3. Additional exhaustive testing, validation, and numerical robustness of the models can always be carried out to determine limitations of the model.
4. Only preliminary comparison of the behavior of the models against original equipment behavior has been carried out. Further testing and validation is ongoing.
5. Validation of robustness of behavior for unbalanced events has not yet been conducted.
6. The values of control gains presently used in the models may not be readily suitable or appropriate for:
    a. Different ratings or operating conditions.
    b. Different network topologies.
    c. Different load dynamic characteristics.
    d. Different number of varied source device characteristics

However, for the above conditions, it can be possible to tune the control gains to bring about a satisfactory response.

It is possible that this EMT model has its limitations and hence can be further improved. Please feel free to send comments/feedback on possible improvements to the model.

2 Background

The development of this model relied on 4 major sources given in section 4. Below are brief summaries for each of these major papers. Sources [1][2][4] are publicly available.

[1] Defines an interoperable primary control grid forming system architecture that is designed for use with both individual IBRs and aggregations. The design is intended to coexist with vendor specific proprietary controls that exchange standardized signals with the system operator to regulate frequency and voltages, or to manage black start. The interoperable primary control allows the grid forming IBRs to adjust their active and reactive power outputs in response to system events. The primary control does not perform frequency regulation, tie line bias control, protection or voltage control. These tasks are left for a secondary control architecture which can be kept at proprietary by vendors but should be tunable to meet the local grid codes or requirements. The paper considers three control strategies: droop, virtual synchronous machine, or dispatchable virtual oscillator control.

[2] Addresses the inherent issue with a large amount of grid following IBRs relying on a strong transmission grid while not contributing to the strength and stability of the grid. The stability of system with high IBR penetration is difficult to ascertain when most IBRs have proprietary controls that make stability assessment difficult. This paper defines how the vendors can provide a linearized state space model which provides the small signal representation of the controls at any operating point in response to being given a power flow solution, while keeping their design proprietary. This allows for IBR modelling in small signal stability assessments and could help in in defining interconnection requirements for future IBRs. The simulations within the paper show that fast terminal voltage control can create behaviour similar to grid forming IBR.

[3] Discusses a high penetration IBR system with zero inertia, with primarily conventional IBRs that are seen by the rest of the power system as current sources. The paper establishes through simulation that with fast voltage and frequency control can result in a stable network even when with 100% IBRs where they are all modelled as current sources using phase locked loops (PLLs). The paper shows an equivalence between and ideal virtual oscillator model and an ideal PLL based control structure for no load open circuit operation. Two modes of IBR operation are tested under the same scenario, fast reactive power control (grid following) and fast terminal voltage control (grid forming). The reaction of the fast terminal voltage control/grid forming IBR to frequency changes, the disconnection of the infinite bus, and a three phase fault is shown to be robust, and the lack of inertia is not shown to result in rates of change of frequency outside conventional criteria. The paper takes a part of the North American Eastern Interconnection power network and adjusts it resulting in a power network with 15 IBR plants (seven wind, eight PV), two STATCOMS, and no synchronous generation. In various scenarios, one, half or all the PV IBR plants have inverter level voltage control. The response of the IBRs in these scenarios were tested with load increases is robust and improves with a greater number of IBR plants under inverter level voltage control. The response to three phase faults is system collapse with only one IBR in inverter level voltage control, but with some to all IBR plans with inverter level voltage control the system stabilises quickly. The paper proposes that IBRs with fast response inverter level voltage control can be used by transmission planners to contribute to system stability.

[4] Describes the performance of the generic grid forming IBR model that is provided in the PSCAD model. This technical update describes the four grid forming control methods available: droop based, virtual synchronous machine based, dispatchable virtual oscillators based, and PLL based. The update discusses the input parameters the user can set and provides example results of the model behaviour.

3 Model Overview

The model has two 100 MVA PV Models, which can be grid following or grid forming, and a very simple power system between them, shown in Figure 1.

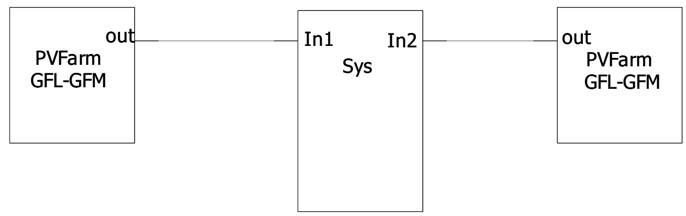

Figure 1: EPRI Main Page GFM Model Main Page

The PV model is shown in Figure 2. The power system modelled is very simple consisting of a new PI section line and loads and is shown in Figure 3.

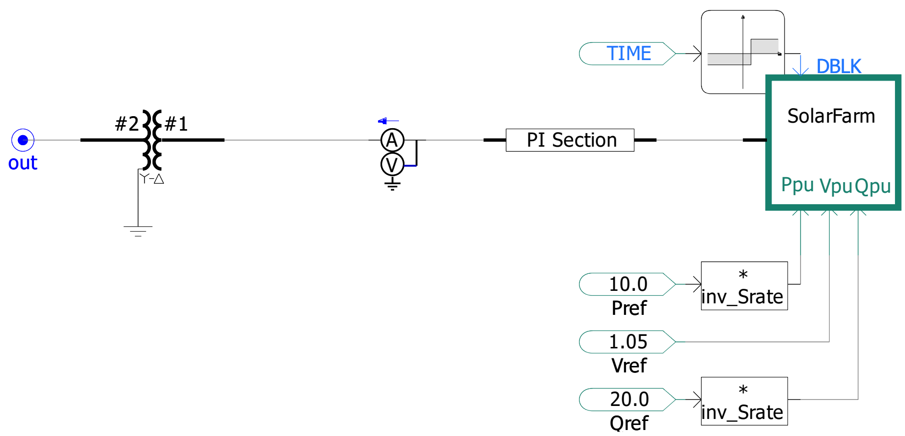

Figure 2: PV Model

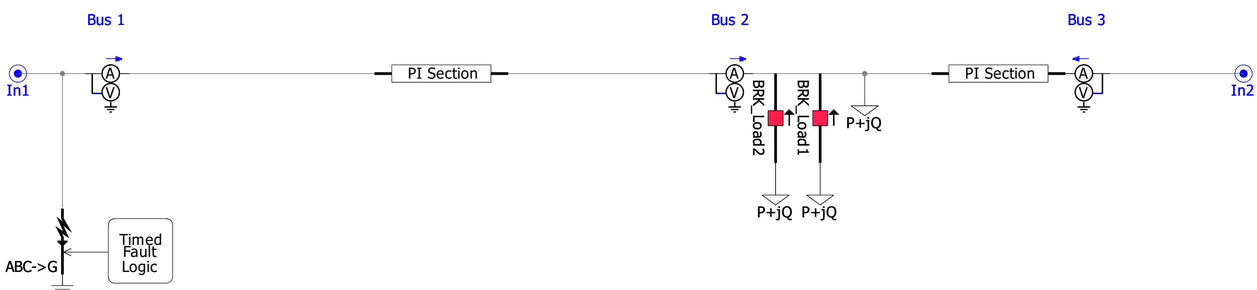

Figure 3: System Model

For grid following mode, the options for that can be used are:

a) W evaluation type => SRF-PLL, Qflag = 0
b) W evaluation type => SRF-PLL, Qflag = 1, Vflag = 1

In this mode, the model will try to control P and Q injection, with some amount of frequency support at the inverter level.

For grid forming mode, the options for that can be used are:

c) W evaluation type => SRF-PLL, Qflag = 1, Vflag = 0 for PLL based grid forming mode
d) W evaluation type => Droop for non-PLL based grid forming mode
e) W evaluation type => VSM for non-PLL based virtual synchronous machine mode
f) W evaluation type => dVOC for non-PLL based dispatchable virtual oscillator mode

W evaluation type is set within the parameters of the Solar farm module, shown in Figure 4.

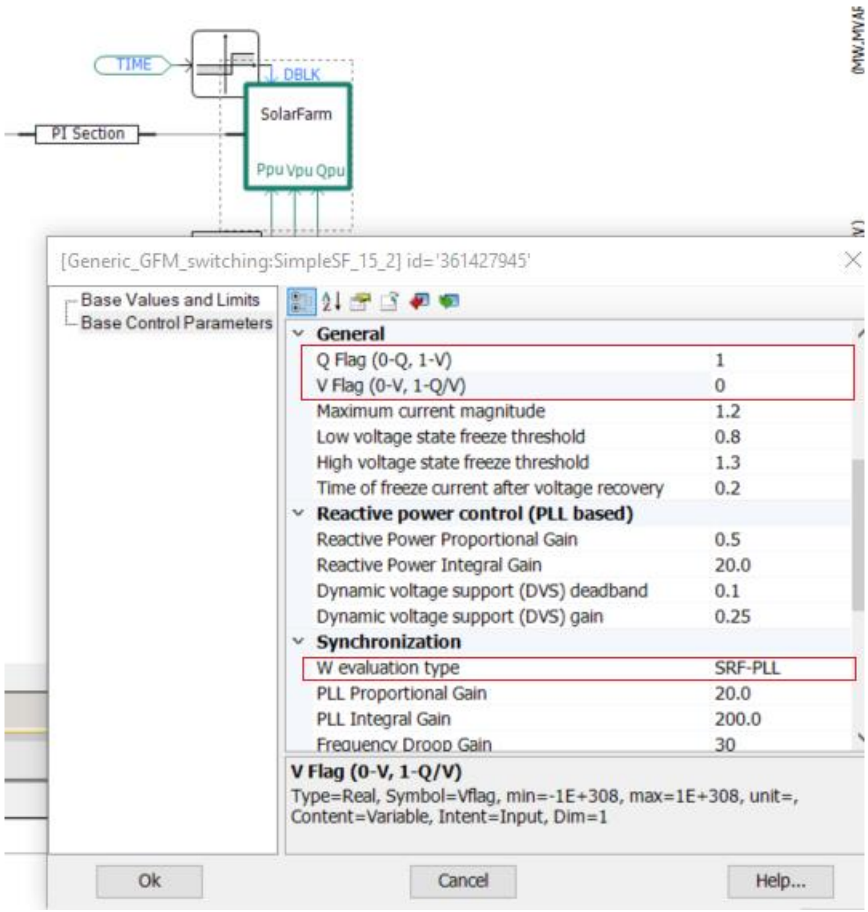

Figure 4: W evaluation type

For greater detail on the model parameters please refer to the EPRI technical update about this model [4].

4 References

[1] B. Johnson, T. Roberts, O. Ajala, A. D. Dominguez-Garcia, S. Dhople, D. Ramasubramanian, A. Tuohy, D. Divan, and B. Kroposki, "A Generic Primary-control Model for Grid-forming Inverters: Towards Interoperable Operation & Control," 2022 55th Hawaii International Conference on System Sciences (HICSS), Maui, HI, USA, 2022, pp. 1-10 https://scholarspace.manoa.hawaii.edu/handle/10125/79751

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[3] D. Ramasubramanian, "Differentiating between plant level and inverter level voltage control to bring about operation of 100% inverter based resource grids," Electric Power Systems Research, vol. 205, no. 107739, Apr 2022 https://www.sciencedirect.com/science/article/pii/S0378779621007203

[4] Generic Positive Sequence Domain Model of Grid Forming Inverter Based Resource, EPRI Palo Alto, CA: 2021, 3002021403 https://www.epri.com/research/products/000000003002021403