Standard Library Plant Controller Model Specification for a Grid-Forming Hybrid Control Inverter-based Resource (REPCGFM_C1)

Wei Du[1], Sai Gopal Vennelaganti[2], Deepak Ramasubramanian[3], Jinho Kim[1], Udoka Nwaneto[1], Quan Nguyen[1], Ali Mohammadpour[2], Sarah Walinga[2], Lilan Karunaratne[2], Mostafa Mahfouz[2], Mohammed Nassar[2], Sushrut Thakar[3], Chengwen Zhang[3], Sheik Mohammad Mohiuddin[1], James Weber[4], Mengxi Chen[5], Jayapalan Senthil[6], James Feltes[6], Pouyan Pourbeik[7], Fred Howell[8], Jeff Bloemink[8], Song Wang[9], Doug Tucker[10], Songzhe Zhu[11], Juan Sanchez[12]

1 Pacific Northwest National Laboratory
2 Tesla Energy
3 Electric Power Research Institute
4 PowerWorld
5 GE Vernova
6 Siemens
7 Power and Energy, Analysis, Consulting and Education (PEACE®) PLLC
8 PowerTech Labs
9 Portland General Electric
10 Western Electricity Coordinating Council
11 GridBright, a Qualus Company
12 GE Vernova (retried)

Suggested Citation

Du, Wei, Sai Vennelaganti, Deepak Ramasubramanian, *et al.*, 2024. Standard Library Plant Controller Model Specification for a Grid-Forming Hybrid Control Inverter-based Resource (REPCGFM_C1). *UNIFI-2025-1-29*

DISCLAIMER

Technical Report
January 2025

Acknowledgments

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Solar Energy Technologies Office Award Number 38637. We would like to acknowledge the Western Electricity Coordinating Council (WECC) Modeling and Validation Subcommittee (MVS) for supporting this model development work. In addition, we would also like to acknowledge Hussam Alatrash, Prashant Kansal, and Askhat Tullegen for their contribution to the model development during their time at Tesla Energy.

1 Introduction

This document describes a standard library plant controller model to interface with the grid-forming hybrid control inverter-based resource (IBR) model. The initial version of model specification was jointly developed by Pacific Northwest National Laboratory (PNNL), Tesla Energy, and EPRI, and it was revised multiple times later to incorporate suggestions from WECC MVS members. Tesla Energy provided main control blocks to support the development of this model specification.

This standard library model is developed to help the utility industry better understand the GFM technology. The model could be used to represent equipment for long-term planning studies where vendor-specific models are not available. As equipment mature and improve, standard library models will be updated to capture the new functionalities of GFMs. It is not intended that these models will always remain representative of all future GFM technologies.

2 Overall Control Structure

Figure 1 shows the overall control structure of the plant controller. It sends the active and reactive power references to the GFL branch and the voltage and frequency references to the GFM branch of the GFM hybrid IBR model.

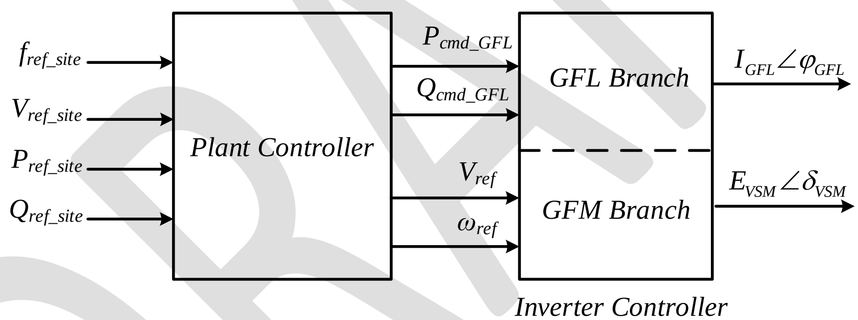


Figure 1 Overall control structure.

3 Voltage and Frequency Reference Generator for the GFM Branch

Figure 2 and Figure 3 show the voltage and frequency reference generator for the GFM branch. In Figure 2, f_{site} refers to the frequency at the plant bus, or a remote bus. f_{ref} will be connected to ω_{ref} in the REGFM_C1 inverter model.

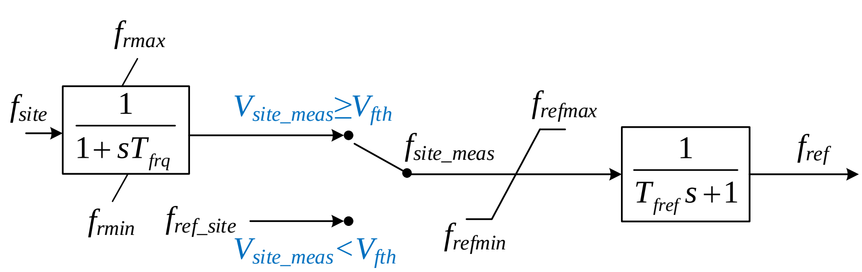


Figure 2 Frequency reference generator for the GFM branch.

In Figure 3, V_{site} refers to the voltage of the plant bus, or a remote bus. V refers to the inverter terminal voltage. $\frac{P_{target} - jQ_{target}}{1}$ represents the current in per unit value assuming the plant bus voltage is 1 pu. Because the plant bus voltage is not always 1 pu in a real system, ΔV_{err} is added in Figure 3 to simplify the initialization.

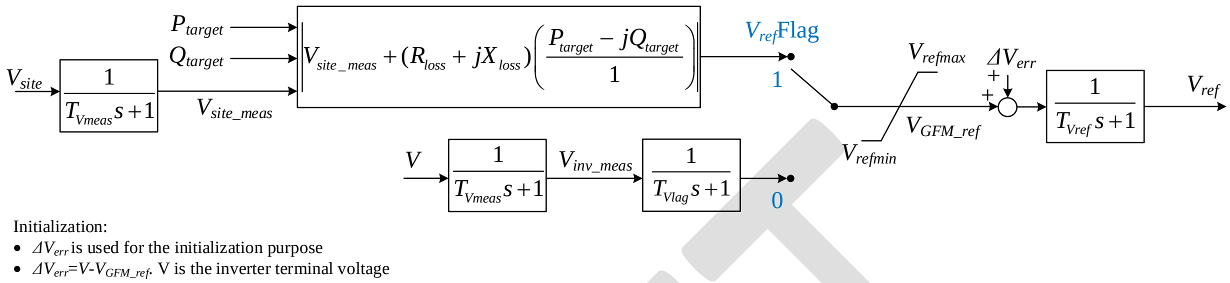


Figure 3 Voltage reference generator for the GFM branch.

4 Active and Reactive Power Blocks for the GFL Branch

Figure 4 and Figure 5 show the active and reactive power paths, and Figure 6 shows the voltage control added on the reactive power path.

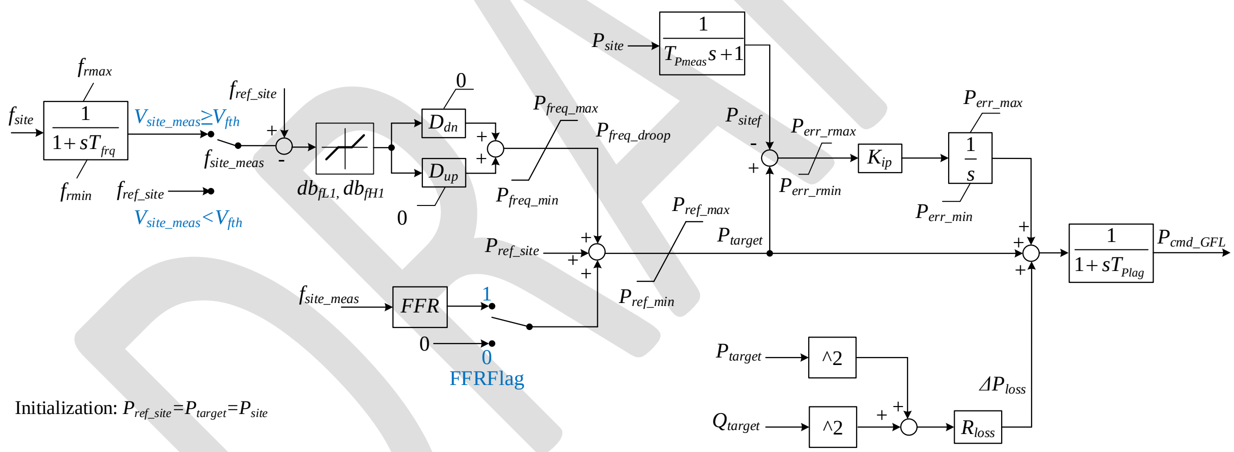


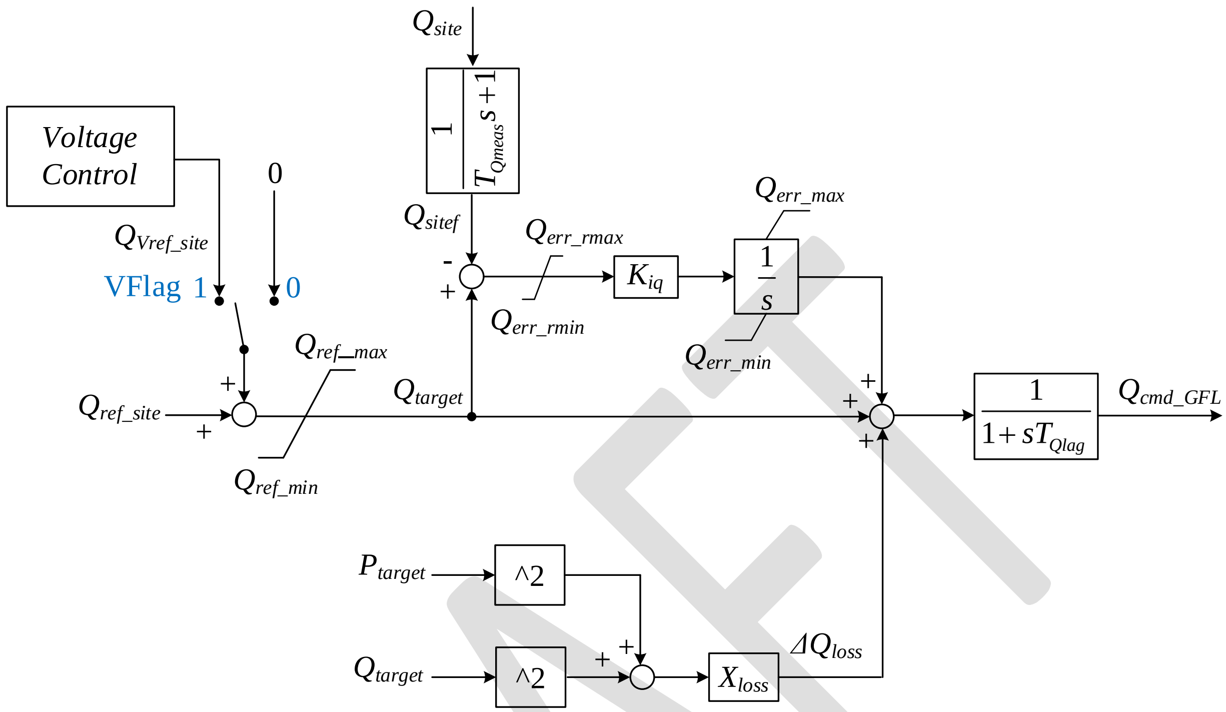
Figure 4 Active power path for the GFL branch.

In Figure 4, the calculation of ΔP_{loss} assumes the plant voltage is 1 pu. P_{site} refers to the plant output active power, which is the same with the branch power (P_{branch}).

Note that the fast frequency response (FFR) function is implemented in the plant controller as shown in Figure 4. The FFR function is described as follows:

FFR Function: Once f_{site_meas} drops below f_{FFR_low} or exceeds f_{FFR_high}, a pre-determined value P_{FFR_low} or P_{FFR_high} will be added on the power refence of the plant controller and lasts for a period of T_{FFR}, and after that P_{FFR_low} or P_{FFR_high} will gradually return to 0 with a ramp rate of D_{FFR}. Once P_{FFR_low} or P_{FFR_high} is added on the power reference, the FFR function will not detect f_{site_meas}, and it will only detect whether f_{site_meas} is below f_{FFR_low} or above f_{FFR_high} again after P_{FFR_low} or P_{FFR_high} returns to 0.

In Figure 5, the calculation of ΔQ_{loss} assumes the plant voltage is 1 pu. Q_{site} refers to the plant output reactive power, which is the same with the branch reactive power (Q_{branch}).



Initialization:

- When VFlag=0, $Q_{ref\_site}=Q_{target}=Q_{site}$
- When VFlag=1, $Q_{Vref\_site}=Q_{target}=Q_{site}$, and $Q_{ref\_site}=0$

Figure 5 Reactive power path for the GFL branch.

Figure 6 shows the voltage control block for the GFL branch. Note that the integral gain K_{i_vc} can also be set as 0 so that the plant control follows the *Q-V* droop.

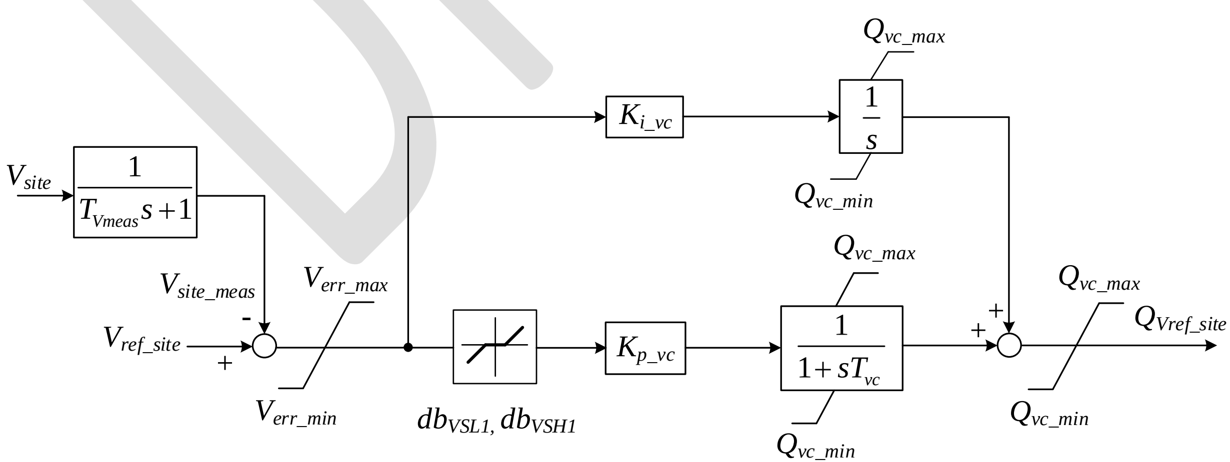


Figure 6 Voltage control block for the GFL branch.

Table 1 Parameters

Name	Description	Unit	Example Value
Bus Number	Bus number for voltage control. V_{site} in the specification refers to the voltage at the specified Bus Number.	NA	NA
FROM Bus	Monitored branch FROM bus number for calculating P_{branch} and Q_{branch}. P_{site} in the specification refers to P_{branch}.	NA	NA
TO Bus	Monitored branch TO bus number for calculating P_{branch} and Q_{branch}. Q_{site} in the specification refers to Q_{branch}.	NA	NA
Circuit ID	Branch circuit ID for calculating P_{branch} and Q_{branch}	NA	NA
VFlag	A flag to determine if the voltage control for the GFL branch is enabled (1) or disabled (0).	NA	1
V_{ref}Flag	A flag to select whether the plant voltage measurement (1) or the inverter voltage measurement (0) is used to generate the voltage reference of the GFM branch.	NA	1
FFRFlag	A flag to select whether the FFR function is enabled (1) or disabled (0).	NA	0
f_{refmax}	Upper limit of the frequency reference generator of the GFM branch.	pu	1.05
f_{refmin}	Lower limit of the frequency reference generator of the GFM branch.	pu	0.95
f_{rmax}	Upper rate limiter for the plant frequency measurement	pu/s	0.05
f_{rmin}	Lower rate limiter for the plant frequency measurement	pu/s	-0.05
V_{fth}	Voltage threshold for the plant frequency measurement	pu	0
T_{frq}	Time constant of the low-pass filter.	s	0.02
T_{fref}	Time constant of the low-pass filter.	s	0.3
R_{loss}	Resistance used to estimate the active power loss of the plant.	pu	Resistance of the transformers
X_{loss}	Reactance used to estimate the reactive power loss of the plant.	pu	Reactance of the transformers
V_{refmax}	Upper limit of the voltage reference generator of the GFM branch.	pu	1.1
V_{refmin}	Lower limit of the voltage reference generator of the GFM branch.	pu	0.85
T_{Vmeas}	Time constant of the low-pass filter for voltage measurement.	s	0.01
T_{Vref}	Time constant of the low-pass filter.	s	0.3
T_{Vlag}	Emulate the time delay of sending the inverter terminal voltage to the plant controller	s	0.2
db_{fL1}	Lower threshold of the frequency deadband	pu	-0.0005
db_{fH1}	Upper threshold of the frequency deadband	pu	0.0005
D_{dn}	Downside of frequency versus power droop gain	pu	20
D_{up}	Upside of frequency versus power droop gain	pu	20
P_{freq_max}	Upper limit of the frequency versus active power droop reference	pu	2
P_{freq_min}	Lower limit of the frequency versus active power droop reference	pu	-2
P_{ref_max}	Upper limit of the active power reference	pu	0.95
P_{ref_min}	Lower limit of the active power reference	pu	-0.95
T_{Pmeas}	Time constant of the low-pass filter for P measurement.	s	0.01
K_{ip}	Controller gain for the active power path	pu	0.1
P_{err_max}	Upper limit of the integrator for the active power path	pu	0.1
P_{err_min}	Lower limit of the integrator for the active power path	pu	-0.1
P_{err_rmax}	Upper limit of the input for the active power path	pu	0.1
P_{err_rmin}	Lower limit of the input for the active power path	pu	-0.1

T_{Plag}	Emulate the time delay of sending the P command from the plant controller to the inverter controller	s	0.04
Q_{ref_max}	Upper limit of the reactive power reference	pu	0.3122
Q_{ref_min}	Lower limit of the reactive power reference	pu	-0.3122
T_{Qmeas}	Time constant of the low-pass filter for Q measurement.	s	0.01
K_{iq}	Controller gain for the reactive power path	pu	0.1
Q_{err_max}	Upper limit of the integrator for the reactive power path	pu	0.1
Q_{err_min}	Lower limit of the integrator for the reactive power path	pu	-0.1
Q_{err_rmax}	Upper limit of the input for the reactive power path	pu	0.1
Q_{err_rmin}	Lower limit of the input for the reactive power path	pu	-0.1
T_{Qlag}	Emulate the time delay of sending the Q command from the plant controller to the inverter controller	s	0.04
V_{err_max}	Upper limit of the voltage reference	pu	0.05
V_{err_min}	Lower limit of the voltage reference	pu	-0.05
db_{VSL1}	Lower threshold of the plant voltage controller deadband	pu	0
db_{VSH1}	Upper threshold of the plant voltage controller deadband	pu	0
K_{p_vc}	Controller gain of the plant voltage controller	pu	2
Q_{vc_max}	Upper limit of the reactive power of the plant controller	pu	0.3122
Q_{vc_min}	Lower limit of the reactive power of the plant controller	pu	-0.3122
T_{vc}	Time constant of the low-pass filter	s	0
K_{i_vc}	Controller gain of the plant voltage control	pu	6
f_{FFR_low}	Lower threshold of the FFR function	pu	0.99
f_{FFR_high}	Upper threshold of the FFR function	pu	1.01
P_{FFR_low}	Power command of FFR when frequency is lower than f_{FFR_low}	pu	0.3
P_{FFR_high}	Power command of FFR when frequency is higher than f_{FFR_high}	pu	-0.3
D_{FFR}	Ramp rate for the FFR to quit operation	pu/s	0.01 pu/s
T_{FFR}	Time duration of the FFR	s	300

References

[1] Sai Gopal Vennelaganti, Mostafa Mahfouz. Tesla Plant Controller Block Diagrams (Unpublished).

For more information, visit:

https://unificonsortium.org/

www.energy.gov/eere/solar/unifi-consortium