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

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DISCLAIMER

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Acknowledgments

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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 algorithms 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 2 shows the one-line diagram of a typical IBR plant and clarify the setting of the plant controller model.

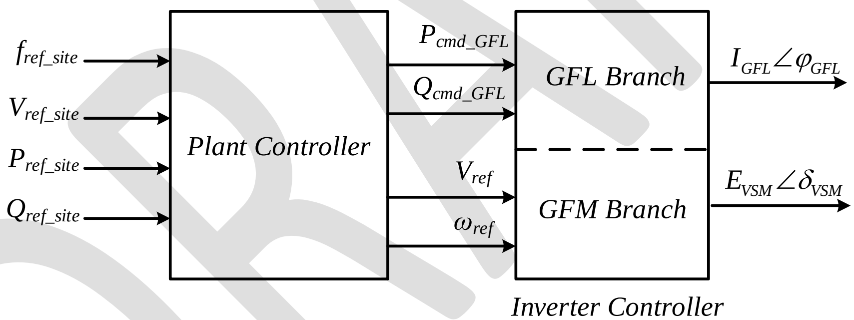
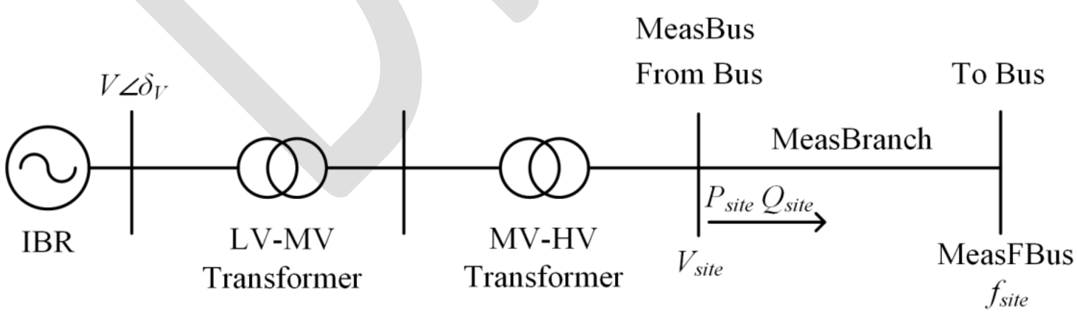


Figure 1 Overall control structure.



- MeasBus is used for V_{site}, P_{site}, Q_{site} measurement. By default it is the same with From Bus
- MeasFBus is used for frequency measurement
- If a branch is specified, but a MeasBus is not specified, then From Bus will be used
- If a branch is not specified, then P_{site} and Q_{site} will be the output of the generator, V_{site}=V, and R_{loss}=X_{loss}=0
- If MeasFBus is not specified, then frequency will be measured at the same location as the P_{site}, Q_{site}, and V_{site} measurements

Figure 2 One-line diagram of a typical IBR plant and model setting.

3 Voltage and Frequency Reference Generator for the GFM Branch

Figure 3 and Figure 4 show the voltage and frequency reference generator for the GFM branch. In Figure 3, 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. $V_{MeasFBus}$ refers to the voltage at which the frequency f_{site} is measured

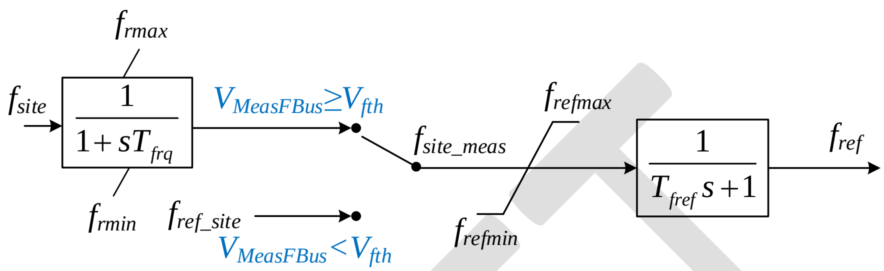


Figure 3 Frequency reference generator for the GFM branch.

In Figure 4, 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. V_{est} is the estimated inverter terminal voltage. Because the plant bus voltage is not always 1 pu in a real system, ΔV_{err} is added in Figure 4 to simplify the initialization.

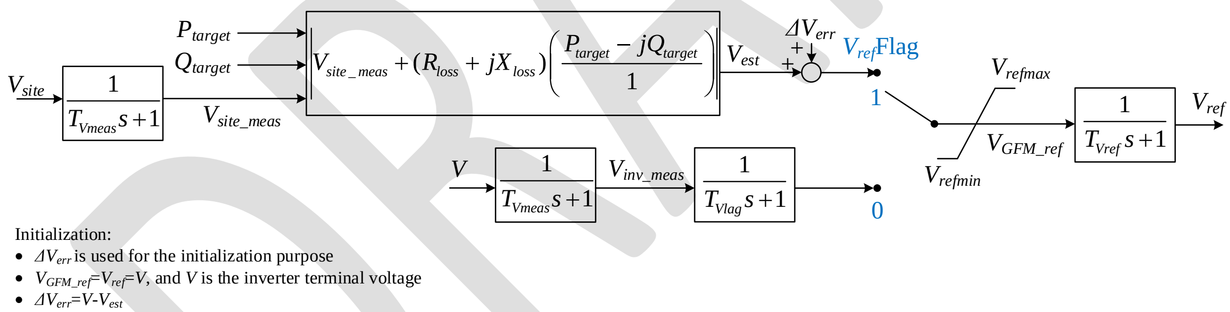


Figure 4 Voltage reference generator for the GFM branch.

4 Active and Reactive Power Blocks for the GFL Branch

Figure 5 and Figure 6 show the active and reactive power paths, and Figure 7 shows the voltage control added on the reactive power path.

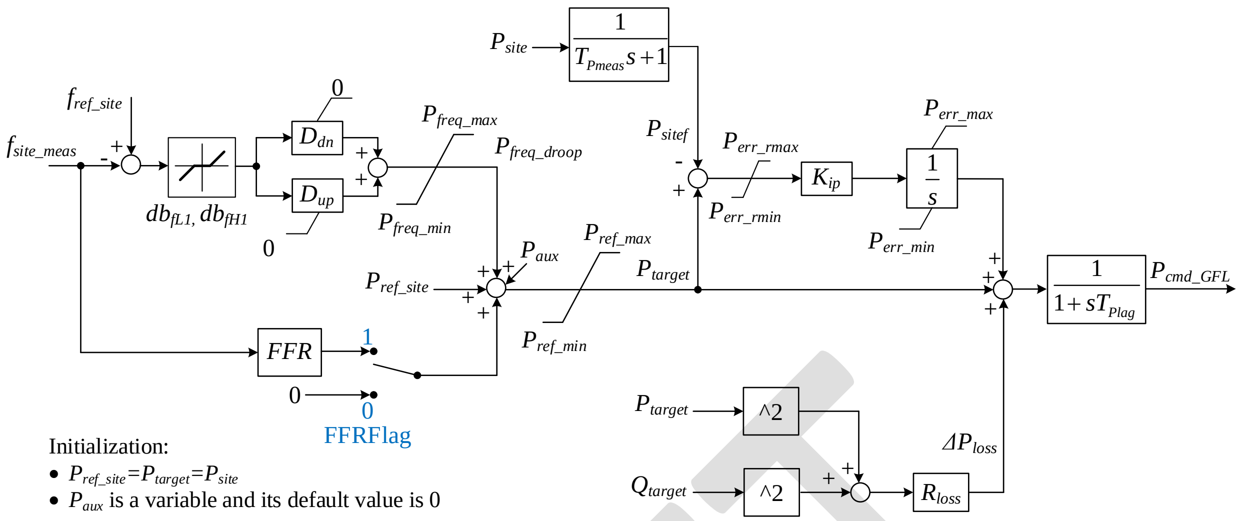


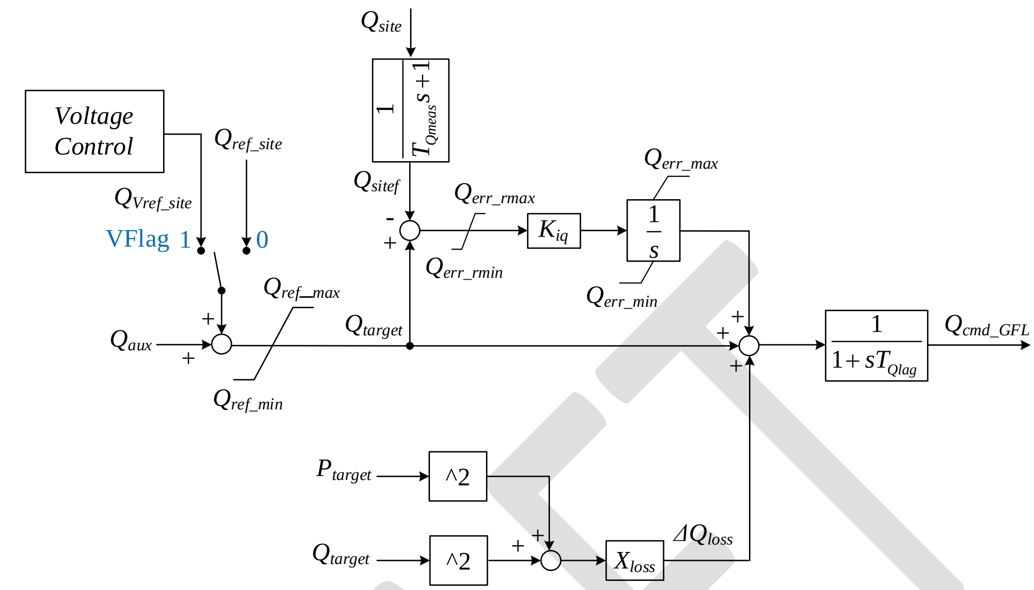
Figure 5 Active power path for the GFL branch.

In Figure 5, the calculation of ΔP_{loss} assumes the plant voltage is 1 pu. P_{site} refers to the plant output active power.

Note that the fast frequency response (FFR) function is implemented in the plant controller as shown in Figure 5. 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 6, the calculation of ΔQ_{loss} assumes the plant voltage is 1 pu. Q_{site} refers to the plant output reactive power.

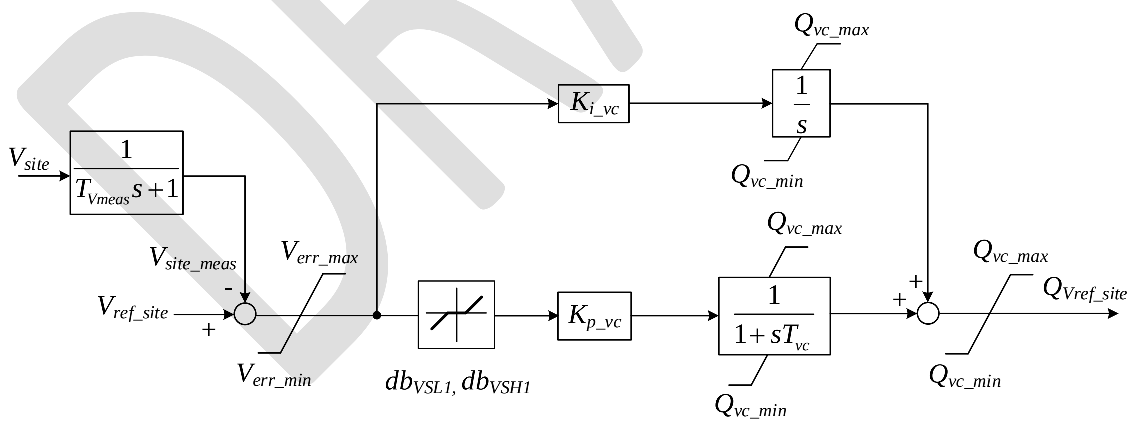


Initialization:

- When VFlag=0, Q_{ref_site}=Q_{target}=Q_{site}
- When VFlag=1, Q_{Vref_site}=Q_{target}=Q_{site}
- Q_{aux} is a variable and its default value is 0

Figure 6 Reactive power path for the GFL branch.

Figure 7 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.



Initialization:

- If K_{i_vc} is not 0, output of the integrator in the K_{i_vc} branch equals to Q_{Vref_site}=Q_{site}, and V_{ref_site}=V_{site}
- If K_{i_Vc} is 0, output of the lag block in the K_{P_VC} branch equals to Q_{Vref_site}=Q_{site}

  If Q_{site} = 0, V_{ref_site} = V_{site}

  If Q_{site} > 0, V_{ref_site} = V_{site} +db_{VSH1} + Q_{site}/K_{p_vc}

  If Q_{site} < 0, V_{ref_site} = V_{site} +db_{VSL1} + Q_{site}/K_{p_vc}

Figure 7 Voltage control block for the GFL branch.

Table 1 Parameters

Name	Description	Unit	Example Value
MeasBus	Used for V_{site}, P_{site}, and Q_{site} measurements, and by default it is the same with the From Bus	NA	NA
From Bus	Monitored branch From bus	NA	NA
To Bus	Monitored branch To bus	NA	NA
MeasFBus	A bus for frequency measurement. If MeasFBus is not specified, then From Bus will be used	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
PltBase	The MVA base used for the plant controller	MVA	NA
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	Total resistance of the LV-MV and MV-HV transformers
X_{loss}	Reactance used to estimate the reactive power loss of the plant.	pu	Total reactance of the LV-MV and MV-HV 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

Special initialization for R_{loss}: if a user sets $R_{loss} \leq 0$, then at initialization R_{loss} is calculated to ensure the output of the integrator in the K_{ip} branch is 0.
Special initialization for X_{loss}: if a user sets $X_{loss} \leq 0$, then at initialization X_{loss} is calculated to ensure the output of the integrator in the K_{iq} branch is 0.

Pseudo code for R_{loss} and X_{loss} initialization if not specified properly

```
If FlowMeasBranch not specified Then
  // Output of the generator will now be Psite and Qsite, thus modelling losses does not make sense
  RLoss = 0
  XLoss = 0
Else
  Ssite2 = sqr(Psite) + sqr(Qsite)
  If Ssite2 > 1E-6 Then // avoid divide by zero when initial site has near zero flow
    If RLoss <= 0 Then RLoss = (Pgen - Psite)/Ssite2
    If XLoss <= 0 Then XLoss = (Qgen - Qsite)/Ssite2
  Else
    // in unlikely event it operating and initialized at P + jQ = 0 + j0
    // and Rloss and Xloss are negative, then just set Rloss and Xloss to 0
    If RLoss <= 0 Then RLoss = 0
    If XLoss <= 0 Then XLoss = 0
  EndIf
EndIf
```

References

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

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