TECHNICAL BRIEF

Power Oscillation Damping through Grid Forming Inverters

1 INTRODUCTION

The increasing integration of inverter-based renewable resources (IBRs) poses new challenges to the secure and reliable grid operation. One of these challenges is oscillations of different frequency ranges. Due to the retirement of conventional synchronous generators (SGs) and the corresponding Power System Stabilizers (PSSs), the bulk power system is losing its capability to stabilize these oscillations. The location of the remaining SGs may render them insufficient to provide damping control. Also, the intermittent feature of renewable energy can result in significant grid operating condition variations and associated varying oscillation modes.

Inverter control technologies have also advanced in recent years, one of which is grid-forming (GFM) inverter control. Although there is no universal definition of GFM, it refers to a suite of control strategies that maintain a constant or nearly constant internal voltage phasor in transient and/or sub-transient time frame to allow fast response to grid disturbance, black start, islanding operation, etc. [1] This technical brief investigates the potential oscillation damping control of GFM inverters with different control designs. A case study is conducted on the modified two-area four-machine system model.

2 GENERIC GRID-FORMING POSITIVE SEQUENCE MODEL

In this document, a GFM IBR is defined as a source that can maintain both voltage and frequency within standard limits while also serving load and riding through faults in a robust manner [2]. A generic GFM positive sequence model has been developed in multiple simulation platforms, including Siemens PTI's PSS®E, GE's PSLF, and DIgSILENT's PowerFactory. The block diagram of the developed generic GFM model is shown in Figure 1 [2]. The developed model can represent three different types of GFM control methods that have been proposed in research literature: droop, virtual synchronous generator (VSG), and dispatchable virtual oscillator (dVOC).

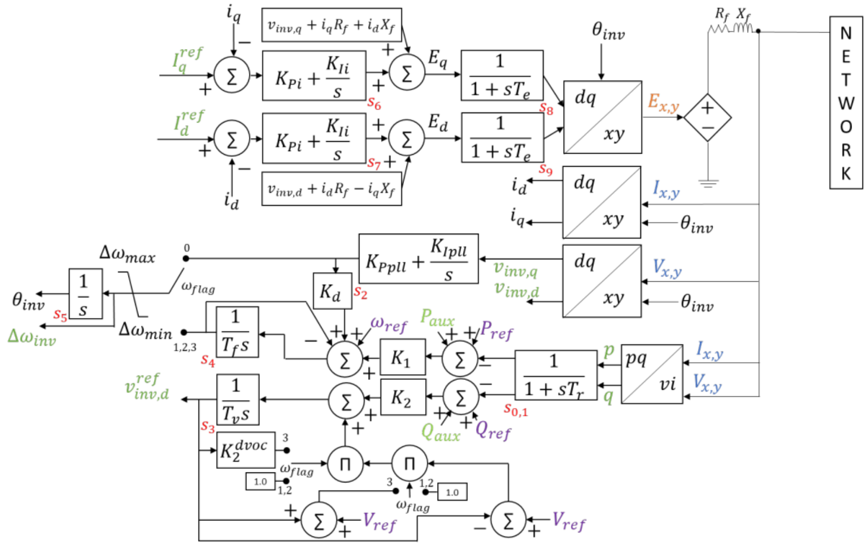


Figure 1. Generic grid forming (GFM) renewable generator/converter model.

3 CASE STUDY

This chapter introduces a case study on the modified two-area four-machine system model with simulations in Siemens PTI's PSS®E. The case study evaluates the oscillation damping control performance of GFM inverters with three different control designs. Also, the case study performs sensitivity analysis with respect to two selected parameters: frequency droop and voltage droop.

3.1 Study System

The study system is the modified two-area four machine system, as shown in Figure 2. The generator at Bus 1 is replaced by an inverter-based resource modeled as a GFM inverter. The dominant oscillation mode is the one between the left area and the right area. The oscillation frequency of the original system without the GFM inverter is 0. 601 Hz, and the damping ratio is -0.624%. The disturbance is a 80 MW load pickup at Bus 8.

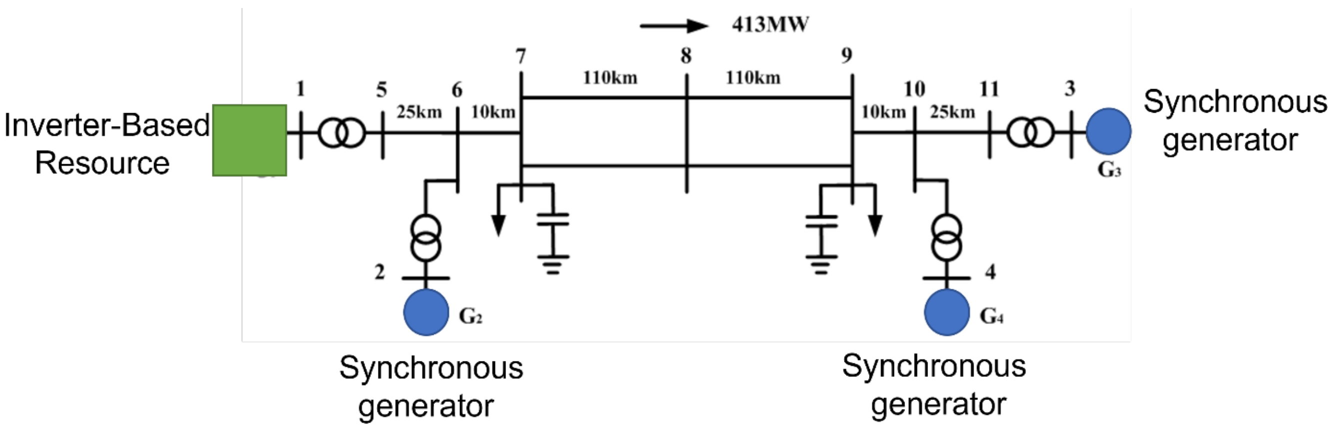
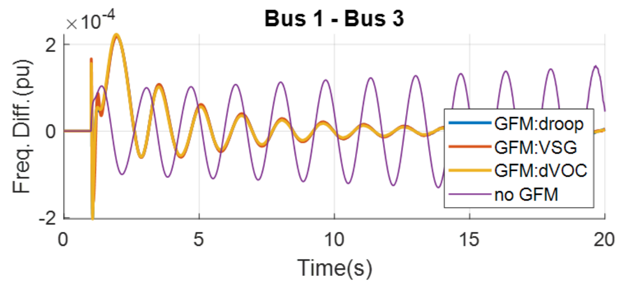


Figure 2. *Study system: Modified two-area four-machine system.*

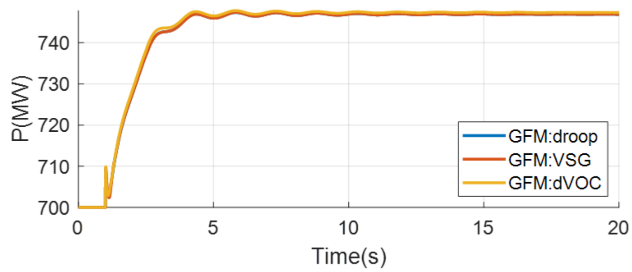
3.2 Simulation Results

Four scenarios are simulated in this case study. The first scenario compares the damping control performance of three GFM control designs with the original case with no GFM. In the other three scenarios, sensitivity study of frequency droop and voltage droop is performed for each GFM control design.

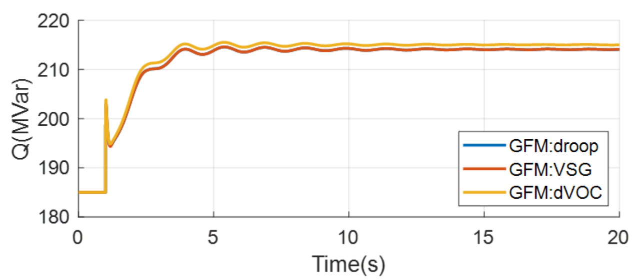
The bus frequency difference between Bus 1 and Bus 3, active power of the GFM inverter, and reactive power of the GFM inverter in the first scenario are shown in Figure 3. The target oscillation mode is observed through the bus frequency difference. It is shown that with the GFM inverter the oscillation can be damped compared with the no GFM inverter case. Also, it is noted that the three GFM control designs have similar damping control performance. This observation can be confirmed by the Prony analysis results in Table 1. After replacing the synchronous generator at Bus 1 with a GFM inverter, the oscillation frequency increased from 0.601 Hz to 0.663 Hz for the three GFM control designs, and the damping ratio increased to 5.555%, 5.480%, and 5.943% for droop, VSG, and dVOC, respectively.



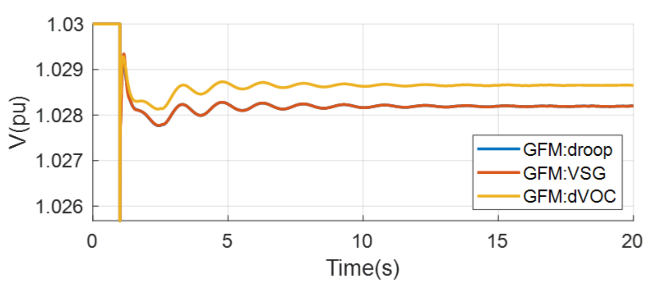
(a) Frequency difference between Bus 1 and Bus 3



(b) GFM active power



(c) GFM reactive power



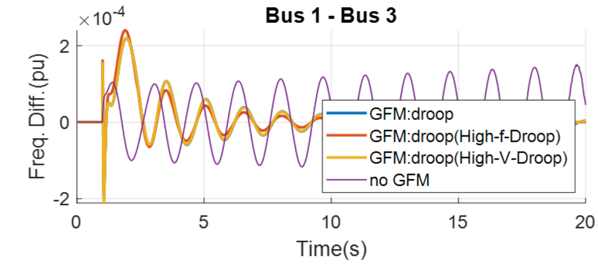
(d) GFM bus voltage

Figure 3. *Damping control performance: Three GFM control designs.*

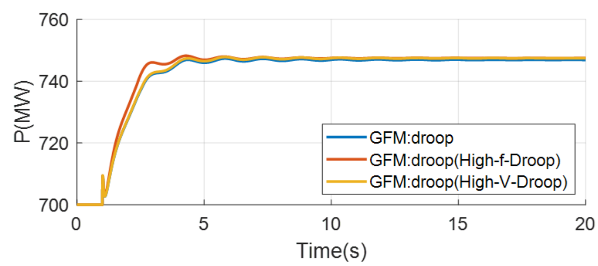
Table 1. *Prony Analysis results.*

	OSCILLATION FREQUENCY (HZ)	DAMPING RATIO (%)
No GFM	0.601	-0.624
GFM: Droop	0.663	5.555
GFM: VSG	0.664	5.480
GFM: dVOC	0.664	5.943
GFM: Droop – High f droop	0.662	7.151
GFM: Droop – High V droop	0.664	5.721
GFM: VSG – High f droop	0.661	7.084
GFM: VSG – High V droop	0.664	5.542
GFM: dVOC – High f droop	0.662	7.649
GFM: dVOC – High V droop	0.664	5.915

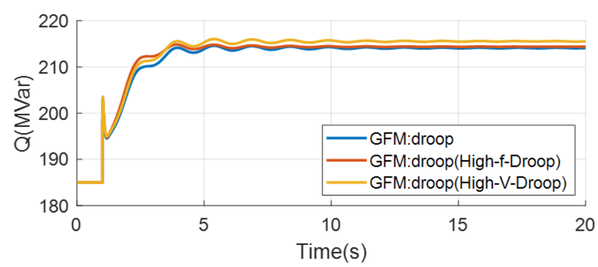
In scenario 2, the frequency droop is changed from 3.3% to 2.5%, and the voltage droop is changed from 5% to 2.5% when using droop control design for the GFM inverter. The simulation results are given in Figure 4. When the GFM inverter has higher frequency droop gain (lower frequency droop %), the damping control performance is improved. However, higher voltage droop gain does not noticeably improve the damping control performance. According to the Prony analysis results in Table 1, the higher frequency droop gain can increase the damping ratio from 5.555% to 7.151%. The damping ratio improvement for higher voltage droop gain is negligible.



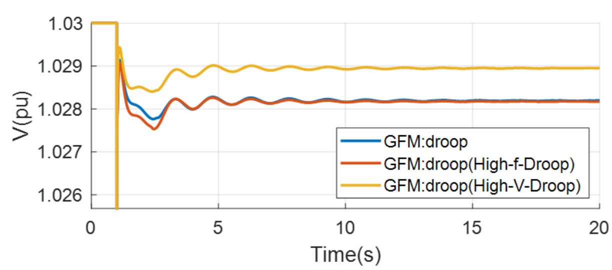
(a) Frequency difference between Bus 1 and Bus 3



(b) GFM active power



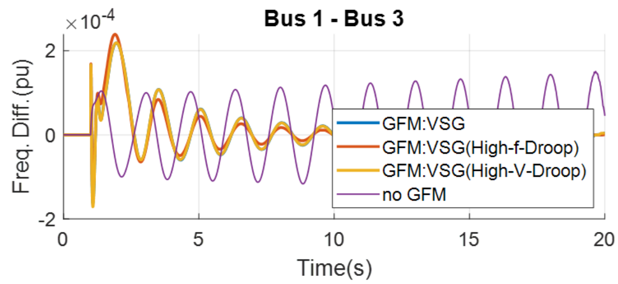
(c) GFM reactive power



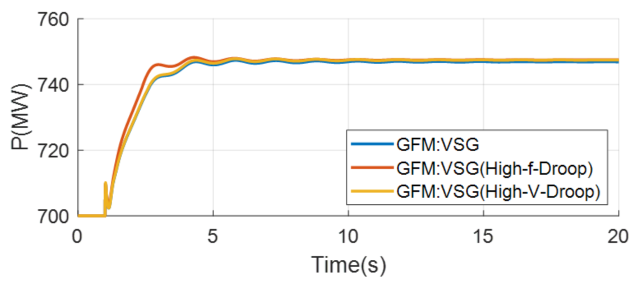
(d) GFM bus voltage

Figure 4. *Damping control performance: GFM droop control design with high frequency or voltage droop.*

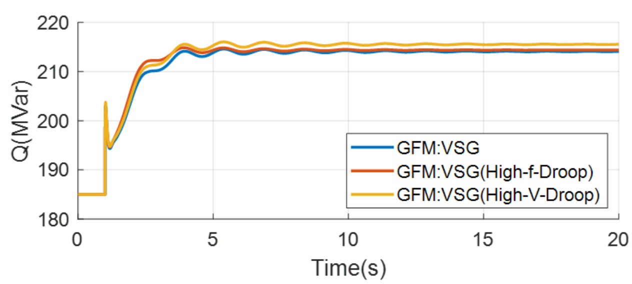
In scenario 3, the frequency droop is changed from 3.3% to 2.5%, and the voltage droop is changed from 5% to 2.5% when using VSG control design for the GFM inverter. Similar to the results in scenario 2, higher frequency droop gain can achieve better damping control performance, while higher voltage droop gain has negligible impact on the damping ratio of the target oscillation mode. The simulation results of scenario 3 are shown in Figure 5, and the associated Prony analysis results are given in Table 1. The same conclusion can be drawn for scenario 4 in which dVOC is used as the GFM control design. The simulation results of scenario 4 are shown in Figure 6, and the associated Prony analysis results are given in Table 1.



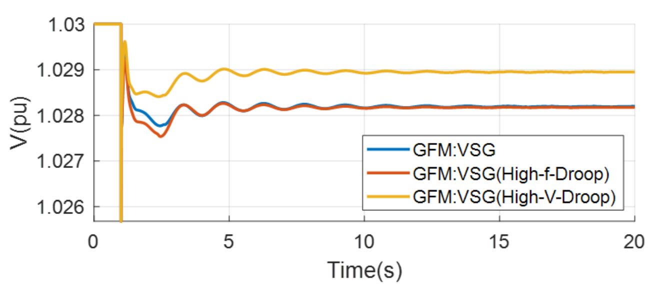
(a) Frequency difference between Bus 1 and Bus 3



(b) GFM active power

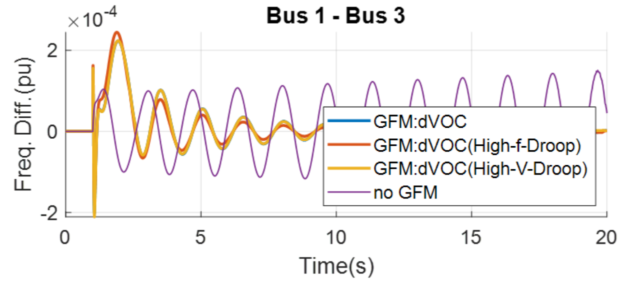


(c) GFM reactive power

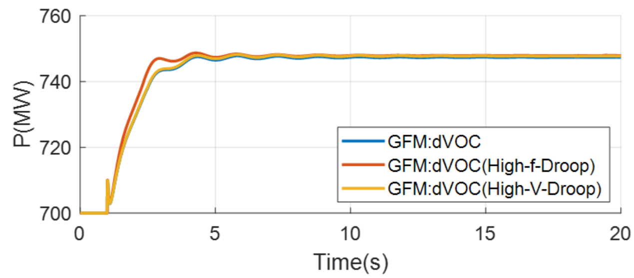


(d) GFM bus voltage

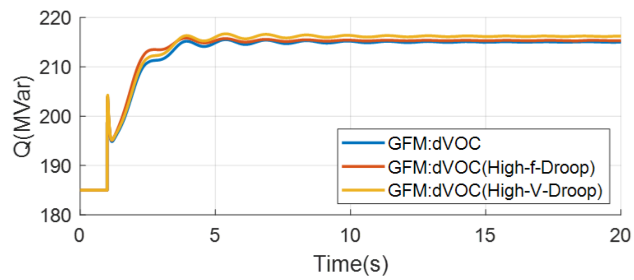
Figure 5. *Damping control performance: GFM VSG control design with high frequency or voltage droop.*



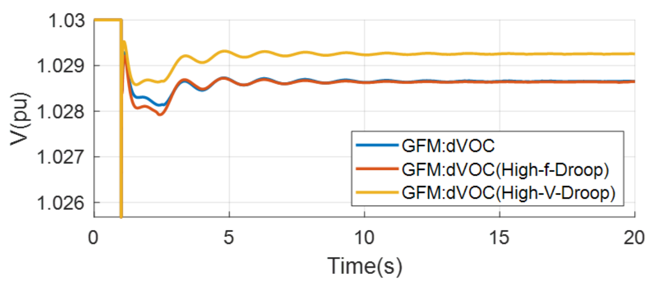
(a) Frequency difference between Bus 1 and Bus 3



(b) GFM active power



(c) GFM reactive power



(d) GFM bus voltage

Figure 6. *Damping control performance: GFM dVOC control design with high frequency or voltage droop.*

4 SUMMARY

This technical brief investigates the potential damping control contribution from GFM inverters in the two-area four-machine system by simulations. Three different GFM control designs (droop, VSG, and dVOC) can improve the damping ratio of the target oscillation mode, and their control performance are close to each other. Also, a sensitivity study with respect to frequency droop and voltage droop is performed. Larger frequency droop gain can improve the damping control performance for all three GFM control designs, while larger voltage droop gain has negligible impact on the damping control performance for the three GFM control designs.

5 REFERENCES

[1] NERC. Grid Forming Technology - Bulk Power System Reliability Consideration, available [online]: https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_Grid_Forming_Technology.pdf.

[2] EPRI. *Generic Positive Sequence Domain Model of Grid Forming Inverter Based Resource*. PID 3002021403. https://www.epri.com/research/products/000000003002021403.

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