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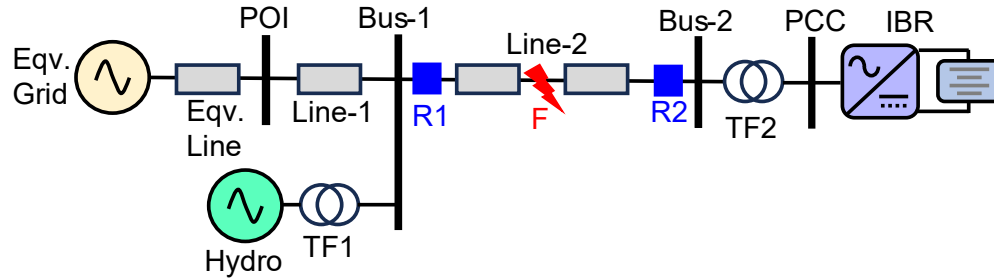
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# How Inverter-based Resources (IBRs) Affect Protection Relay Elements

From the Perspective of GFM IBR  
compliance of IEEE Std. 2800-2022

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## Subclause 7.2.2.3.4 of IEEE Standard 2800<sup>[1]</sup>

### Under balanced faults

- IBR shall operate in a low-voltage ride-through mode and inject reactive current dependent on IBR terminal (PCC) voltage
- Unless specified by the system owner, default in reactive current priority mode with flexibility of active current priority mode

### Under unbalanced faults

- IBR shall inject negative sequence current with :
  - magnitude dependent on PCC negative sequence voltage
  - leads the PCC negative sequence voltage by 90°-100°

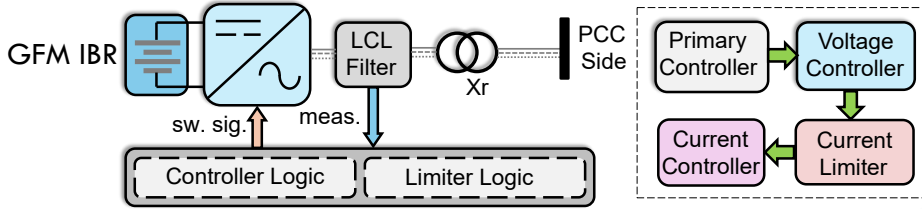
### Fault Response Time

- Meet the specifications in table

Parameters	Requirements
Step Response Time	$\leq 2.5$ cycles
Settling Time	<span style="border: 2px solid red; padding: 2px;"><math>\leq 4</math> cycles</span>
Settling Band	-2.5% to 10% of

[1] IEEE Standards Association. "IEEE standard for interconnection and interoperability of inverter-based resources (IBRs) interconnecting with associated transmission electric power systems." *IEEE Std* (2022): 2800-2022.

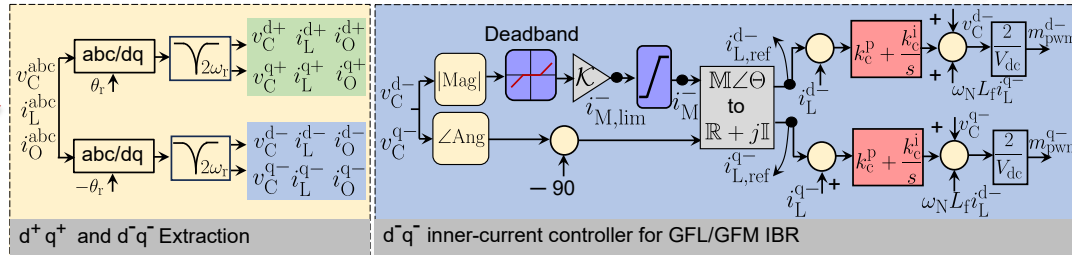
# Implementation of Neg. Sequence Current Control



Controller Type	For GFM IBR
Primary Controller	Pf-QV Droop Law
Voltage Controller	PI regulator-based controller in d,q domain
Current Limiter	Dynamic saturation-based with d-q priority selection
	Limited magnitude-based with d-q priority selection
Current Controller	K-factor and PI regulator-based controller in d <sub>2</sub> q <sub>2</sub> domain

$d_1$ : positive sequence d-axis  
 $d_2$ : negative sequence d-axis  
 $q_1$ : positive sequence q-axis  
 $q_2$ : negative sequence q-axis

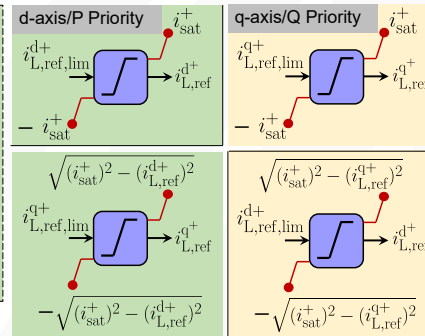
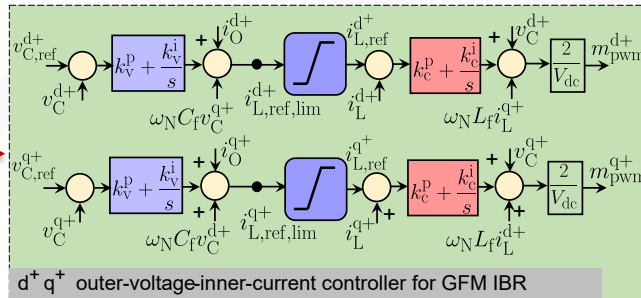
Extract positive and negative sequence components



Negative sequence current control

*It requires exhaustive tuning to tune the positive and negative sequence current controller to achieve 4-cycle setting time of the output current.*

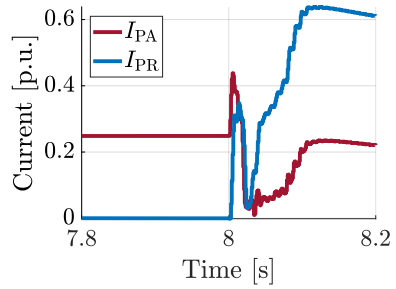
Positive sequence outer-voltage-inner-current control



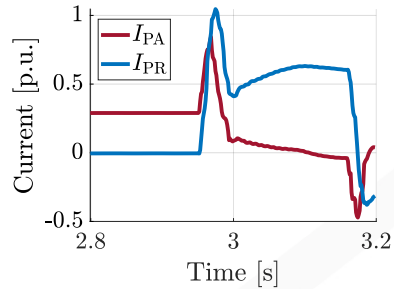
saturation-based with d-q priority selection

# IEEE 2800 Compliant GFM-IBR Fault Response

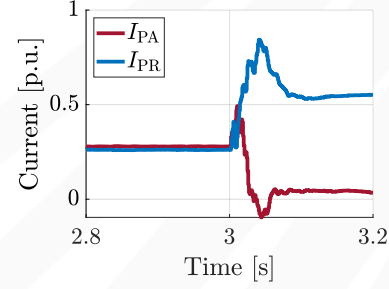
GFM OEM 1



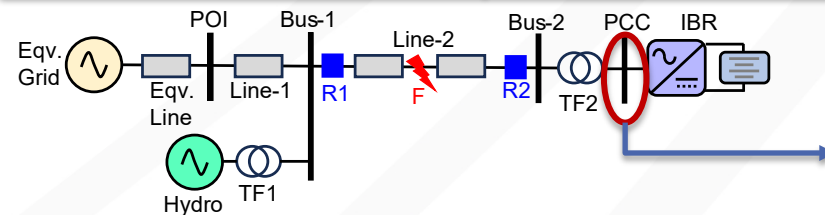
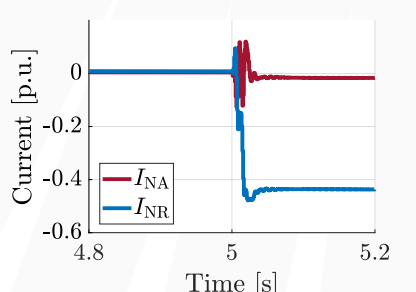
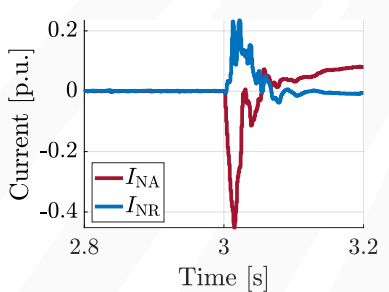
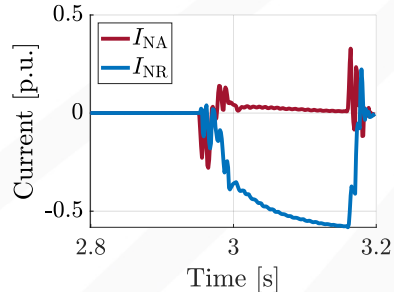
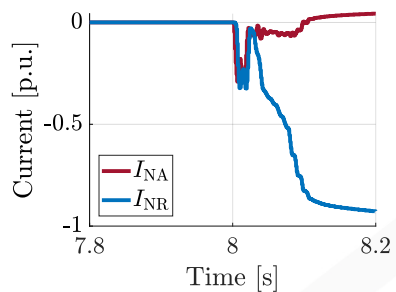
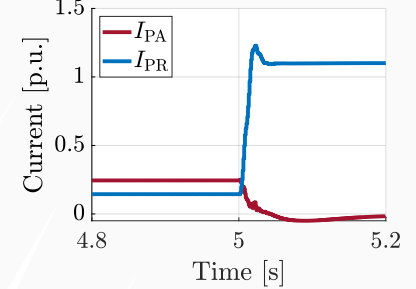
GFM OEM 2



GFM OEM 3



Generic GFM



Measurements based on PCC → Bolted BC fault @ 50% of Line-2

Computed quantity

$$I_{PA} := |\bar{I}_1| \cos(\angle \bar{V}_1 - \angle \bar{I}_1) \dots I_{NA} := |\bar{I}_2| \cos(\angle \bar{V}_2 - \angle \bar{I}_2)$$

$$I_{PR} := |\bar{I}_1| \sin(\angle \bar{V}_1 - \angle \bar{I}_1) \dots I_{NR} := |\bar{I}_2| \sin(\angle \bar{V}_2 - \angle \bar{I}_2)$$

# Impact on Protection Relay Elements

dq-domain controlled GFM [relay R2]

IEEE 2800 Compliant GFM [relay R2]

Synchronous Generator [relay R1]

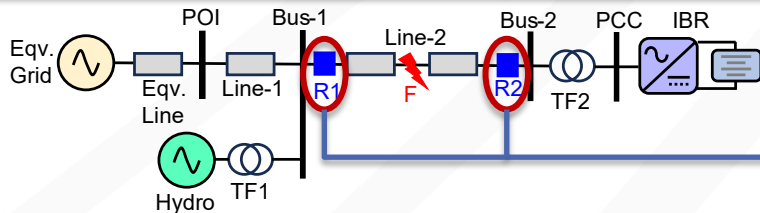
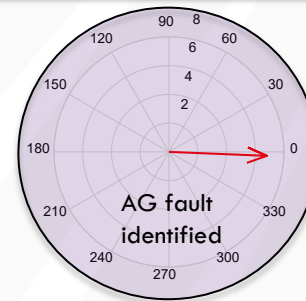
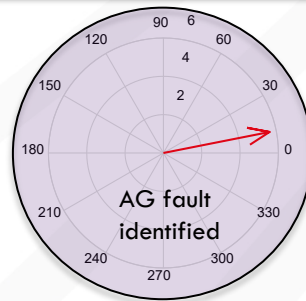
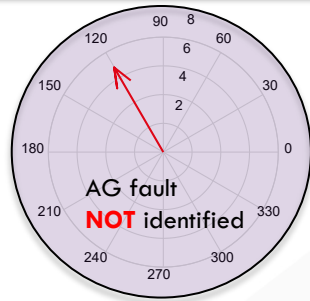
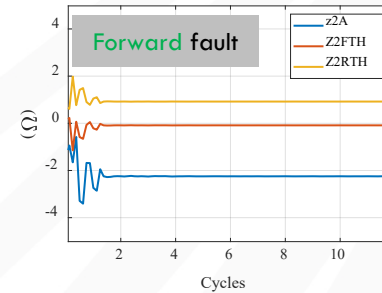
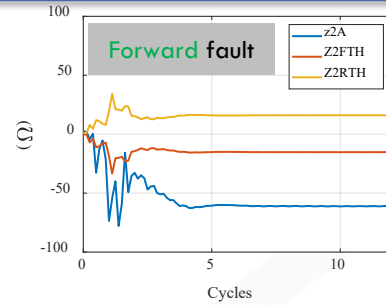
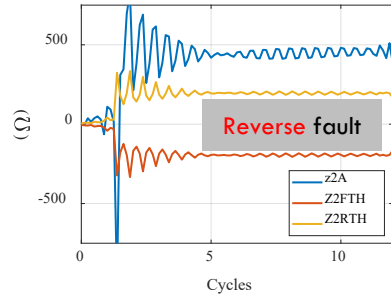
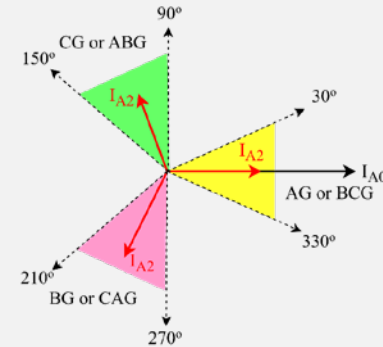
**Negative-sequence-based directional element**

$$z2A = \frac{\text{Re}[V_2 \cdot (I_2 \cdot 1\angle Z_{1L})^*]}{|I_2|^2}$$

- z2 compared with threshold
  - dynamic forward (Z2FTH)
  - dynamic reverse (Z2RTH)
- forward fault if  $z2 < Z2FTH$
- reverse fault if  $z2 > Z2RTH$

**Fault Identification Logic**

- differentiate LG and LLG faults
- Checking  $\angle I_{A0} - \angle I_{A2}$



Response based on R2 (GFM-IBR), R1 (SynGen) → Bolted AG & BC fault @ 50% of Line-2

# Impact on Protection Relay Elements

- Usually following relay elements are enabled for system with IBRs
  - ✓ 87LP: Phase current differential protection
  - ~~✓ 87LQ: Negative sequence current differential protection~~
  - ✓ 87LG: Zero-sequence current differential protection
  - ✓ M21P: Phase distance protection using positive-sequence memory polarized mho element
  - ✓ M21G: Ground distance protection using positive-sequence memory polarized mho element
  - ~~✓ X21P: Phase distance protection using negative-sequence polarized quad element~~
  - ~~✓ X21G: Ground distance protection using zero/negative-sequence polarized quad element~~
  - ~~✓ 32Q: Negative-sequence directional element for unbalanced phase faults~~
  - ~~✓ 32QG: Negative-sequence directional element for ground faults~~
  - ✓ 32V: Zero-sequence directional element (active for ground faults only)
- Need to improve FID logic (based on angle difference between  $I_0$  and  $I_2$ ) and might use voltage-based FID logic
- Directional element might fail to pick up due to lack of supervising  $I_2$

# Summary

- GFM IBRs naturally generate negative sequence current, but not all GFM IBRs are IEEE 2800 compliant
- It is critical to have GFM IBRs generate the  $I_2$  that is IEEE 2800 compliant
  - Control parameter tuning is critical
- Future work will provide recommendation for IEEE 2800-2022 for relaxing the settling time requirement for IBR





# Thank you

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