Grid Forming Inverter-Based Resources

Applications and Requirement discussion- BESS, Wind and Solar

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Sebastian Achilles

sebastian.achilles@ge.com

GE Energy Consulting

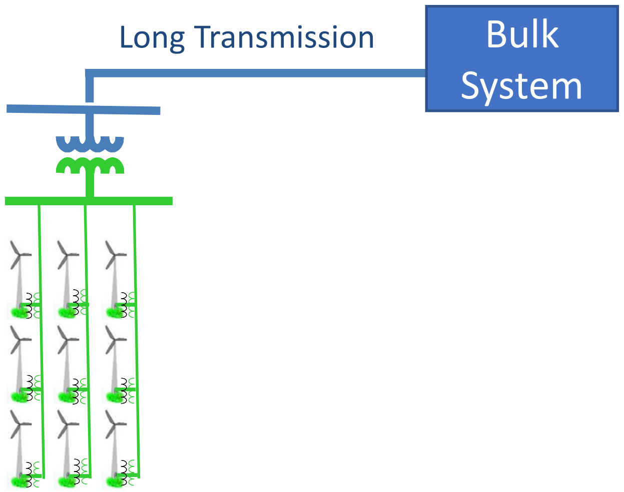
Includes work @ GE Energy Consulting from:
Dustin Howard, Einar Larsen and Shruti Rao

Outline

- Low System Strength – Relevance to GFM
- How higher IBR penetration of scenarios affect SCR index and fault behavior evaluation

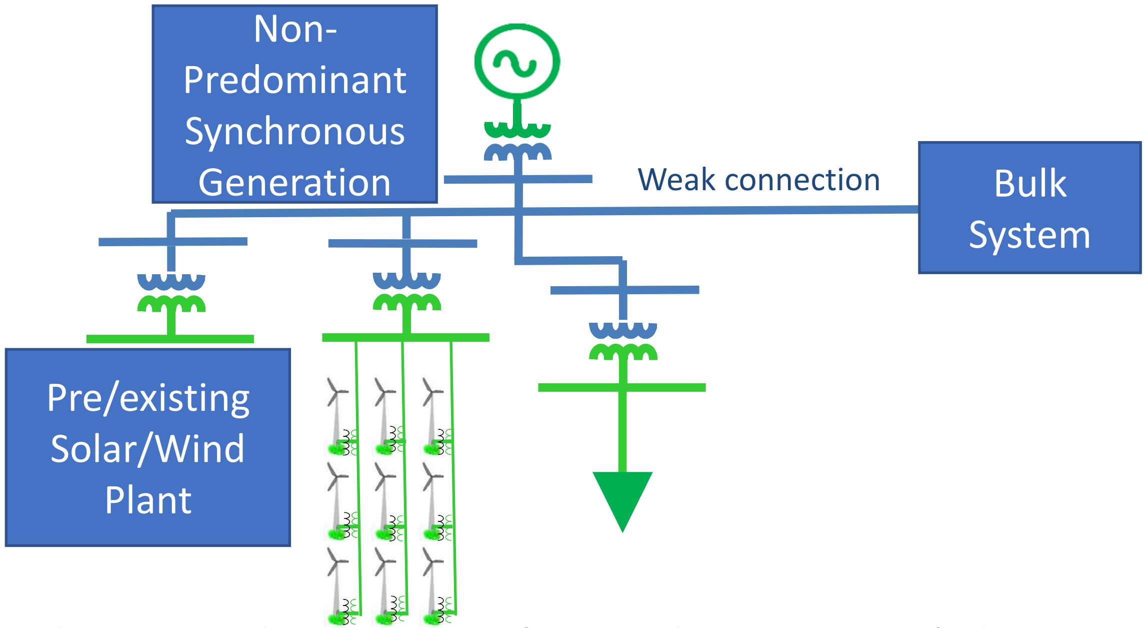
Aspects of low-system-strength challenges

Power Transfer Challenges



- Remote IBR plant or clusters
- Main challenges related to fault behavior and recovery during N-1 or weaker
- Frequent challenge in current and past projects or systems
- Mature GFL IBR design processes and controls

High IBR Penetration Challenges



- Relevant in the context of de-carbonization of electricity
- Less frequent in current and past projects
- Transferring power over long electrical distance is **not** necessarily the challenge
- **Instability risks of GFL inner loops or interactions**
- **Larger ROCOF and Angle fluctuations**
- System operation and restoration

What problem are we trying to solve with GFM?

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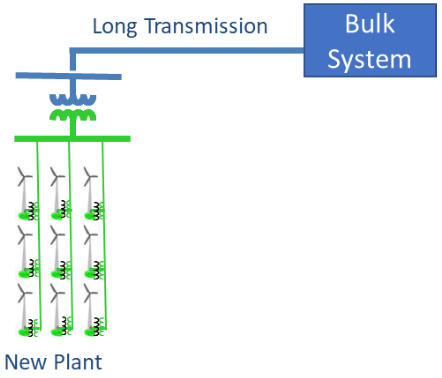
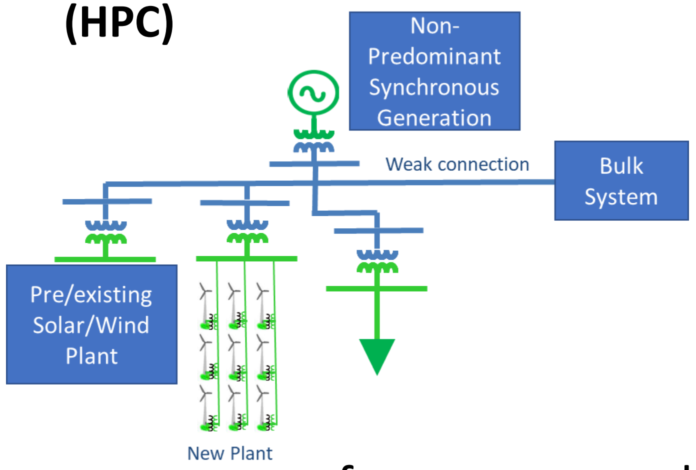
Low-system-strength challenges and SCR

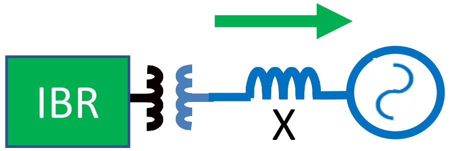
Power Transfer Challenges (PTC)

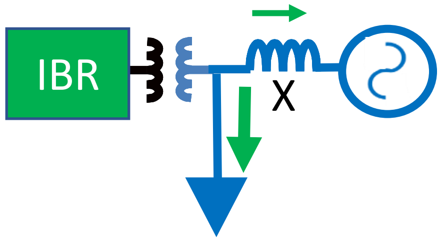


High IBR Penetration Challenges (HPC)



Simple conceptual equivalents considering power flow with respect to source of system strength related mostly to **steady state, fault and recovery performance**





For example, if in both circuits SCR = 0.5, X = 2pu

- PTC equivalent does not have a feasible steady state operating condition
- HPC , if the load is 1pu, there is a feasible steady state operating condition. If the IBR controls are small signal stable, an IBR system may operate stably

Same SCR value has a different interpretation in these circuits

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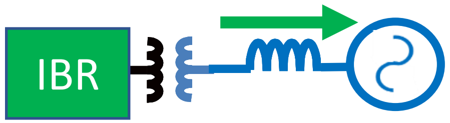
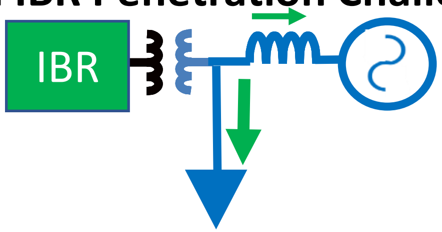
System strength challenges and GFM/GFL performance expectations

Power Transfer Challenges (PTC)

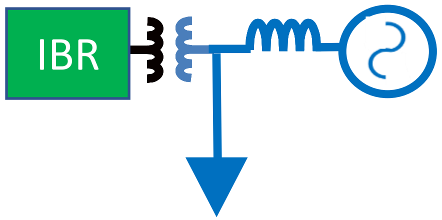


High IBR Penetration Challenges (HIPC)



Load Power [pu] (1)	SCR (2)	GFL (3)	GFM	Challenge
0	1.5+	☑	☑	
0	1.0 to 1.5	Could work	Could work	PTC
0	<1.0	☒ 	☒	PTC
0.5	0.75+	☑	☑	
0.5	0.5 – 0.75	Could work	Could work	PTC and HIPC
0.5	<0.5	☒	☒	PTC and HIPC
1	<0.2	☒(4)	☑ 	HIPC

(2) X = 1/SCR



(1) Load

(3) Advance commercially available GFL IBR technology

(4) May work in some conditions

Comparisons of apples  with bananas  are not recommended

This assessment does not evaluate all important HPC performance aspects

System strength challenges and GFM/GFL performance expectations

Other performance associated with High IBR Penetration Challenges

- Voltage angle jump response expectations:
  - Requirements related to tolerating voltage angle jumps without tripping – GFL and GFM
  - Requirements to “oppose” voltage angle changes by injecting or absorbing active power **very quickly** after event.
    - GFM is intended to do this-within the limitations of equipment
    - GFL would be expected to have no significant response or potentially a delayed response if specifically designed for it
- Fast rate of change of frequency (ROCOF)
  - Requirements related to tolerating ROCOF events without tripping – GFL and GFM
  - Requirements to “oppose” ROCOF events by injecting or absorbing active power **with a mitigating effect similar to synchronous machines**.
    - GFM is intended to do this-within the limitations of equipment
    - GFL would be expected to have no significant response or potentially a delayed response if specifically designed for it
- Comments on Voltage Control
  - Low system strength – Voltage Control usually more adequate than Reactive Power Control
  - Voltage control at plant level
  - GFL IBR terminal voltage control - superior performance in low system strength, but not widely used or required
  - GFM IBR terminal voltage control – likely not to go through current control

Noticeable GFM differentiation to GFL

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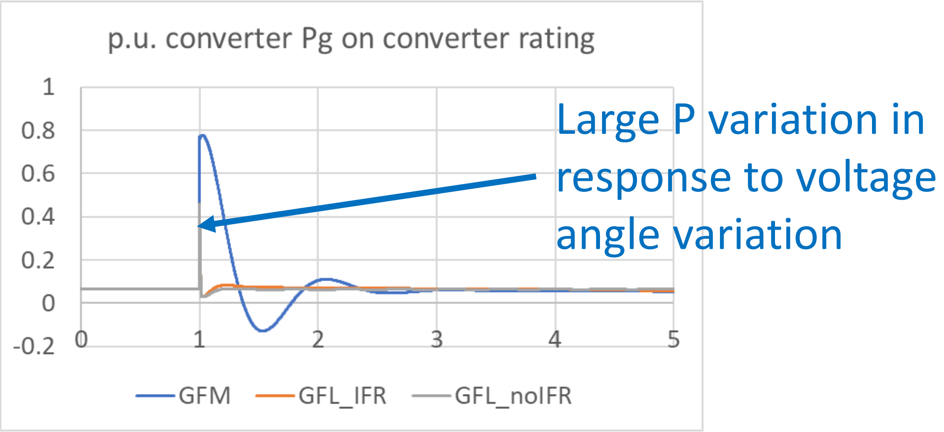
GFM inverter vs GFM resource

- Resources designed for GFL operation need **more than inverter control modifications** to provide reliable GFM behavior
- Angle jump or ROCOF trigger different behavior from GFM than GFL
- Load/Generation balance is **more complex in PV solar systems and wind turbines than with BESS**
    - Fast bidirectional active power fluctuations demanded by grid angle fluctuations
    - Drive train has stored energy and constrains(wind)
    - Additional hardware (energy buffer/storage) may be required depending on performance requirements
    - Curtailment
- Current rating and fault contributions



P output in pu from IBR, GFM vs. GFL with and without inertia-like response

Source: Shruti D Rao, et al. "Grid-forming Inverters –Real-life Implementation Experience And Lessons Learned", IET RPG 2021

GFM BESS MW scale projects

•BESS projects are usually not GFM

Key GFM BESS Projects:

- Metlakatla Power & Light 1MW/1.4MWh-1995 [1]
- Vernon CA 5MW/2.5MWh- 1996 [2]
- IID 30MW/22MWh- 2017. Black start of GT auxiliaries and other services
- Entergy Perryville - Black start of GT auxiliaries with 7.5 MW x 7.5 MWh BESS – 2019

•Black start of GT auxiliaries with 13 MW x 13 MWh BESS - 2020

Projects demanded:

- Black start of industrial and complex load (SCR= 0)
- Black start field demonstration
- Modular solutions with distributed BESS

IID (complete, COD: 2Q2017)

Entergy Perryville (complete, COD 4Q2019

Distributed BESS systems with GFM control approach compatible with interconnected grids

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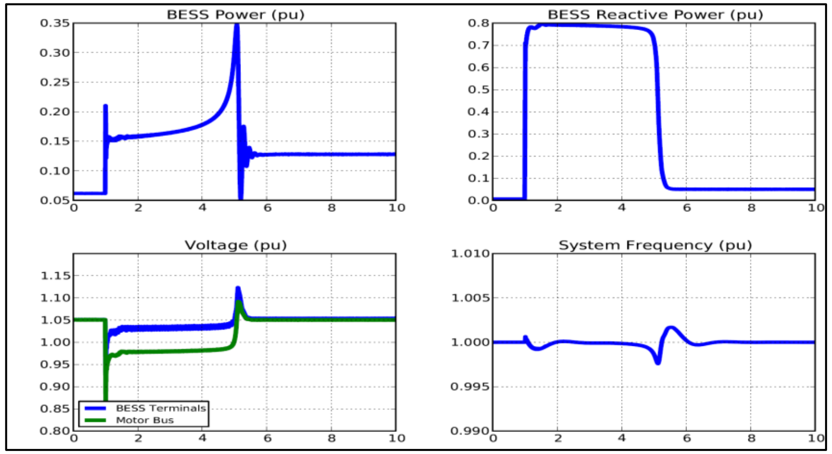
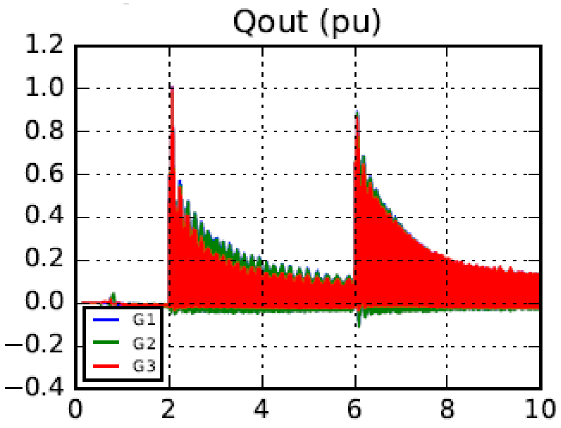
GFM BESS MW scale projects

- Large drives fed from BESS
- Motor and transformer energizations/ Inverter rating optimizations
- Performance Requirement definition are key to design and not simple
  - Current rating vs frequency and voltage sags for critical events
  - Complexity of applications drives need for extensive study efforts
- Few control observations:
  - Hierarchical control with plant-level supervisory controller which sends commands to inverters based on POI measurements (same as most sizable IBR plants)
  - Co-ordinated control between multiple inverters without need for fast communications
  - In islanded mode, plant controller controls voltage and keeps frequency close to nominal

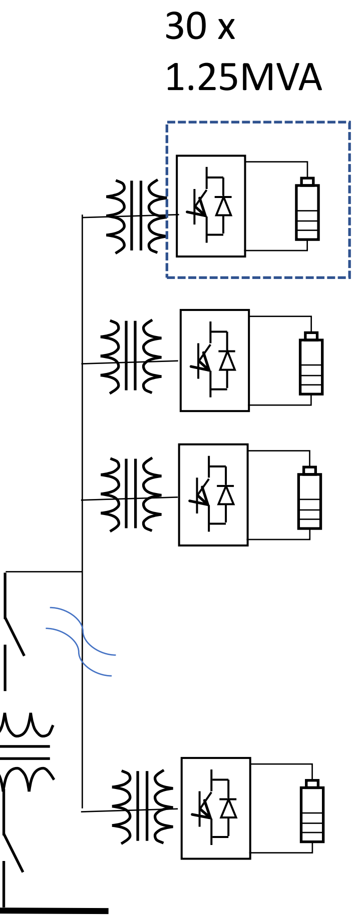


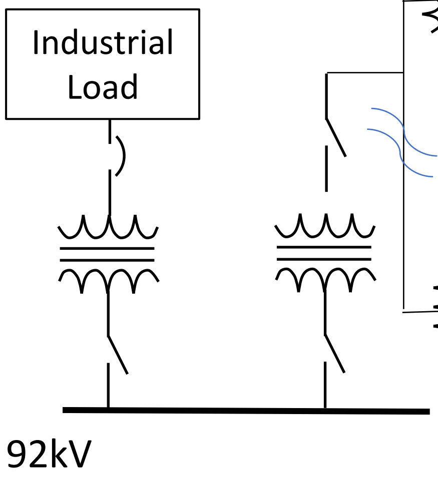
Direct start of large asynchronous machines

Source: Shruti D Rao, et al. “Grid-forming Inverters –Real-life Implementation Experience And Lessons Learned”, IET RPG 2021



Transformer Energization





Performance requirements definitions are complex

How much GFM is GFM enough?

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GFM Wind turbine experience

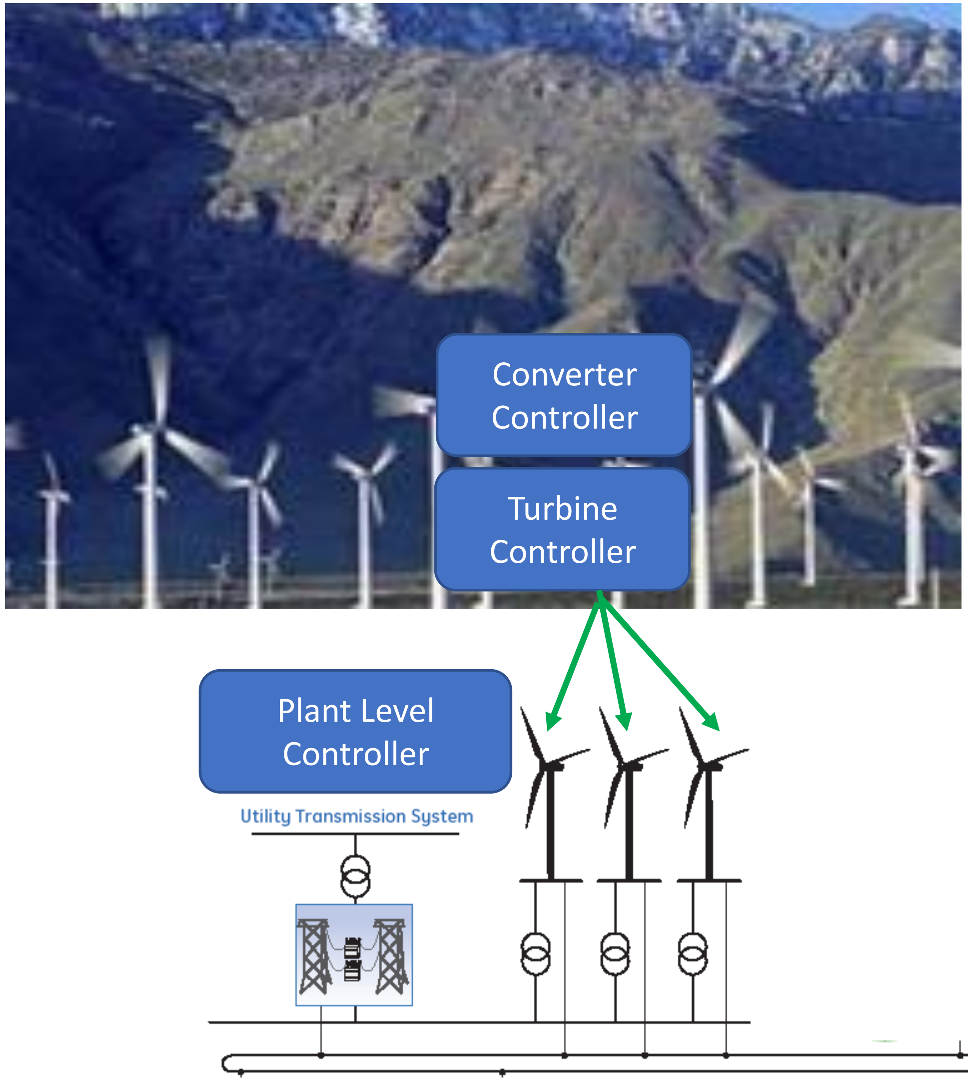
From GFL to GFM…

- Converter, Turbine and plant controls coordination is different
- More Frequent and faster active power fluctuations has impact on drive train
- Several GFM performance aspects benefit from overload capabilities

Type 3 GFM WTG electrical system lab demonstrations well underway

Performance requirement definition

- Performance definitions are different from some of the BESS projects mentioned
- Likely to continue changing as more markets request features
- GFL vs GFM requirement approach may need to be different
- Consideration of equipment limitations



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Final Comments

- Grid forming technology can support mitigation of several aspects of low system strength…not all of them.
- GFM performance options are very broad. Performance requirement definition is not simple. Manufacturers require good level of performance definition to design products.
- Several BESS grid forming applications deployed
- PV systems and Wind Turbine design/control based on maximum energy capture. Grid forming operation could lead to significantly reduced energy capture
- GFM capabilities in wind and solar progressing
  - GFM performance requires more than controller code modifications
  - Market size associated to increased performance requirements
- Likely increase in application complexity for stakeholders (Reliability entity, Transmission operator, plant developer, OEMs). Effect in project award/deployment cycles.

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