



Weak Grid Connection of Inverter-Based Resources

Why Are We Still Talking About This?

Nov 10, 2021

Sebastian Achilles

sebastian.achilles@ge.com

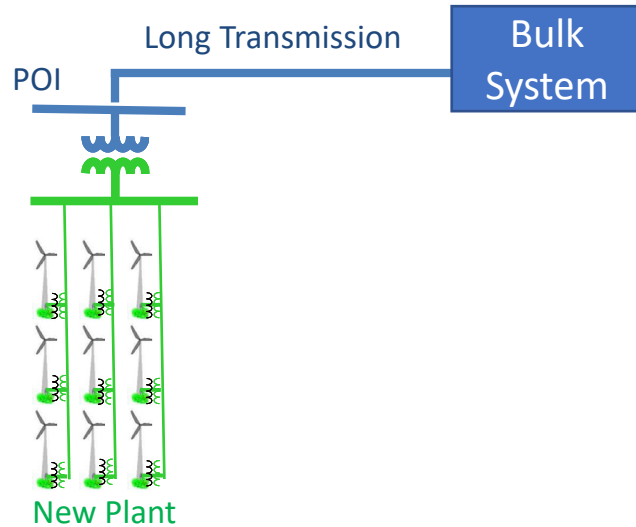
GE Energy Consulting



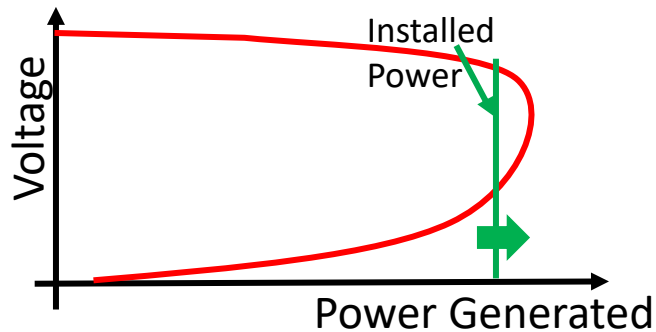
Outline

- Inverter Based Resources (IBR) in weak grid conditions – aspects that were discussed for some time
 - Performance Challenges
 - Mitigations and Project Experience
- What's new with IBR and weak grids
- Grid Following (GFL) and Grid Forming (GFM) IBR resources in the context of weak grids
- short circuit ratio (SCR) screening aspects based on recent experiences
- Final Remarks

Weak Grid Connection of IBR – nothing new



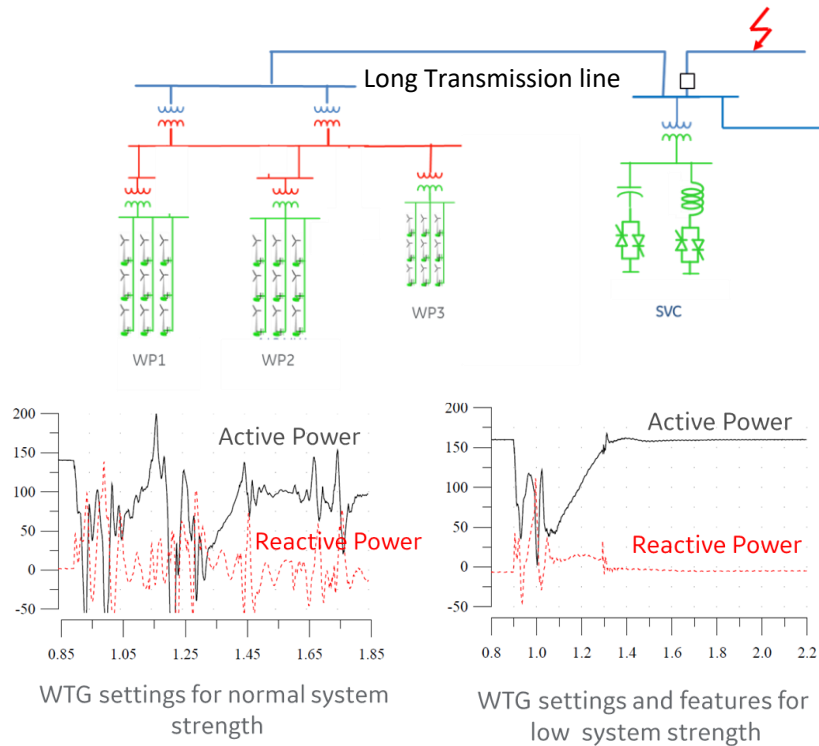
- Remote IBR plant or clusters
- Nomenclature: Weak Grid \approx Low System Strength
- System is weak when the IBR currents affect Point-of-Interconnection (POI) voltage magnitude significantly
 - Inertial response or fast voltage angle fluctuations
- Main challenges related to fault behavior and recovery during N-1 or weaker
- LVRT and HVRT demands in these scenarios. Large voltage angle shifts.
- Improvement in technology allowing operation close to steady state limits
- Utilities, transmission companies and system operators have processes to address/evaluate
- EMT studies occasionally required
- OEMs incorporated related scenarios in design processes



*PV curve of an IBR project -
Conceptual graph*

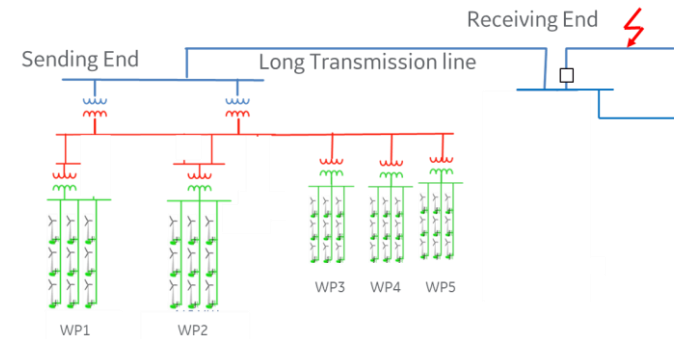
Stability risk examples and mitigations – nothing new

Fast Control Interaction



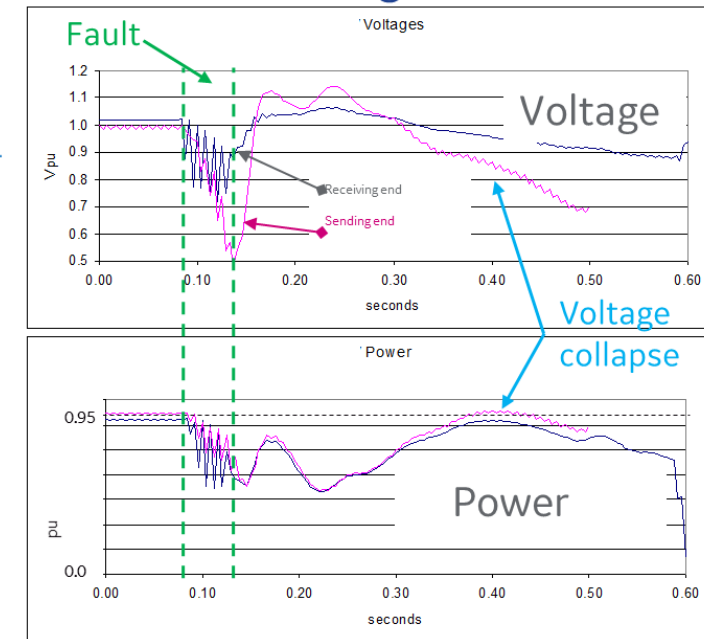
- Extreme low SCR, for all plants
- 5-20Hz interactions between IBR and SVC only present in weak condition
- Voltage control modifications at IBR and/or SVC

Voltage Collapse



- Extreme low SCR
- Remote Fault
- Fast voltage collapse during power pickup
- IBR trips or line protection operations (without fault)
- Adjustment of reactive power IBR controls to sustain power transfer was possible to resolve this risk

Field Recordings



More on Stability Risk Mitigations

General view –OEM oriented

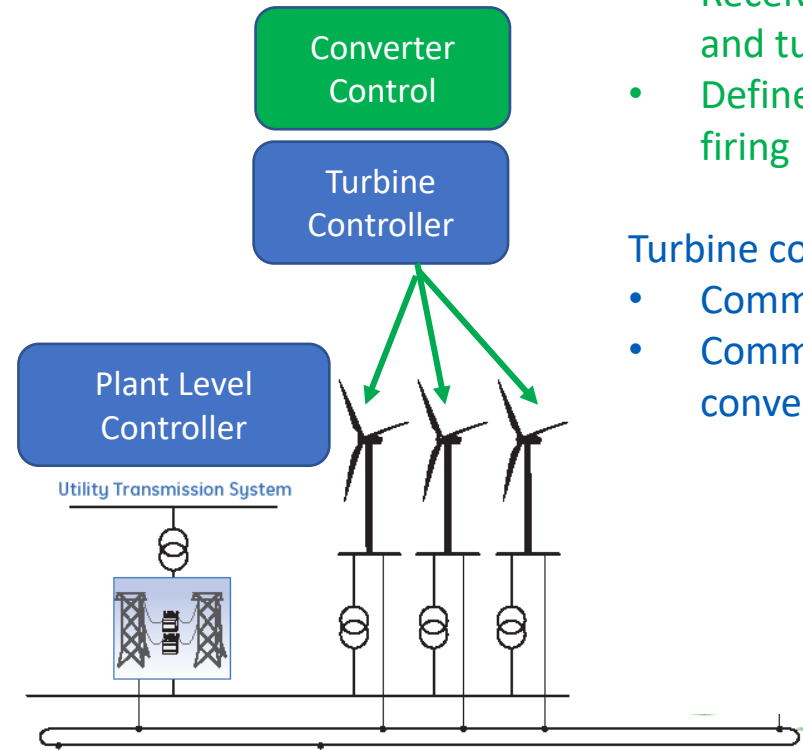
- Some applications **may** need mitigations to achieve desired system performance under very low system strength conditions
- Mitigations can include
 - Transmission upgrades
 - Additional lines
 - Meshed vs radial
 - Series compensation
 - Synchronous condensers (System strength, dynamic VARs)
 - SVC, STATCOM (dynamic VARs, control challenges)
 - Special protection schemes (such as transfer trips)
- IBR may have control features to improve performance in low system strength conditions
- Plant level control coordination

Project experience shows....

- IBRs are highly controllable. Most developers prefer to explore IBR control modifications first.
- On the potential issues:
 - Large signal over small signal. Most challenges are on recovery after faults. Steady state operation is not usually a concern, even for extreme low system strength.
 - Requirements that demand “maximum and fastest possible response” tend to drive projects with longer processes that lead to slower and more appropriate IBR configurations
- On IBR or other power-electronic control modifications
 - Reduce IBR active power recovery after fault (for systems that require fast recovery)
 - High voltage magnitude control on fault recovery
 - Control adjustments in new IBR plant vs old IBR plant close-by
 - Slow down SVC/STATCOMs
 - Review setting estimations based on unrealistic grid conditions (like infinite system strength at POI)

Weak Grid and OEM design processes

- Controllers affected by grid strength
 - Response times of voltage regulator affected
 - System ability to absorb active power
 - **Mostly Converter or Inverter control**
- **Product** (Inverter, WTG) design processes
 - Short product cycles
 - Range of system conditions considered with simulations and IBR lab and container tests
 - Sophisticated performance evaluations beyond equipment damage and trips
 - Project specifics are usually unknown
- **Project** (solar plant, wind plant , etc)
 - Interconnection processes
 - Modeling needs



Converter control

- Receives commands (Plant and turbine control)
- Defines power electric device firing

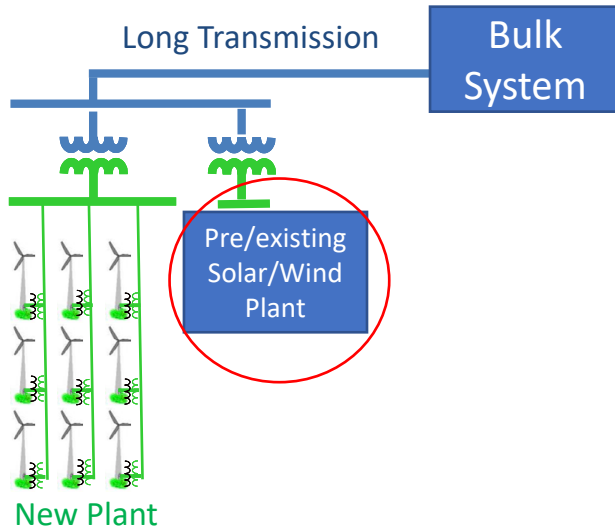
Turbine controller

- Command to pitch
- Commands torque to converter control

Established design processes and product improvements
Project interconnection efforts becoming more involving

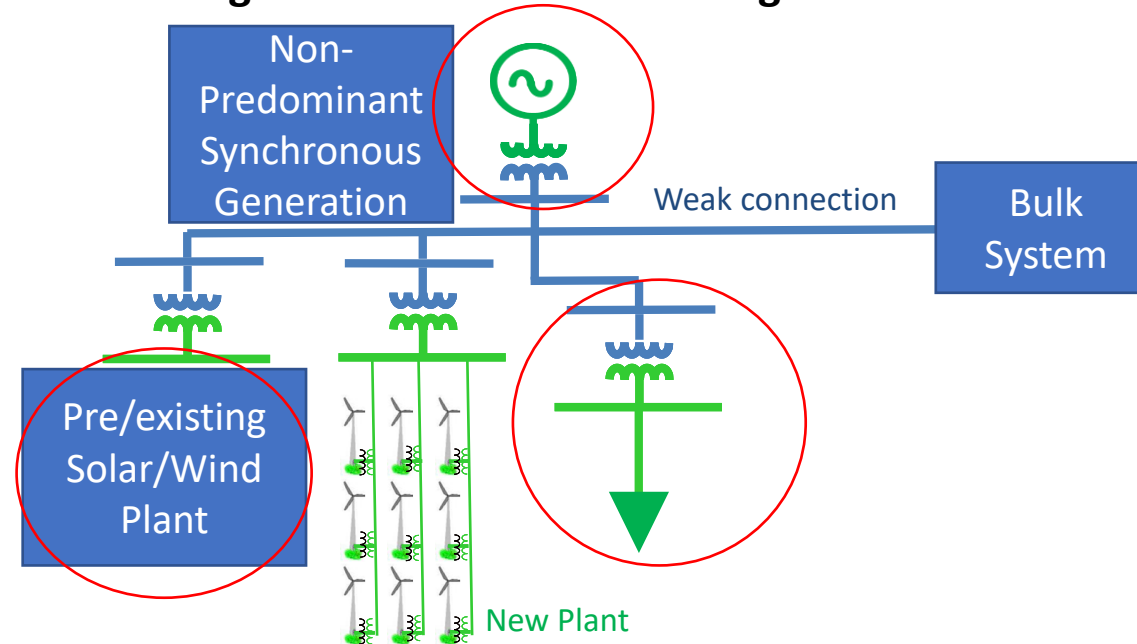
Weak Grid Connection of IBR – *updated*

Power Transfer Challenges



- Same as discussed earlier
- Frequent challenge in current and past projects or systems
- Mix of different vintage IBR is sometimes a challenge
- Increased interaction risk
- Older plants “see” a weaker grid than before the new projects

High IBR Penetration Challenges

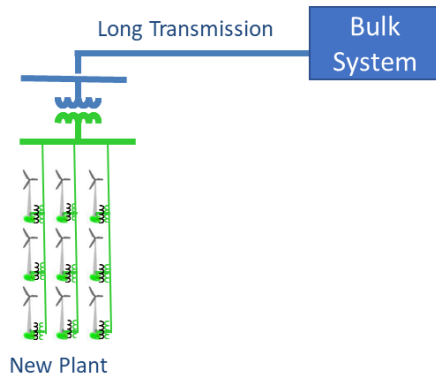


- Relevant in the context of de-carbonization of electricity
- Less frequent in current and past projects
- Transferring power over long electrical distance is **not** necessarily the challenge
- **Instability risks of converter control inner loops or interactions**
- **Larger ROCOF and Angle fluctuations**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

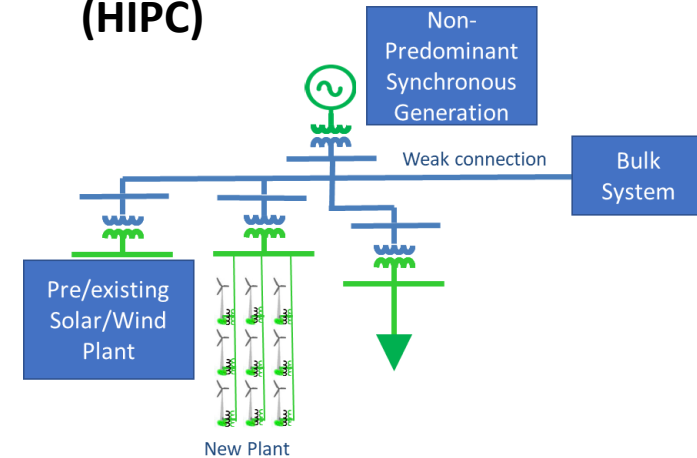
Increased IBR penetration is shifting the focus of “weak grid connection”

Weak Grid and SCR

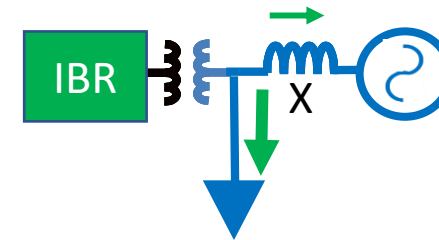
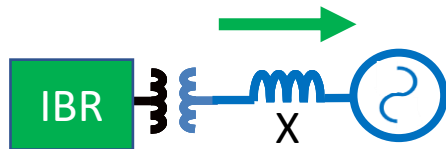
Power Transfer Challenges (PTC)



High IBR Penetration Challenges (HIPC)



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



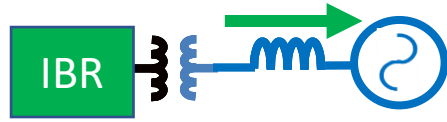
For example, if in both circuits $SCR = 0.5$, $X = 2pu$

- PTC equivalent does not have a feasible steady state operating condition
- HIPC, 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

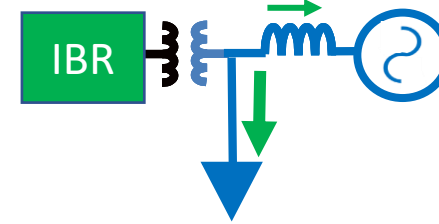
Same SCR value has a different interpretation in these circuits

SCR to evaluate Grid Following (GFL) and Grid Forming (GFM)

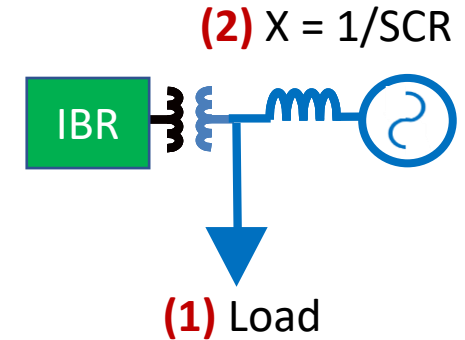
Power Transfer Challenges (PTC)



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



(3) Advance commercially available GFL IBR technology

(4) May work in some conditions

Comparisons of 🍎 with 🍌 are not recommended
 GFM main advantages are not related to Power Transfer constrained applications

Key Advantages of GFM IBR

Other performance associated with High IBR Penetration Challenges

- **Voltage angle jump**

- 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

- **System Restoration and/or Black start**



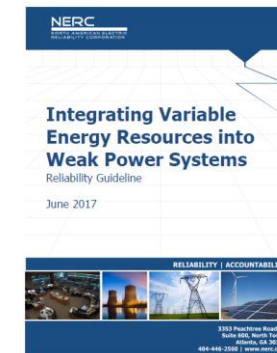
SCR Metrics – what is changing

- (not new) Short circuit ratio (SCR) without consideration of Multiple IBR plants highly optimistic and not recommended *for Power Transfer constrained applications*
- (not new) SCR-based metrics considering infeed recommended *for Power Transfer constrained applications* -not new: Weighted short circuit ratio (WSCR), Composite short circuit ratio (CSCR), others
- (not new) SCR metric converted from POI to IBR terminals for determination if detailed studies are required for a given project
- (new) **In scenarios related to High IBR Penetration, SCR based metrics tend to be pessimistic when the systems are not Power Transfer constrained**
- NERC guideline and CIGRE B4.62 are example publications on SCR methods

$$SCR_{POI} = \frac{SCMVA_{POI}}{MW_{VER}}$$

$$WSCR = \frac{\sum_i^N SCMVA_i * P_{RMW_i}}{(\sum_i^N P_{RMW_i})^2}$$

$$CSCR = \frac{CSC_{MVA}}{MW_{VER}}$$



https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Item_4a_Integrating%20Inverter-Based_Resources_into_Low_Short_Circuit_Strength_Systems_-_2017-11-08-FINAL.pdf

Final Comments

- Power Transfer constrained project are challenging but not new to the industry
- High IBR Penetration scenarios have new challenges
- OEMs design processes improved over the years with influence of projects and requirements
- Increase in project complexity for stakeholders (Reliability entity, Transmission operator, plant developer, OEMs). Effect in project award/deployment cycles.
- Grid forming technology can support mitigation of several aspects of weak grids...not all of them.
 - Power Transfer constrained systems can benefit from advance GFL IBR (as much as from GFM)
 - System response to voltage angle jumps and ROCOF improves with GFM IBRs (compared to GFL)
 - System Restoration requires some level of GFM

Weak Grid Connection of Inverter-Based Resources

Why Are We Still Talking About This?

Sebastian Achilles

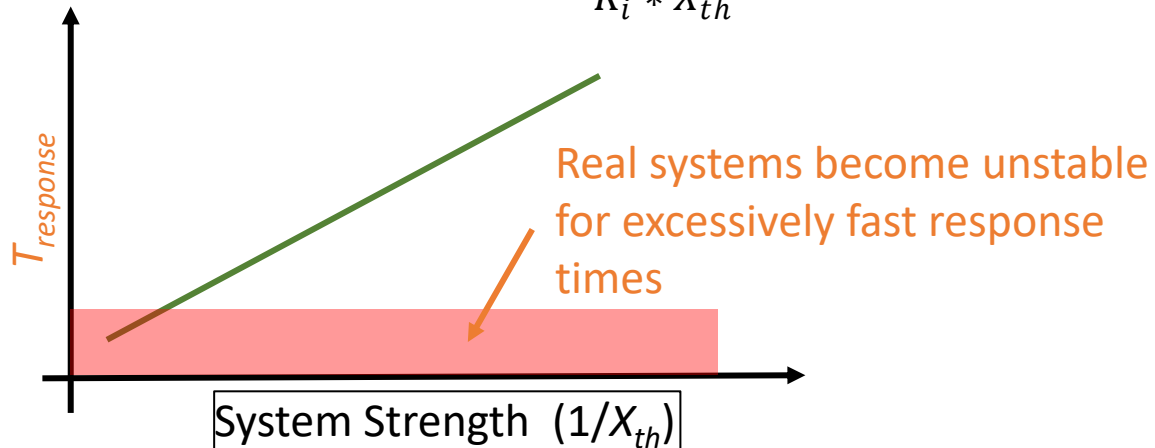
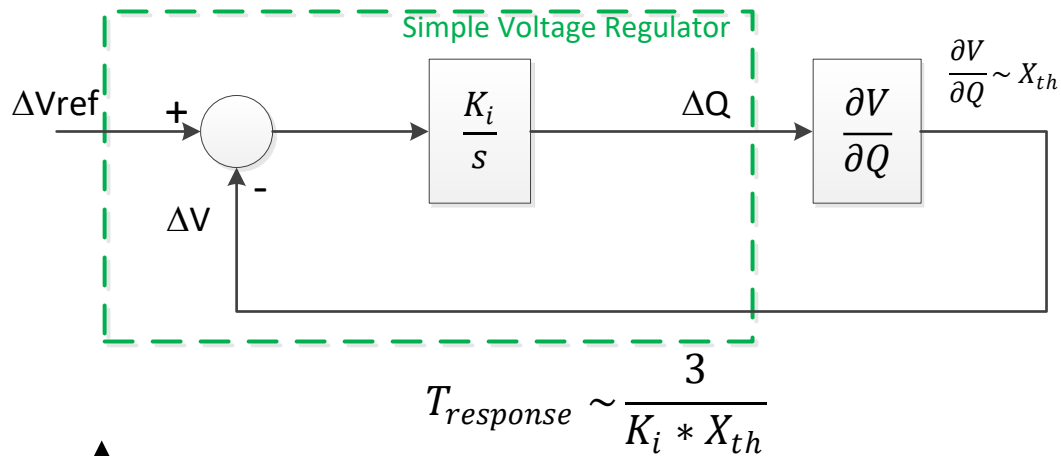
sebastian.achilles@ge.com

GE Energy Consulting

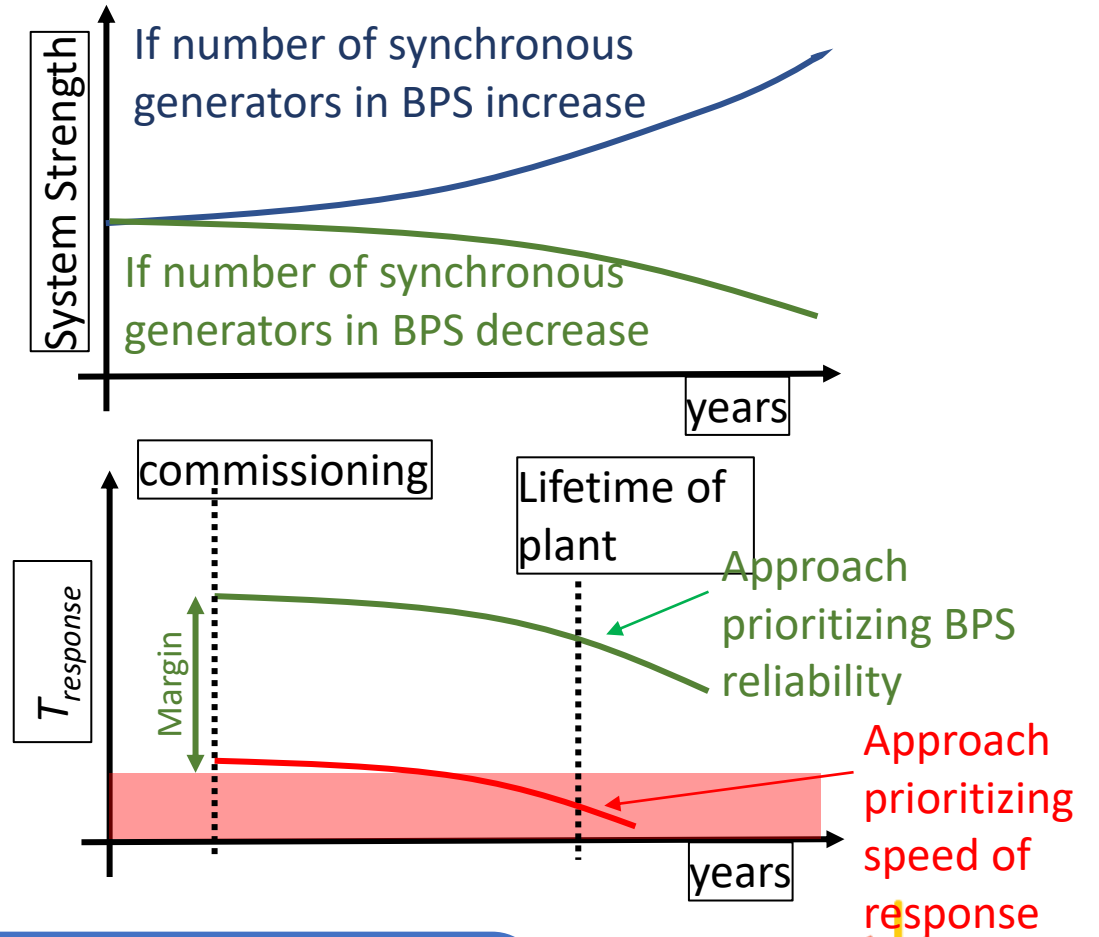


Response Time Requirements and System Strength

Equipment Considerations



Planning/Requirements Approach



Priority on BPS reliability over speed-of-response is recommended

Important details on N-1 vs N-0, effect of additional IBR plants close-by, different regulators affected, plant level vs IBR unit level responses

