Weak Grid Connection of Inverter-Based Resources

Why Are We Still Talking About This?

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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

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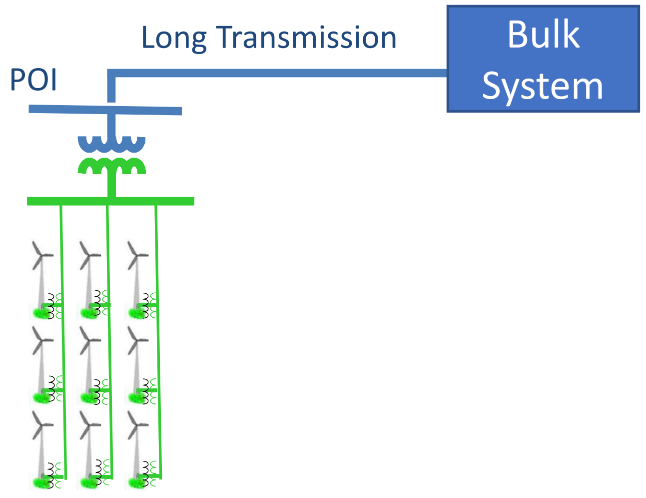
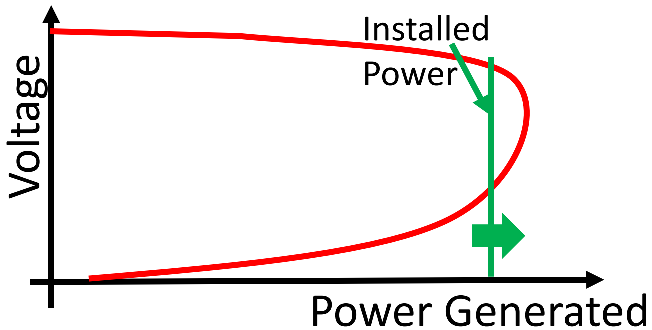
Weak Grid Connection of IBR – nothing new





PV curve of an IBR project - Conceptual graph

- Remote IBR plant or clusters
- Nomenclature: Weak Grid ≈ 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

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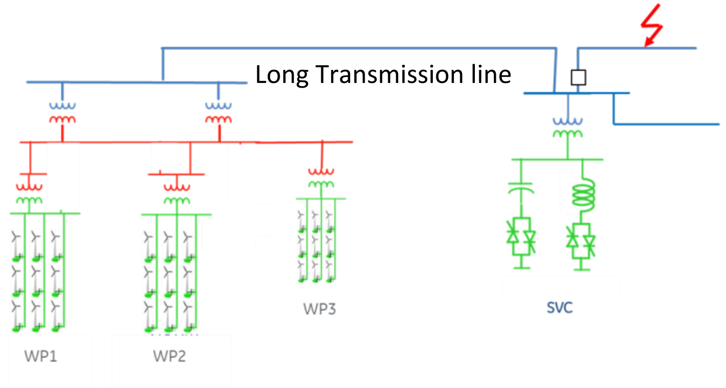
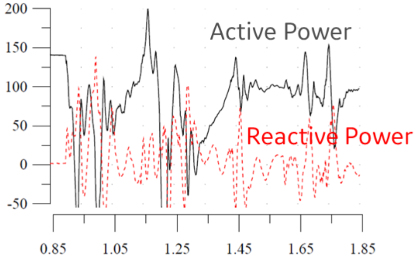
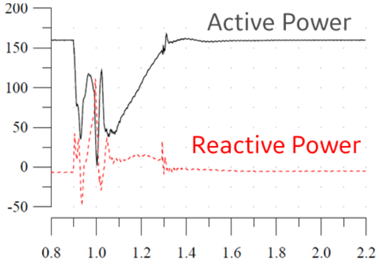
Stability risk examples and mitigations – nothing new

Fast Control Interaction





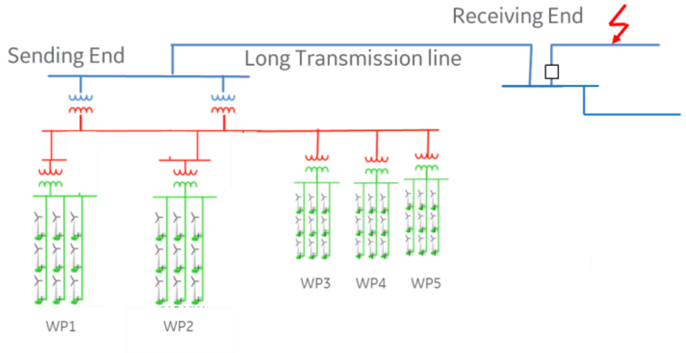
WTG settings for normal system strength

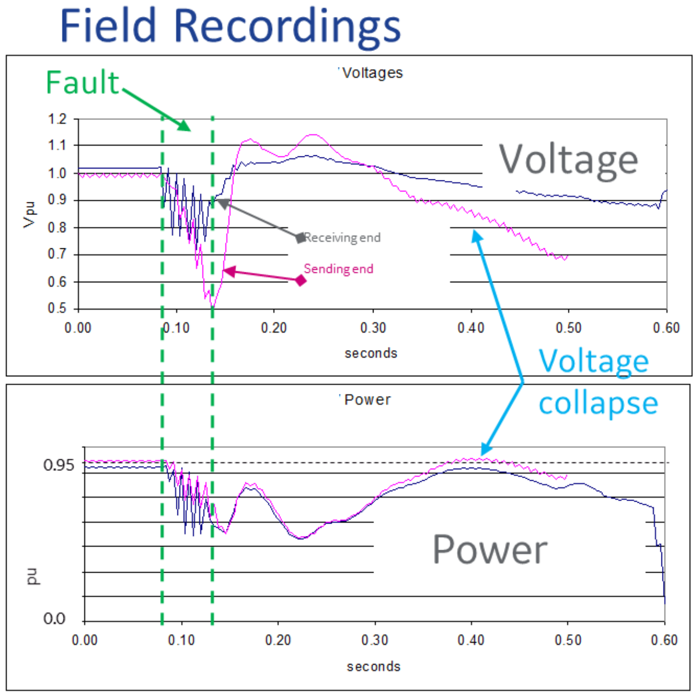


WTG settings and features for low system strength

- 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

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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)

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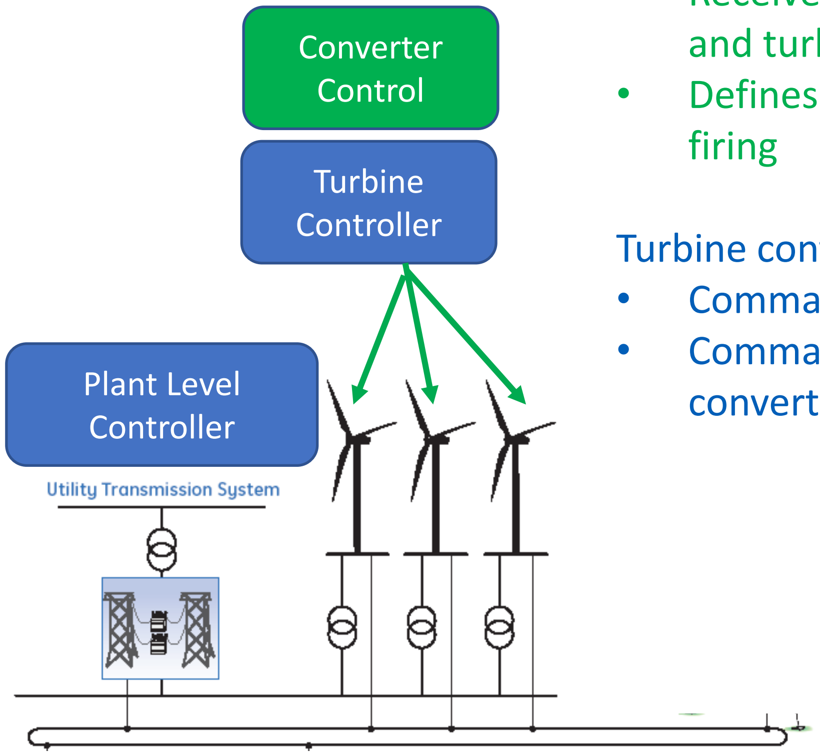
Weak Grid and OEM design processes

- 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



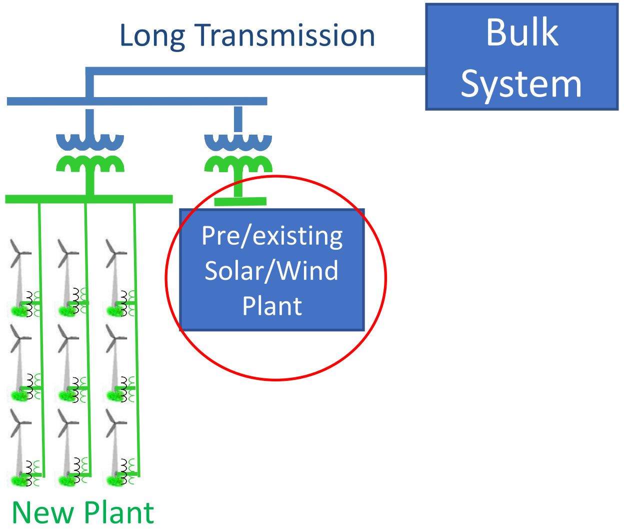
Converter control
- Receives commands (Plant and turbine control)
- Defines power electric device firing

Turbine controller
- Command to pitch
- Commands torque to converter control

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

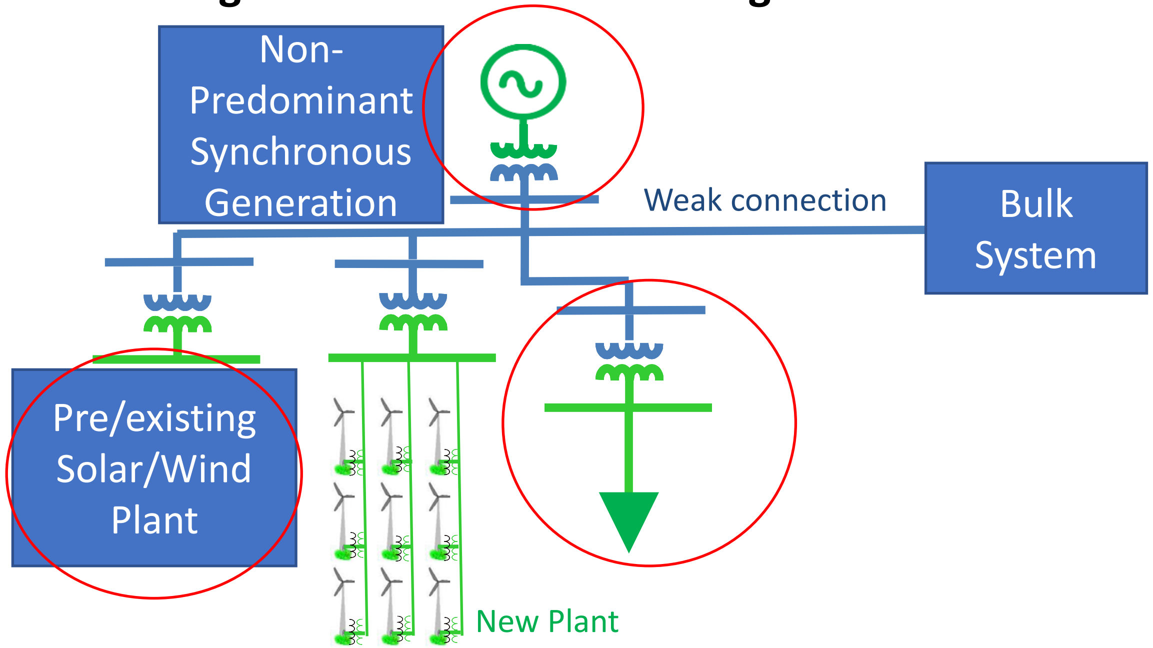
Weak Grid Connection of IBR – *updated*

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"

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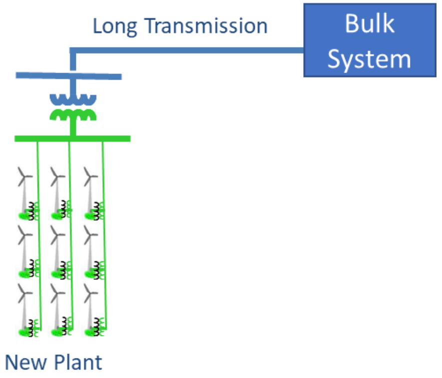
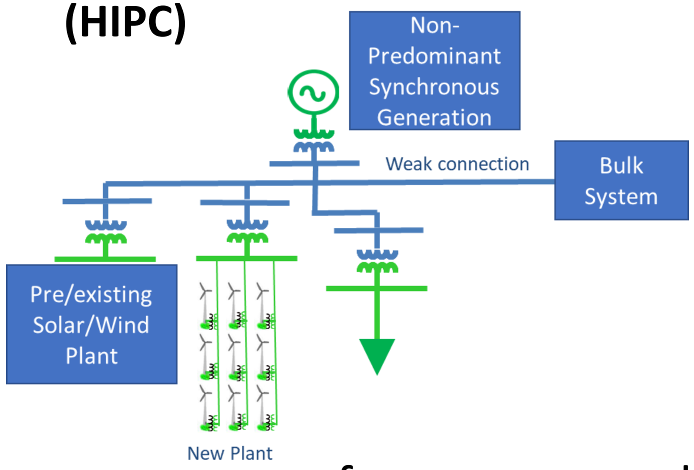
Weak Grid and SCR

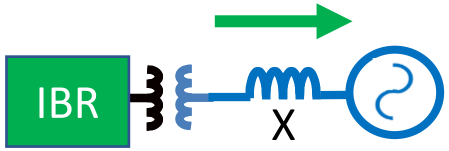
Power Transfer Challenges (PTC)

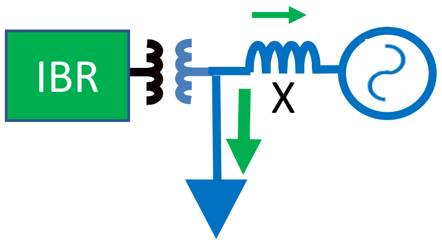


High IBR Penetration Challenges (HIPC)



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

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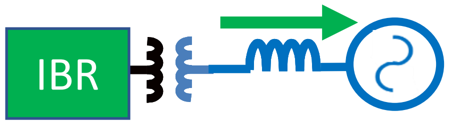
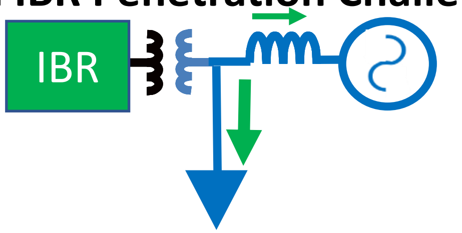
SCR to evaluate Grid Following (GFL) and Grid Forming (GFM)

Power Transfer Challenges (PTC)



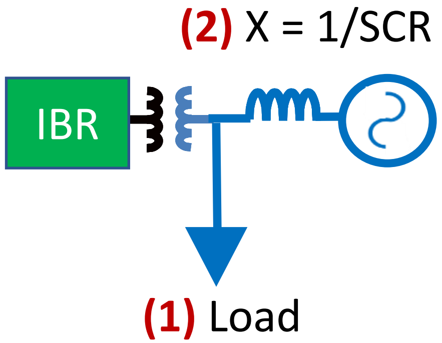
High IBR Penetration Challenges (HIPC)



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

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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**

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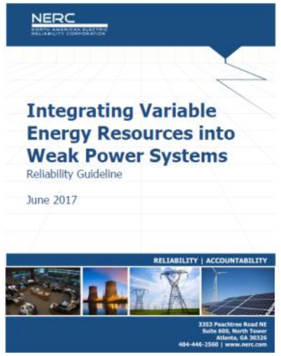
SCR Metrics – what is changing

- (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

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

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

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



https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Item_4a._Integrating%20_Inverter-Based_Resources_into_Low_Short_Circuit_Strength_Systems_-_2017-11-08-FINAL.pdf

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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

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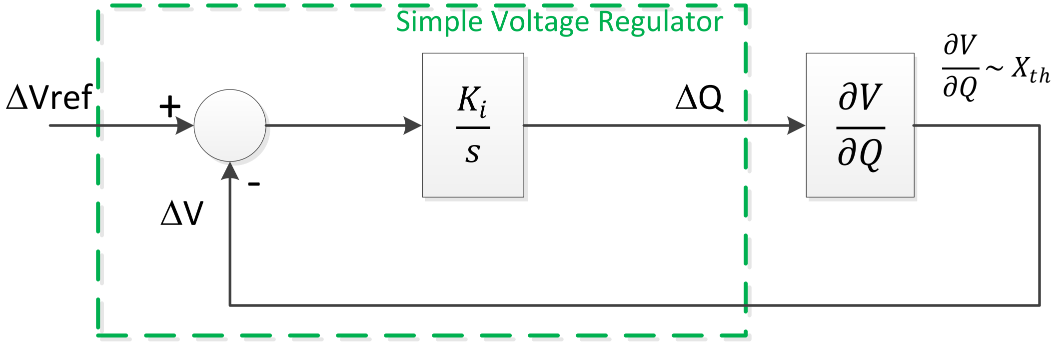
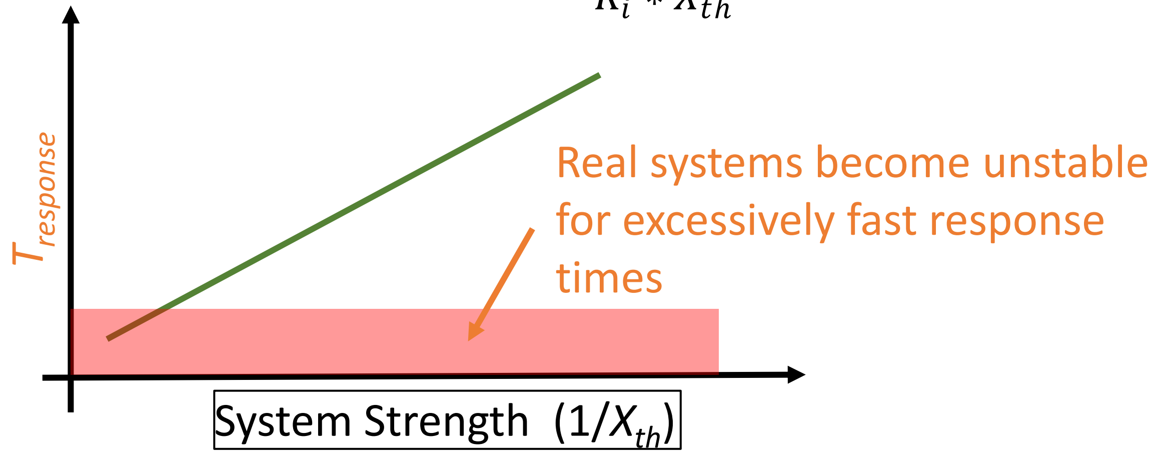
Response Time Requirements and System Strength

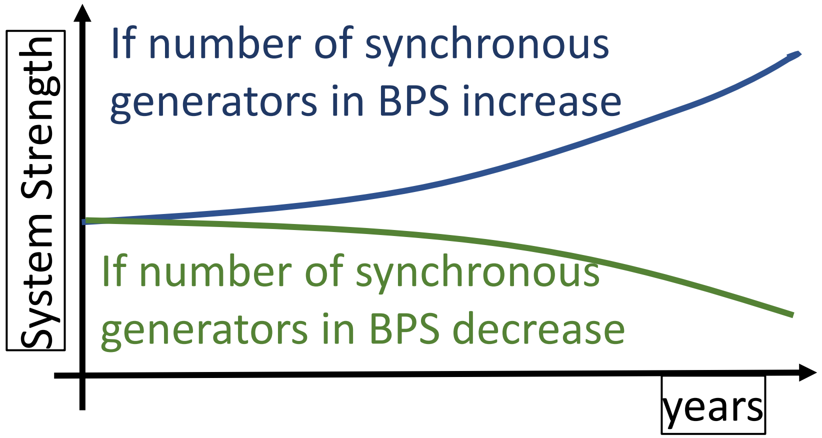
Equipment Considerations

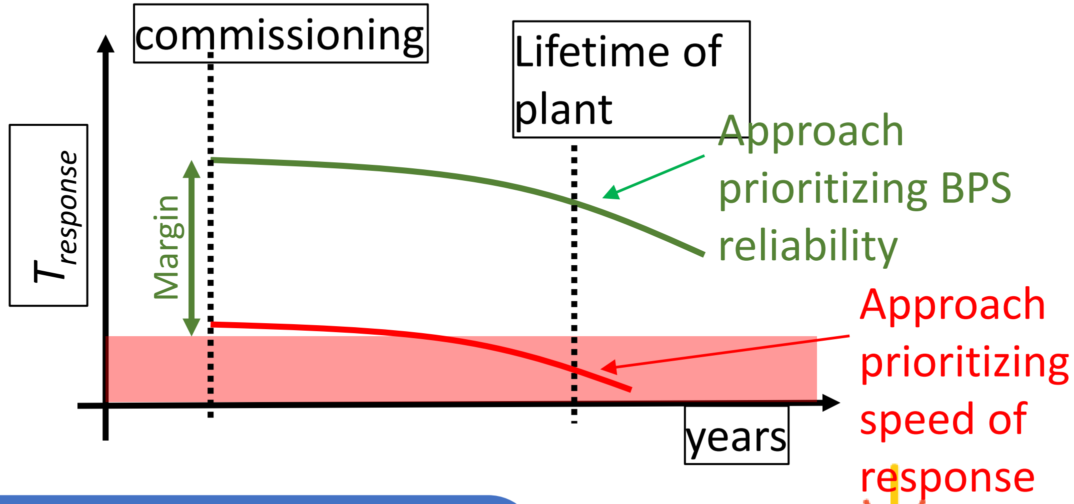


$$T_{response} \sim \frac{3}{K_i * X_{th}}$$



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

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