Do we have the tools to plan and study IBR oscillations during interconnection?

Deepak Ramasubramanian
dramasubramanian@epri.com

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Objectives

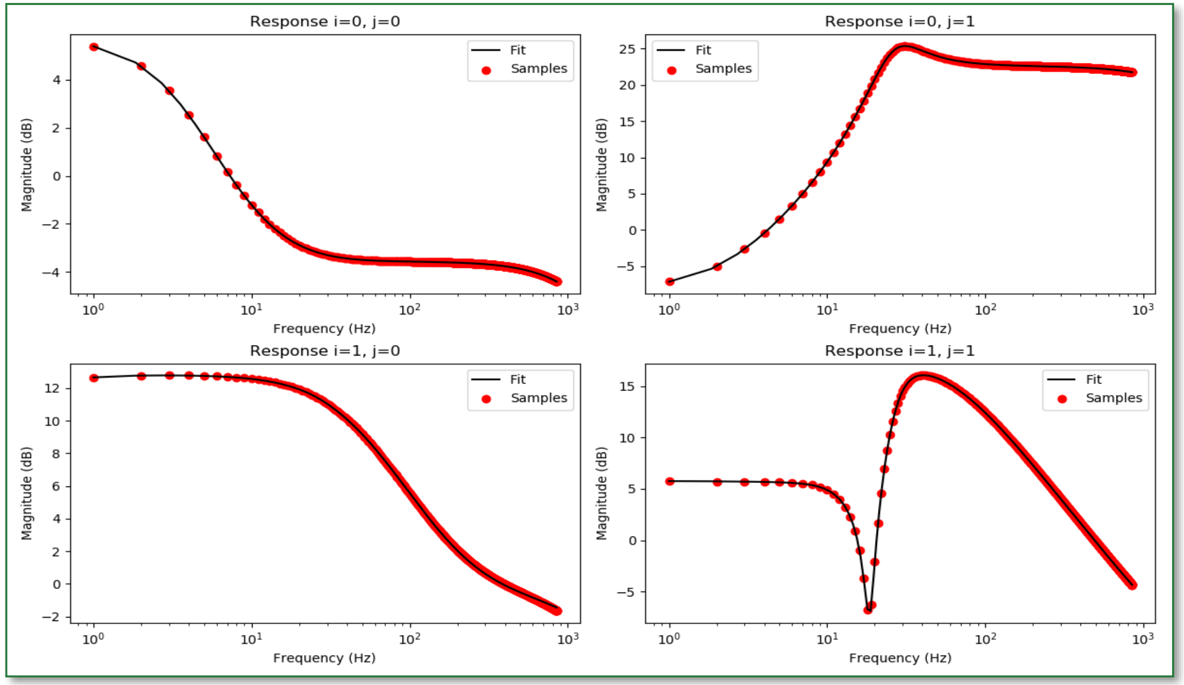
- Increase in inverter-based resources (IBRs) leads to higher chance of interactions in the network
  - Study and evaluation of interactions (chance of occurring and mitigation) presently requires detailed time consuming studies

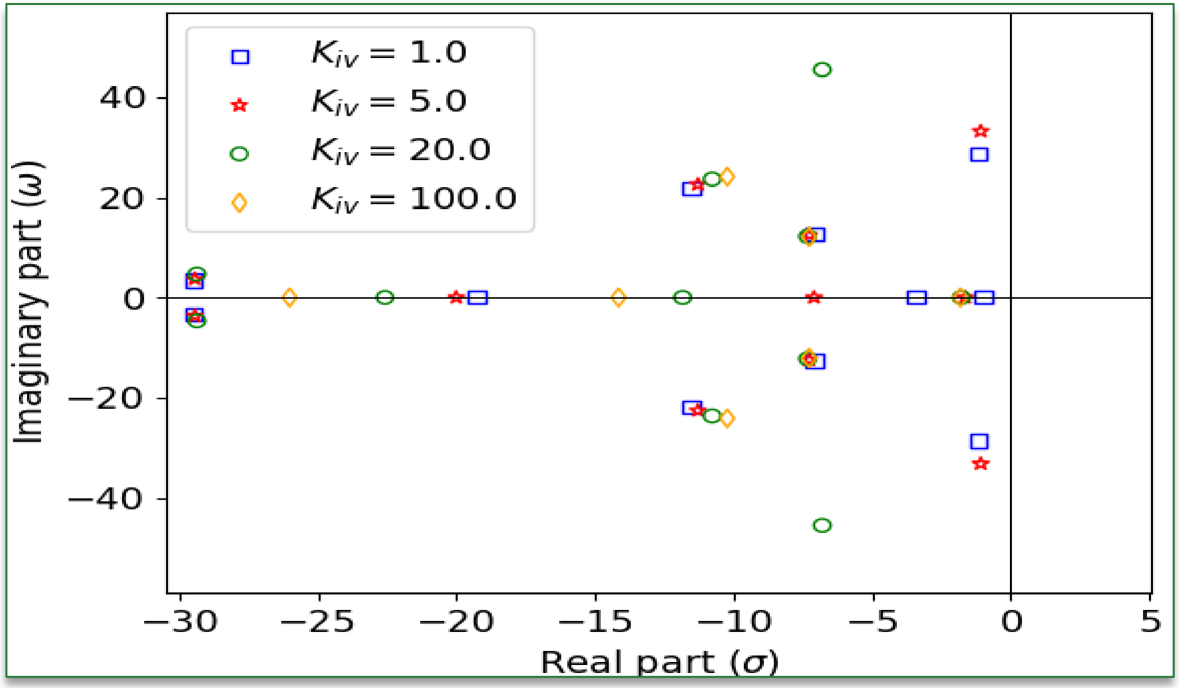
- Improved screening methods are required to quickly identify regions of the network and operating conditions where control interactions could occur.

- Use of screening methods during interconnection process can be beneficial, but also requires additional data to be provided by both TP/PC and IBR OEM

- Screening methods are by definition approximate in nature, and hope to provide more conservative results

Common approaches to evaluate oscillations





- Frequency domain evaluation
  - Example implementation (link)
- Suitable for blackbox models

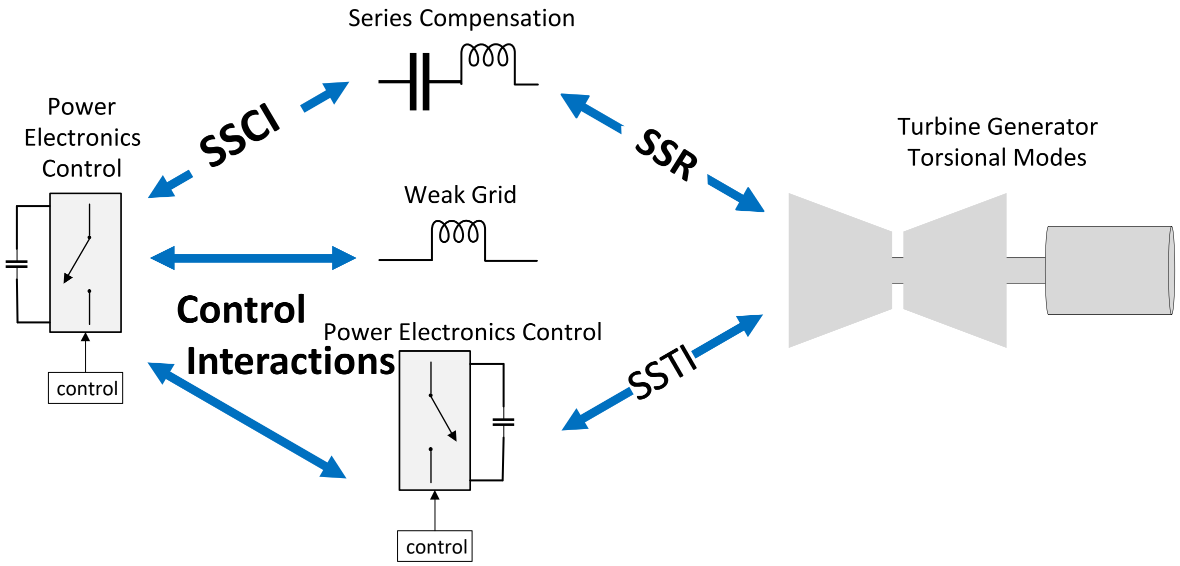
- Linear system analysis
  - Example implementation (link)
- Insight into states participating in modes

Both approaches presently need an operating point around which stability is determined

Frequency spectrum analysis

Different types of inter-element interactions within power system with IBR device

- Classified as
  - ***resonance-driven*** (SSR, SSCI, SSTI), and
  - ***converter driven*** (weak grid driven, PE-PE interactions)
- Oscillations are primarily driven by small-signal events/scenarios
- Blackbox model nature of IBRs makes it challenging to identify chances of oscillations occurring



Expectation of adverse sub-synchronous interaction → **Quick screening to narrow down high-risk system configurations** → **Time-domain simulations to ascertain risks, consider mitigation**

Network/Device Frequency Spectrum Evaluations

Features of the method

- Computes the resistance and reactance vs frequency of a network
- Accounts for various topological configurations
- Allows user to provide input-impedance characteristic of other IBRs in the network

Data Requirements

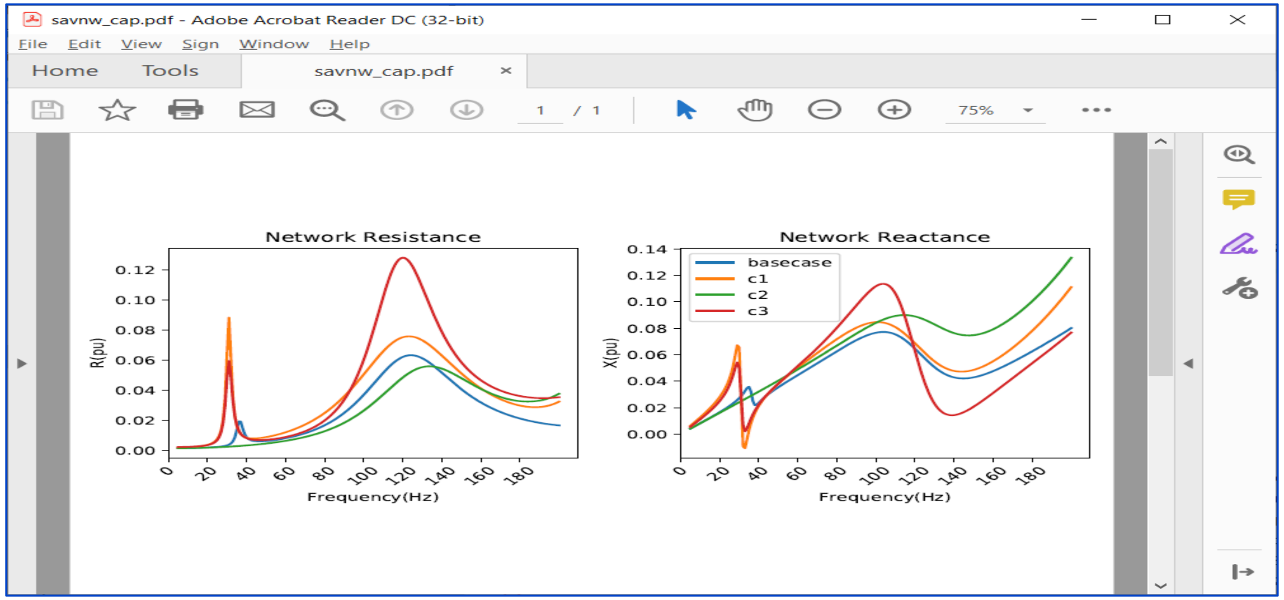
- Powerflow scenarios
- Contingencies to be evaluated
- Generator interconnection locations
- Impedance-frequency characteristic of existing IBRs

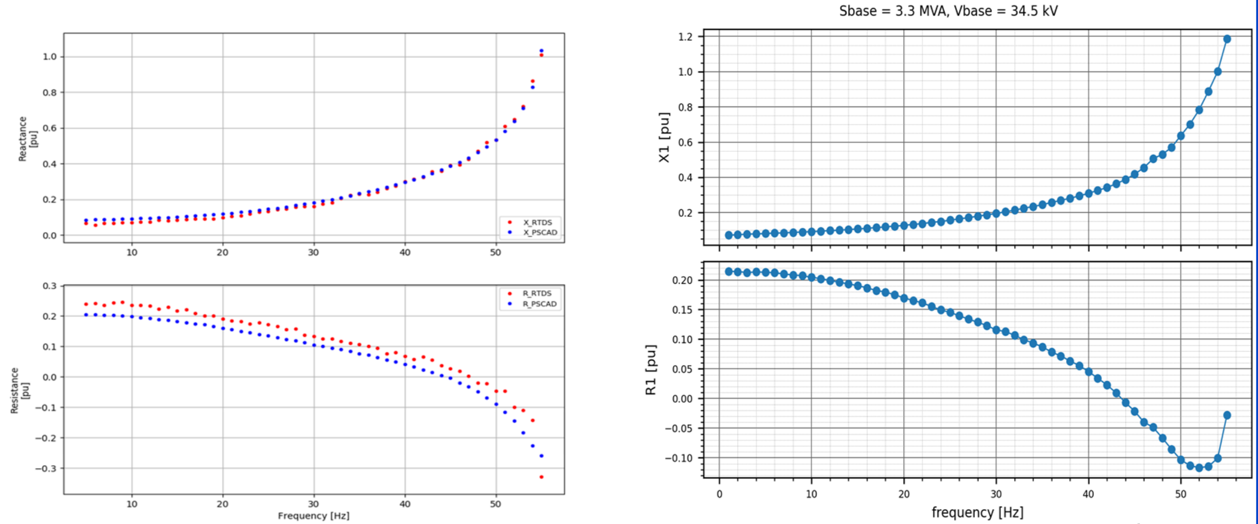
- Is there risk for SSR, SSCI, or SSTI?
- Will presence of nearby IBRs introduce control interactions?
- Will there be a need to re-tune new IBR devices?

All results should be evaluated based on contingencies, topologies, and operating point studied

Use of the method

- TP/PC can perform the network side scanning to provide OEM information on impedance at POI
  - Should take into account device level impedance of other devices in the network
- OEM uses this information to tune their controls.
  - OEM subsequently provides to TP/PC impedance of their device





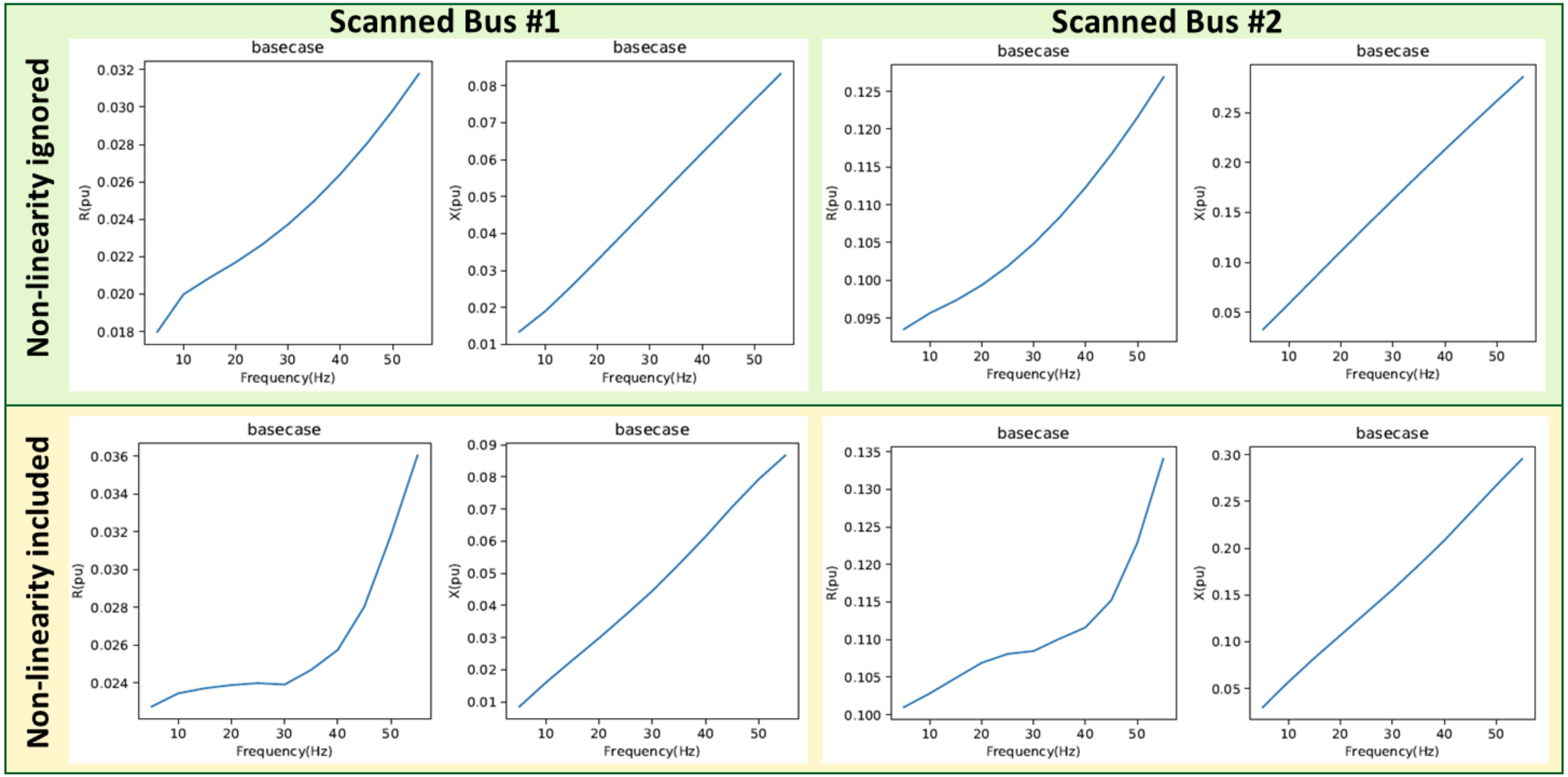
From Equipment OEM

Dynamic impedance scans of UDM

Important to consider impact of neighboring IBR devices

- Difference in Z profile for the case when the non-linearity is considered versus when it is ignored

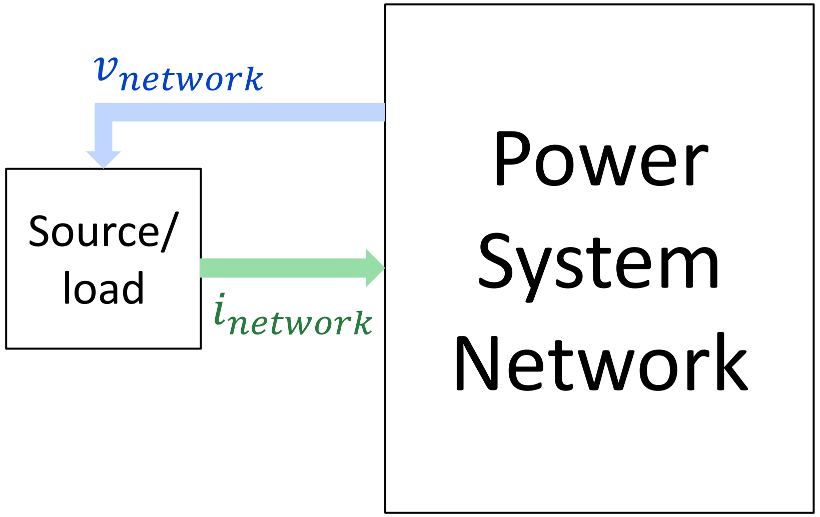
- Incorporating non-linearity of impedance from active devices is more pronounced when the scanning bus has more of these devices in the vicinity



Eigen value analysis

How can transmission planners use this approach?

- Small signal stability of a network depends on:
  - Power flow operating point
  - Dynamic behavior of individual elements at this operating point
  - System that connects the various elements together
- For large networks, it is efficient to adopt a modular structure
  - Each individual element is characterized as a 2 input – 2 output system
  - How to define the small signal dynamic behavior of each element?



Directly obtain numeric state space representation from OEM

$$[\boldsymbol{A}_{device}, \boldsymbol{B}_{device}, \boldsymbol{C}_{device}, \boldsymbol{D}_{device}] = f\left(v_{network}^{powerflow}, i_{network}^{powerflow}, S_{element}^{rating}, gains\right)$$

```
[IBR_ABCD_bus7, IBR_state_position_bus7] = IBR_control_A(Lf=0.15, Sbase=200.0, Kppll=20.0, Kipll=700.0, Kpp=0.5, Kip=20.0, R=20.0,
                                                         Qflag=1, Vflag=0, Kpq=0.5, Kiq=20.0, Kpv=0.5, Kiv=100.0, Kpi=0.5, Kii=20.0,
                                                         Vx0=V[7].real[0], Vy0=V[7].imag[0], Ix0=I[7].real[0], Iy0=I[7].imag[0], theta0=(cmath.phase(V[7])), no=2)
```

- It can be possible to construct a black box state space model with solution from power flow as input
- Output will be state space matrices of device
  - Need not know variable to which each state corresponds
- These can then be interconnected using network equations.
- This can also allow for seamless use of existing small signal analysis tools

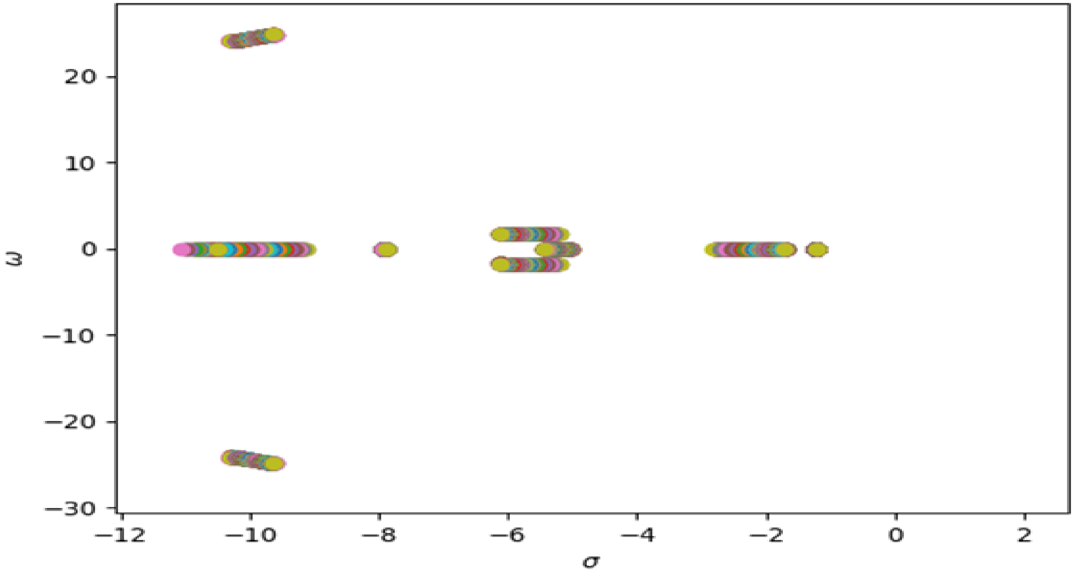
What's the catch?

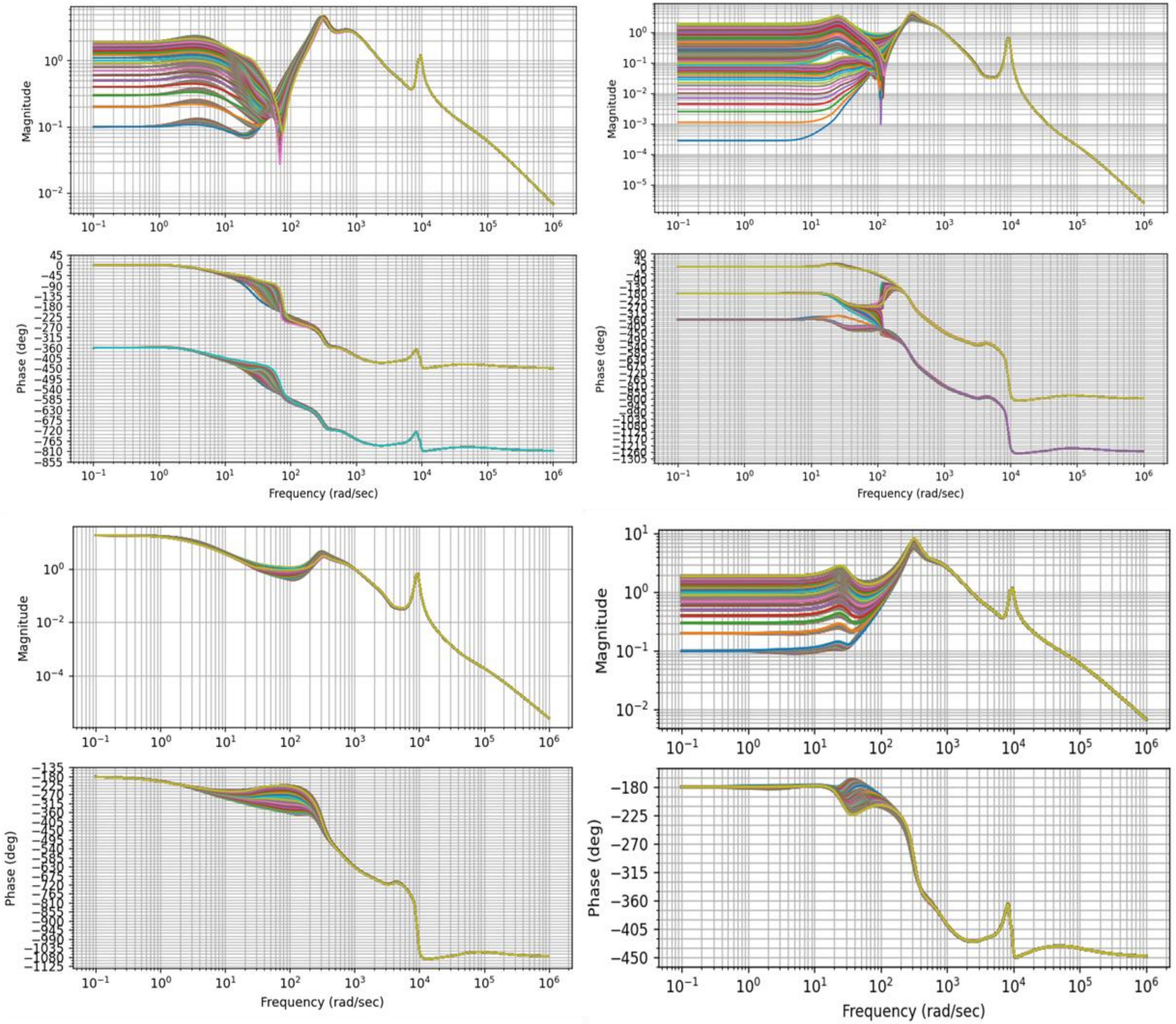
Expanding the concept further

- A power system’s operating point changes through the day
- System stability may have to be re-evaluated at different operating points
  - Cumbersome approach given system operating conditions are continuously changing with loads, variable IBRs, planned and unplanned contingencies
- **Open research question:** *Is there a way to analytically evaluate the change in stability margin when moving across various operating points?*
  - *Additionally, can this be evaluated in real time operations?*

Variation of IBR characteristics with operating point

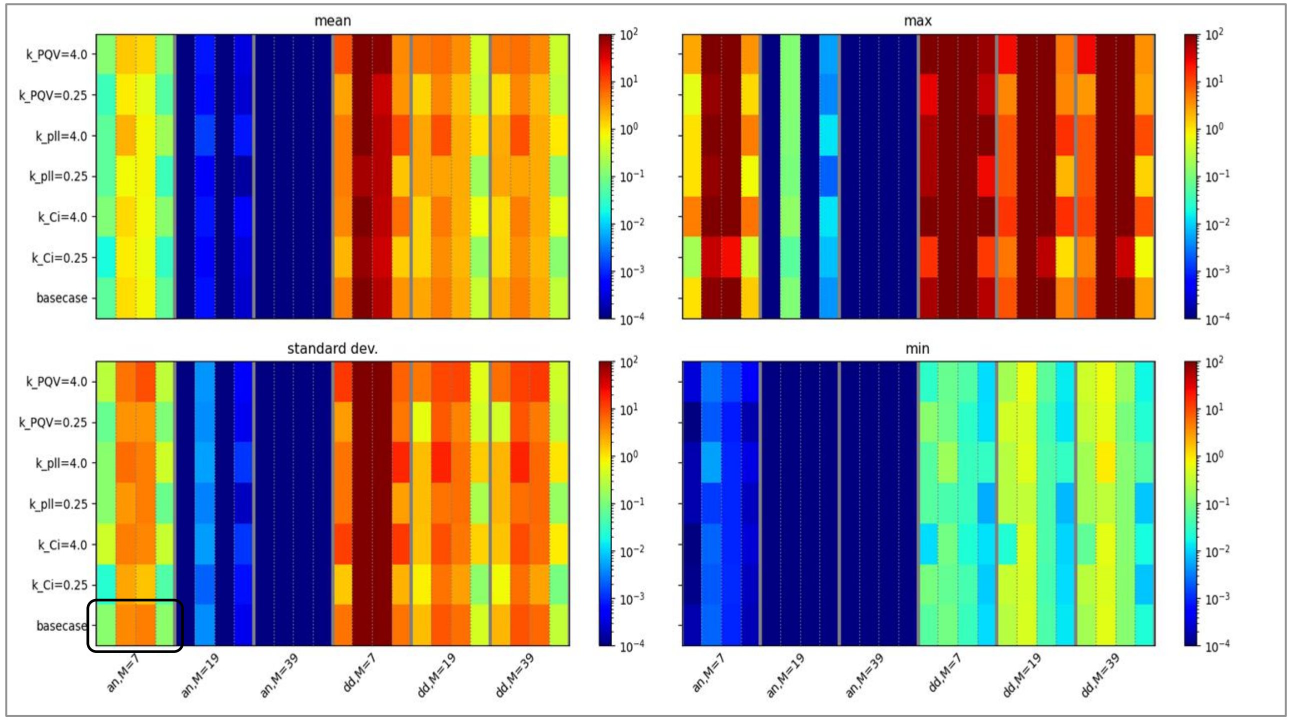
- With change in operating point (P, V):
  - IBR’s impedance profile varies
  - Closed loop stability can be impacted



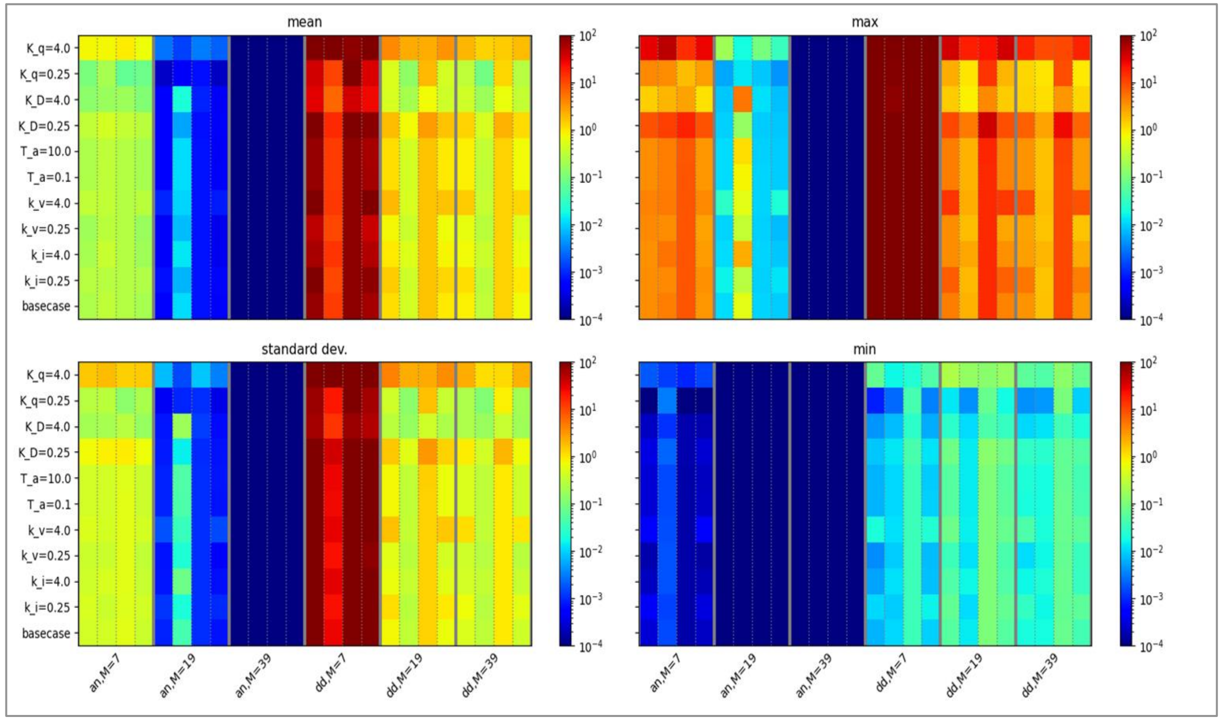


Plots created on example IBR model with variation in Pref from 0.1 to 2.0 MW and variation in Vref from 0.9pu to 1.1pu for a 2.5 MVA IBR

Prediction of frequency domain characteristics at an operating point w.r.t. control parameters and structures



IBR control structure 1



IBR control structure 2

- Different performance of varying prediction methods
- Control structure seems to have an impact on operating point base frequency domain prediction accuracy

Where does this leave us?

Do we have tools and what is needed?

- Tools (commercial and research grade) for both frequency domain evaluation and Eigen value evaluation exist and are available.
- Are we done then? No!
- Challenges that remain (non-exhaustive):
  - Handling multiple operating points in an efficient manner
  - Data sharing rules/requirements between OEM and TP/PC
  - With whom does the burden lie?
  - Using blackbox models
    - Time domain to frequency domain?
    - Linearized state space?
    - Interpreting results
  - Identification of participation in mode and assigning responsibility of mitigation
  - How much can be solved via performance requirements for interconnection request?

Contact presenter for detailed references regarding results shown in slides

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