Analysis of the Coupling Between Power System Topology and Operating Condition for Synthetic Test Case Validation

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Overview

1. Motivation
2. Driving Point Impedances
3. Correlation with Power Injections
4. Conclusion & Future Work

Motivation

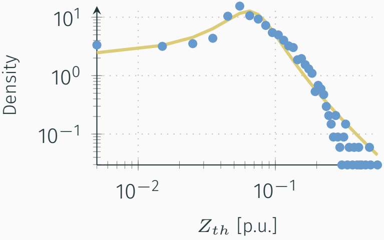
- As part of an ARPA-E project we are developing synthetic transmission system test cases
- Validation criteria are needed to ensure the fictional cases match the behavior of real cases
- The work presented is an intriguing property we observed, which we believe could serve as a valuable tool for this task
- In addition, it provides interesting new insight into the structure of power system test cases

Driving Point Impedances

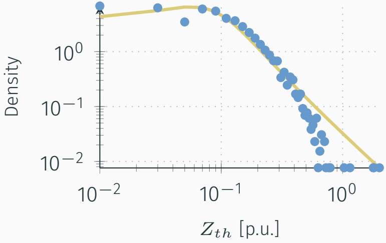
Driving Point Impedances

- Topology is explicitly represented in the Y matrix.
  - Somewhat tricky to extract a number/metric as it is an $N \times N$ object.
- Driving point impedances are the diagonal entries of $Z = Y^{-1}$.
  - The intuition that will come later is that these are the Thévenin equivalent impedances seen looking into the network.
- $Z_{ii} = Z_{th}$ distills in a sense the topology with electrical parameters of conductors into a single number.

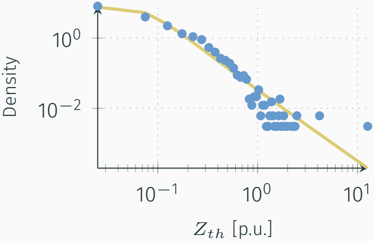
Distribution of Z_{th}



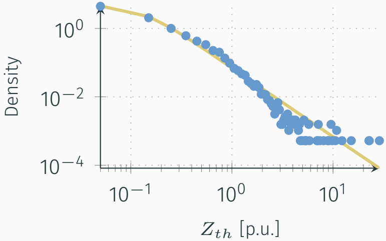
(a) 3375 Bus Winter Peak Polish Case



(b) 6515 Bus RTE Case



(c) ERCOT 2016 Case



(d) WECC 2015 Case

Fitting the Z_{th} Distribution

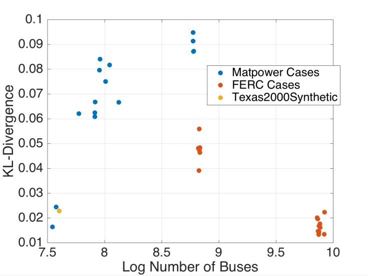
- While magnitudes vary due to system size or modeling choices (e.g. GSU included or not), the over all trend is similar
- Can be fit by a modified Cauchy Distribution

$$f(x; x_0, \gamma) = \left[\arctan\left(\frac{x_0}{\gamma}\right) + \frac{\pi}{2}\right]^{-1} \left[\frac{\gamma}{(x - x_0)^2 + \gamma^2}\right],$$

$$x, \gamma > 0, x_0 \in \mathbb{R}$$

- KL-Divergence, D_{KL}, is relatively low, indicating a good fit

$$D_{KL}(p\|q) = \int_{-\infty}^{\infty} p(x) \log\left(\frac{p(x)}{q(x)}\right) dx,$$



- We can categorize systems based on the value of their parameters from the modified Cauchy distribution
- We are mainly interested in γ since it establishes a break point where a 20 dB/decade decay begins
- This appears to grow linearly with the log of system size.

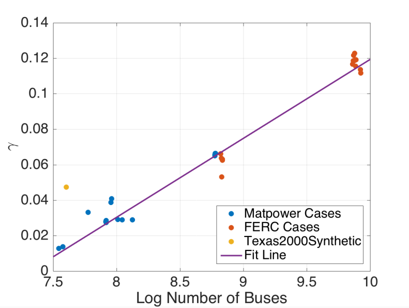


Figure 1: scale parameter γ, of the modified Cauchy distribution fit to $||Z_{ii}||$ versus system size.

Correlation with Power Injections

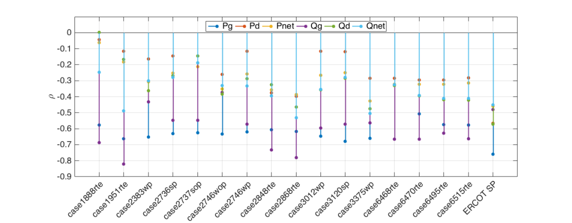


Figure 2: Correlation Coefficients $\ln \|y_i\|$ and $\ln \|Z_{i,i}\|$, where $y = \{P_g, P_d, P_{\text{net}}, Q_g, Q_d, Q_{\text{net}}\}$

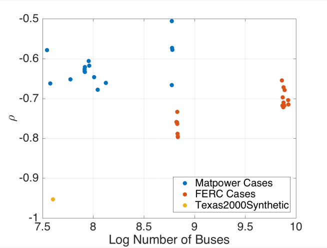


Figure 3: Correlation Coefficients, ρ, between $\ln \|P_g\|$ and $\ln \|Z_{th}\|$.

Intuition for Correlation

- Nontrivial (negative) correlation between Thévenin Impedance and real power generation
- Intuition comes from Ohm's Law:

$$\|Z\| \cdot \|S\| = \|V\|^2 \implies \|S\| \propto \|Z\|^{-1}$$

- Generalize to matrix power flow equations, considering row i:

$$Z_{ii} S_i^* = \|V_i\|^2 - \overbrace{\sum_{k \neq i} Z_{ik} \frac{S_k^*}{V_k^* / V_i^*}}^{X_i} \tag{1}$$

  - We can consider X_i as a random variable
- Still an inverse relationship but with a more variable coefficient

$$\|S_i\| \propto \|Z_{ii}\|^{-k} \tag{2}$$

Conclusion & Future Work

Conclusion and Discussion

- The driving point impedances of are shown to relatively well fit by a specific functional family: the modified Cauchy distribution.
- Parameter, γ, varies with the system size
- The driving point impedances also negatively correlate with power generation
- Suggests an intrinsic link between the structure of the system and the magnitude of injection possible.
    - This is not surprising. The system is built with this sort of concept in mind.
    - Our contribution is identifying the trend

What’s Next

- What is the practical impact of this?
- We are exploring different methods to understand the “feasible” region of loading/generation for a given system
    - Due to the non convex nature of the power flow, we do not expect to find *the* region
    - Instead we are considering reasonable “samples” of it
- Can we link these observation to the size and shape of this region?

Thank you!

Questions?