CPS: Breakthrough: Collaborative Research: WARP: Wide Area assisted Resilient Protection

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PROBLEM/CONTEXT

One wrong move by a protective relay during stressed operation can spell disaster for the power grid; E.g: 2003 NE Blackout.

OVERARCHING GOAL

Can we detect and swiftly correct relay misoperations to avert an impending cascade?

KEY IDEAS

- Supervise relay operation using Dynamic State Estimation (DSE) and extract event "fingerprints" from wide-area measurement sets and energy function components;
- Analytical approach based on energy functions to supervise relay operations associated with transmission lines;
- If relay operation is deemed "correct", do nothing. If relay operation is "incorrect", then correct (reverse) relay operation by switching in/out the system component; Resilience achieved by recovery from misoperations.

MAIN DEVELOPMENTS

- Use the Particle Filter (PF) as the primary tool for Dynamic State Estimation (DSE).
- Use estimated dynamic states to:

  - construct components of the system's energy functions which are very rich in dynamic information at the component level (such as generators, transmission lines, transformers, and loads)

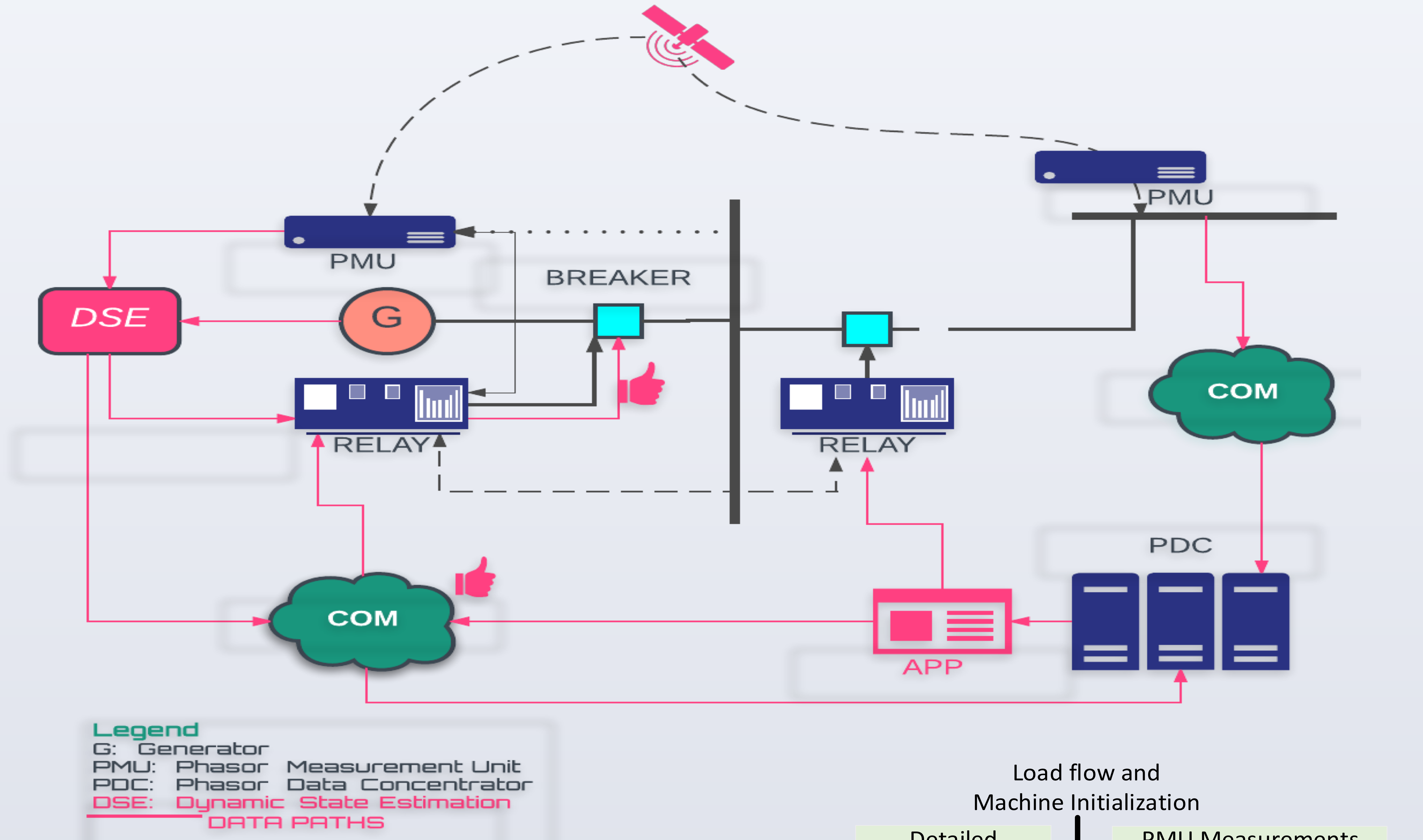
  --detect and flag "events" that might be detrimental to system stability

  --also used to forecast states in over a short time-horizon for look-ahead capabilities.

CHALLENGES

- Speed - Can we be "fast" enough? (order of a few cycles)
- Decisions – Central versus Local
- Communication Channels – Latencies and their impact
- Wide area measurements – Distinguishing "bad data" and noise from genuine system disturbances
- Developing reliable supervisory signals for relays based on DSE and energy function methods

RESEARCH HIGHLIGHTS



[1]Energy Function-based sensitivity analysis for event detection

Use Dynamic State Estimated results for energy function component reconstruction and evaluate their sensitivities to events

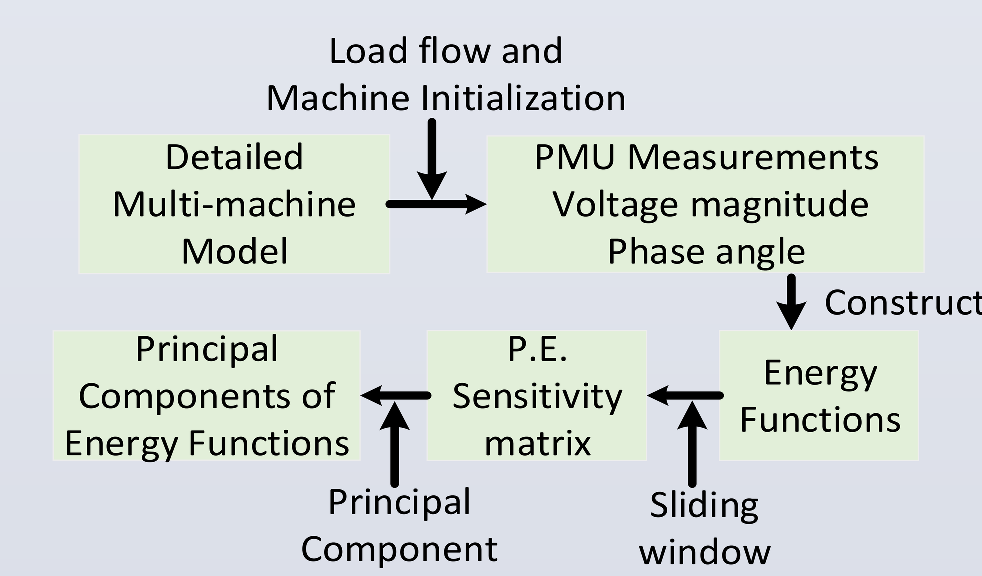


Fig 1: Methodology for computing principal components of energy functions

Events Occurring	Fault Location	Total dominant PC's	% variance
Temporary 3φ fault	bus 7/8	4	≥ 95%
Load change	bus 8	2	≥ 95%
Permanent 3φ fault	bus 7/8	4	≈90%
Excitation failure	Generator 1	2	≈95%

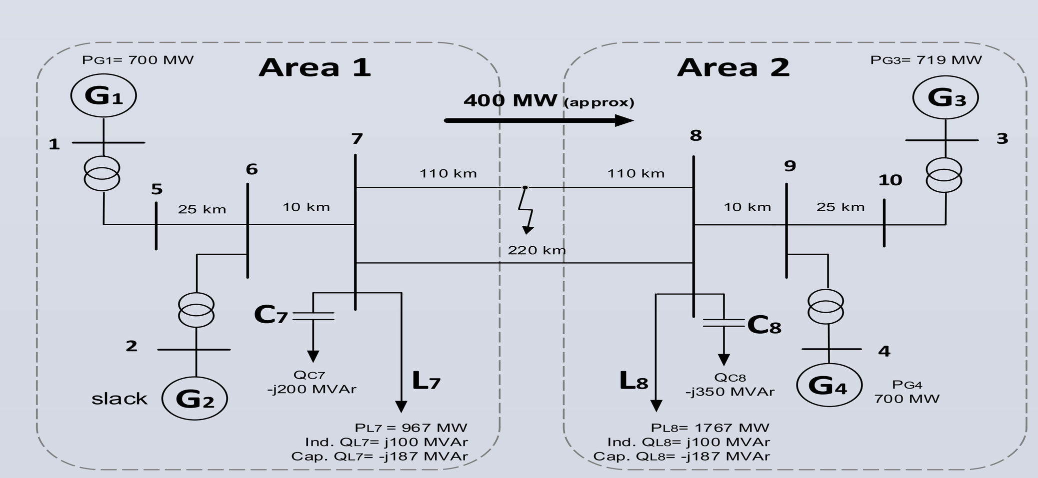


Fig 3: 2-area, 4-machine model

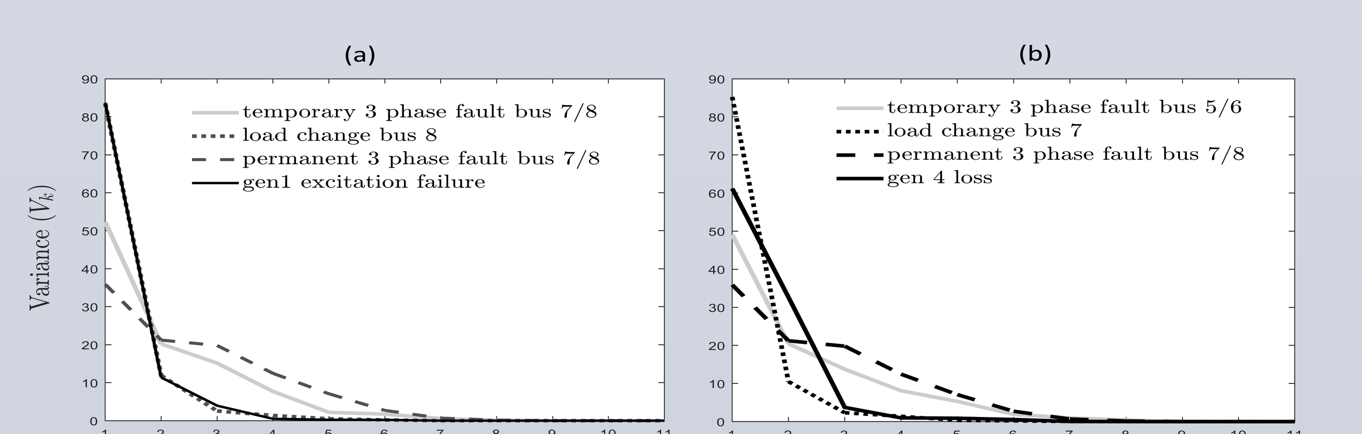


Fig 2: Elbow-scree plot for the faults, (a) Dataset 1 and (b) Dataset 2 simulated on the test system

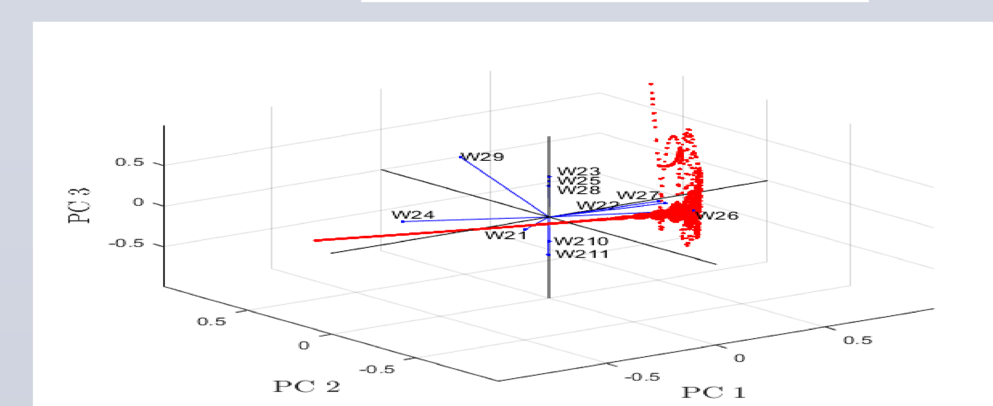


Fig 8: Biplot of principal component coefficients and scores of energy functions

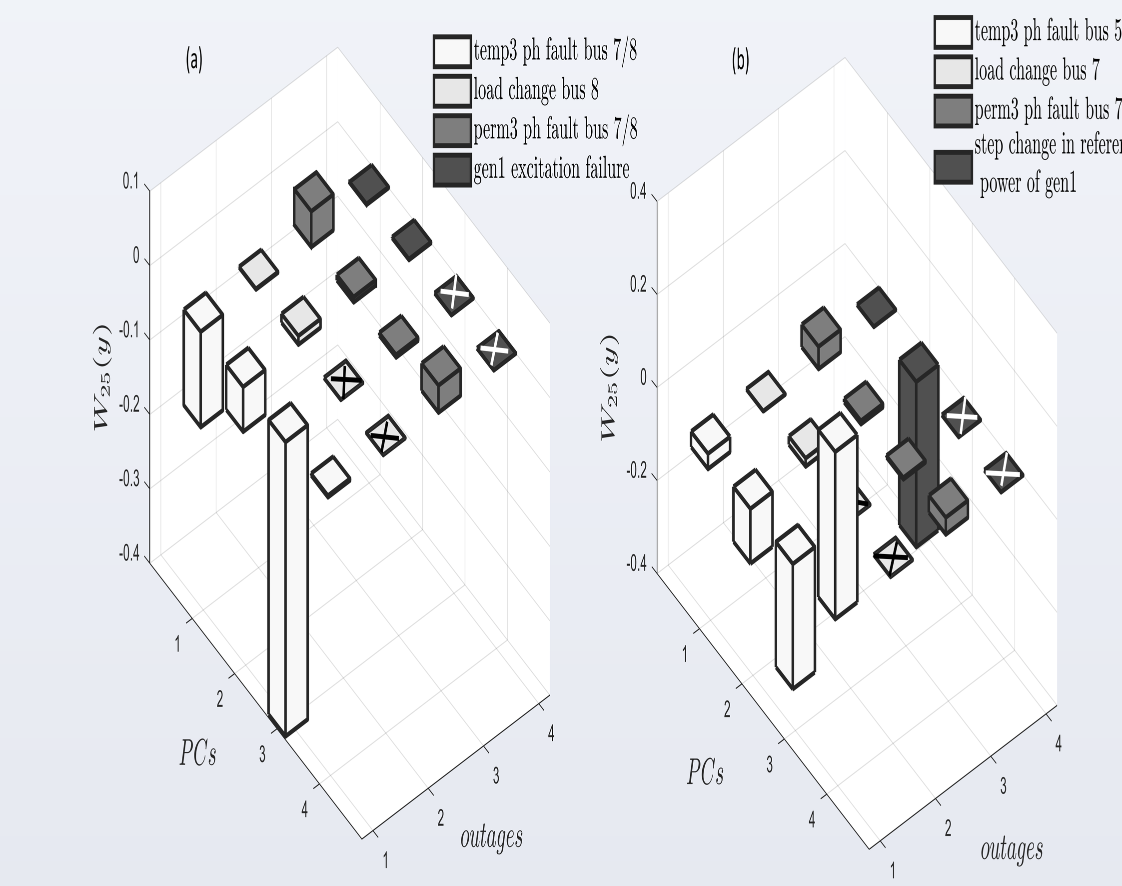


Fig 4: Change in energy component W_{25} with respect to the events in (a) Dataset 1 and (b) Dataset 2 for the (1^{st}-4^{th}) PCs.

Key Takeaways

1. From work [1,2], an alternate method of fault detection by exploring the principal components of the potential energy functions.
2. From work [1,2], method sensitive enough to detect and distinguish distinct event classes.

Ongoing Work

1) Extend analytical tools based on energy function components to provide additional insight, particularly during an evolving cascade.
2) Integrate system tools developed so far to evaluate benefits for relay misoperation.
3) Validation of proposed concepts using field recorded data.

Acknowledgements

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Products/References

1. A. Banerjee, M. Maharjan and R. G. Kavasseri, "Fault Mapping in Multi-machine Power Systems by Principal Component Sensitivity – an Energy Function Perspective", *Proc. 2018 North American Power Symposium*, Fargo, ND, Sep 9 – 11, 2018.
2. A. Banerjee and R. G. Kavasseri, "A Hybrid Approach towards Event Detection in Multi-machine Power Systems", *Proc. IEEE Power and Energy Society General Meeting*, Oregon, Aug 5-9, 2018.