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

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PROBLEM/CONTEXT

One wrong move (misopearion) by a protective relay during stressed conditions can spell disaster for the power grid. Misoperations of relays cannot be detected in real time.

OVERARCHING GOAL

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

KEY IDEAS

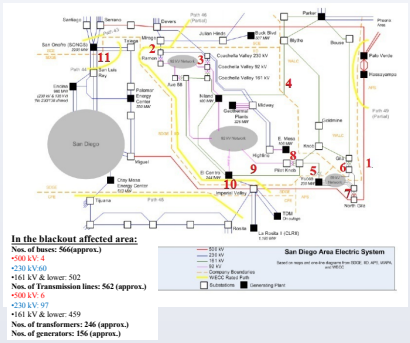
- Supervise relay operation using *components* of energy function that provide event "fingerprints", calculated using wide-area measurement sets;
- Use Dynamic State Estimation (DSE) to calculate components of energy functions where direct measurements are not available (e.g., generators);
- Dynamic simulation of a historic blackout to create test-data - Simulated data should be verified using field data available in blackout report/log;
- Use simulated data and limited available field data to test all proposed theories related to energy functions and communication.

METHOD

- Software Platform- PSLF (Positive Sequence Load flow)
- Data Reference- "Arizona-Southern California Outages on September 8, 2011: Causes & Recommendations"; Prepared by FERC & NERC
- System Description file- 2010 Heavy Summer Demand (10HS3B.epc) as an starting point
- Determination of area of focus- IID, APS, SDG&E, WALC, CFE, part of SCE
- Determination of key facilities- Transmission lines and transformers tripped during the event
- Matching the generation, load and net interchange data in the study areas available from the data reference.
- Solution of power flow and identifying the differences in flows between the software solution and measured data.
- Intelligent guess for redistributing the loads and Var elements at different buses to reduce errors between simulated and field data.
- Dynamic simulation of the whole event.
- **Challenges/Constraints**: Lack of data at more granular level. The only data source available is the report.

Simulating September 8, 2011 Arizona-Southern California Blackout

Fig.1- Overview of the affected power system



Summary of Events:

Affected elements are numbered in fig.1, and described below:

- At 15:27:39, Hassayampa-North Gila (H-NG) 500 kV line tripped. (carrying approx 1400 MW to southern San Diego) – [#1]
- Redistributed flows through Imperial Irrigation District (IID) network (parallel in nature with H-NG) caused to trip IID's northern transmission resources namely Ramon 230/92 kV transformer [#2], Coachella Valley 230/92 kV transformer [#3], Blythe-Niland 161 kV line [#4] by 15:32:13 - **4 min. 34 s.**
- After that, the flows redistributed through Yuma area load pocket and eventually tripped Yucca 161/69 kV transformers [#5] and Gila 161/69 kV transformers [#6] by 15:36:40, leaving Yuma load pocket to draw power through N.Gila 500/69 kV transformers [#7] only – **9 min. 1 s**.
- Increased flows caused Pilotknob 161/92 kV tansformers [#8] and Pilotknob-Elcentro 161 kV line [#9] (Z-3 operation due to load encroachment) to trip. This left IID with only one transmission source- ImperialValley-Elcentro 230 kV (S) line [#10]. S line tripped on 15:38:02 creating IID island – **10 min. 33 s**.
- The aforementioned events were gradually increasing the current in Path 44 [#11]. The current finally reached 8700 amps- enough for tripping (>8000 amps) Path 44. Path 44 tripped at 15:38:21, causing the San Diego island. Frequency in the island dropped rapidly and the generators and loads tripped eventually – **10 min. 52 s to Blackout.**

Error result from the comparison between simulated and actual flows in key lines

We made the comparison of the flows from the simulation at **13 different time stamps** as provided in the report. The errors are plotted below:

Fig.2a- MW errors

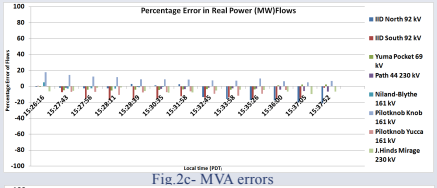


Fig.2b- MVAR errors

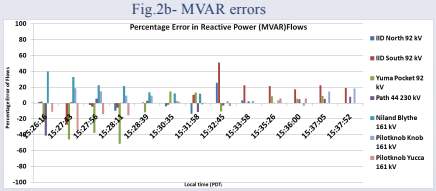
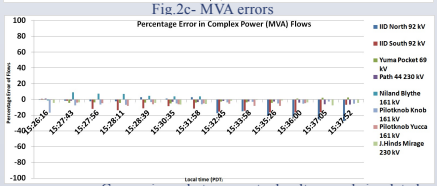


Fig.2c- MVA errors



Observations:

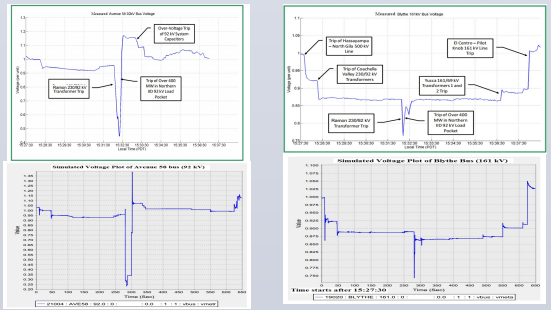
• The simulated result shows close proximity with the actual data. The final average error for the flows are:

$Error_{MW}$= 7.79%

$Error_{MVAR}$= 12.10%

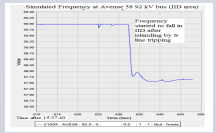
$Error_{MVA}$= 8.26%

Comparisons between actual voltage and simulated voltage



Simulated Frequency Plot

Fig.4 - frequency in IID



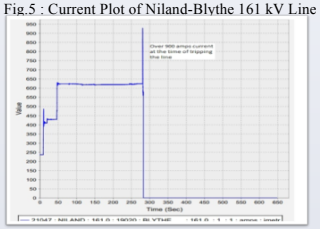
More Results/Observations

- Simulation results also seem consistent at the times when different elements tripped.

Table1: Simulated data at the time of tripping

Local Time (HH:MM:SS)	Time in simulation (in sec)	Equipment Name	Current required to trip	Current observed in Simulation
15:32:33	283s	Niland-Blythe 161 kV Line	762 amps	>900 amps (Fig.5)
15:37:41	552s	Pilotknob 161/91 kV Transformer LV side	268 amps	348 amps
15:38:18	648s	Path 44 (five 230 kV lines from SONGS to San-Diego)	8000 amps	8103 amps

Fig.5 : Current Plot of Niland-Blythe 161 kV Line



Future Work

1. Inserting the relay models in the dynamic simulation and tripping the elements through relays.
2. Implementing the transmission line energy function component on simulated data to check if the misoperations of line relays can be detected.
3. Implementing DSE method on simulated data to check if false tripping of generators can be detected.
4. Exporting the simulation data in different formats (eg, PSSE) to make the simulation compatible to run on different platforms.
5. Archive the simulation data and disseminate.

Acknowledgements

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References

1. Report prepared by the Federal Energy Regulatory Commission (FERC) and the North American Electric Reliability Corporation (NERC), "*Arizona- Southern California Outages on September 8, 2011: Causes and Recommendations*", https://www.ferc.gov/legal/staff-reports/04-27-2012-ferc-nerc-report.pdf

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