Simplifying Wide Area Coordination Of Directional Time Overcurrent Relays Using Automatic Settings Selection

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Presentation Outline

• Challenges in DOCR Wide Area Coordination

• Our Approach and Previous Work

• Experimental Results

• Conclusion and Future Work
Wide Area Coordination

“Wide-area coordination (WAC) analysis is the evaluation of protective device selectivity and sensitivity at a system level (multiple layers of adjacent terminals) with a goal of improving system reliability” [Barman 2014].

• Wide-area coordination is a labor intensive, difficult process.

• Automated tools to verify coordination exist, but less work has been done to automate development of coordinated settings to avoid (or fix) reported violations.

• PRC-027-1 is on the horizon! WAC must be performed with increasing frequency.
Wide Area Coordination

Directional Time Overcurrent Relay coordination is a key component of the wide area coordination problem.

• Difficulty in tightly coupled systems; requires selecting settings for each relay:
  1. Pickup
  2. Time Dial
  3. Curve Type

• Existing approach requires manual, iterative adjustment of settings by the engineer.
6 Bus System With Tight Loops

Taken from [Moirangthem, Dash, Ramaswami 2011].
Our Approach

• Use an *auto-tuner* which can quickly create coordinated relay settings based on guidance from an engineer. Draw from academic literature. Extend for real world grids.

• Leverage our previous work for the automation workflow.
  ✓ Input collection (e.g., backup relay pairs, fault currents) from short circuit program [Boecker, Corpuz, Perez, Hankins 2017].
  ✓ Automated coordination verification [Thomas, Perez, Hankins, Tribur 2018].

• Remove tedious manual settings adjustment. Allows engineer to rapidly test different coordination strategies.
  ✓ Different input fault studies, CTI requirements, etc.
Previous Work in Auto-tuning

Academic literature is rich in ideas, tracks trends in computer science, machine learning, & artificial intelligence.

• Two surveys

• Optimization Theory
  [Urdaneta 1988], [Birla 2006], Damchi [2018]

• Many other approaches:
  ✓ Genetic algorithms [Ravazi 2008]
  ✓ Reinforcement learning [Kilickiran 2018]
  ✓ Graph theory [Madani 1998]
Auto-Tuning Coordination Workflow

- Coordination Project Inception
- Parameter / Constraint Definition
- Supervised Refinement
- Analysis and Verification
- Project Completion

Settings Selection Framework

- Input Collector
- Settings Generator
- Coordination Verifier
- Unsupervised Refinement

Fault Simulation Software
Experimental Setup

• Used optimization theory Settings Generator based on [Urdaneta 1988] and [Damchi 2018].

• Input Collector based on [Boecker, Corpuz, Perez, Hankins 2017].

• Coordination Verifier based on [Thomas, Perez, Hankins, Tribur 2018].

• ASPEN OneLiner V14.6, Intel Core i3-4160, 8GB RAM.

• 3-bus, 9-bus, real world power systems tested.
Experimental Setup

• Tuning requirement: No CTI violations allowed.

• Goal: Minimize response time to Close In fault.

• Initial input provided to settings selector:
  ➢ Relay Primary / Backup Pairs
  ➢ Fault Current Information (for primary and remote lines).
    ✓ Close In, End Open
    ✓ Close In
    ✓ Line End
Experiments – 9 Bus System

- Synthetic power system taken from ASPEN example file.
- 9 buses, 18 relays.
- For auto-tuned settings, backup relays required to respond to line end fault on all remote lines.

- Parameters (taken from SEL 421)
  - Curve: ANSI U3
  - Pickup: [0.25..16]
  - Time Dial: [0.5..15]
  - CT Ratios: Target 20amps secondary for close in fault.
  - CTI: 0.3333
9 Bus System One-Line

Diagram showing the connections and labels for various buses and lines in a 9 bus system.
Results – 9 Bus System

- All relays’ response times are below 1sec for line end fault.
  - Probably slow down further to allow response of Zone 2 element.

- CTI coordination verified.

- Entire coordination + verification computation time: ~30sec.
Experiments – Real World System

• Power System from customer whom wide area coordination was previously performed manually.

• More complex – parallel lines, each ~100 miles long.

• Interconnected – Auto-tuner selected settings for backups in adjacent system (but did not consider their backups).

• Parameters (taken from SEL 421)
  ✓ Curve: ANSI U3
  ✓ Pickup: [0.25..16]
  ✓ Time Dial: [0.5..15]
  ✓ CT Ratios: As previously defined by customer.
  ✓ CTI: 0.3333
Real World System One-Line
Problem Refinement – Real World System

- No solution found to first problem formulation. 
  *Likely due to very long parallel line and remote line end fault response requirement.*

- Engineer refined formulation: *Allow backup relays not to respond to line end fault, but require response to 10% intermediate fault.*

- Simple change, but demonstrates the quick workflow enabled by the auto-tuner.
Results – Real World System

- Response times generally faster than other experiments.
  - Due to relaxation of required response to line end faults on remote lines.
  - As expected, slower response on parallel line relays.
- CTI coordination verified.
- Entire coordination + verification computation time: ~30sec.
Conclusions

• Wide Area Coordination is important for system reliability and is becoming increasingly prevalent (PRC-027-1).

• Existing methods are effective to verify coordination, but do not completely address how to resolve with coordinated settings.

• Presented a solution for Directional Time Overcurrent Relays, one of the challenges of wide area coordination.

• Automated the workflow, auto tuned settings for all relays that are fully coordinated.
Future Work

• Extend the framework to automate more of the wide area coordination problem:
  ➢ Zone 2 distance element coordination together with DOCRs.
  ➢ Different optimization goals:
    ✓ Explore tradeoff between selectivity and sensitivity.
    ✓ Minimize the numbers of relays whose existing settings are changed.
  ➢ Additional parameters (e.g., select per relay overcurrent curves).
  ➢ Incorporation of more best practices / rules of thumb
    (filter response to very low currents, etc).

• Work with partners to run on larger and more complex real world power systems.
QUESTIONS

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