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].

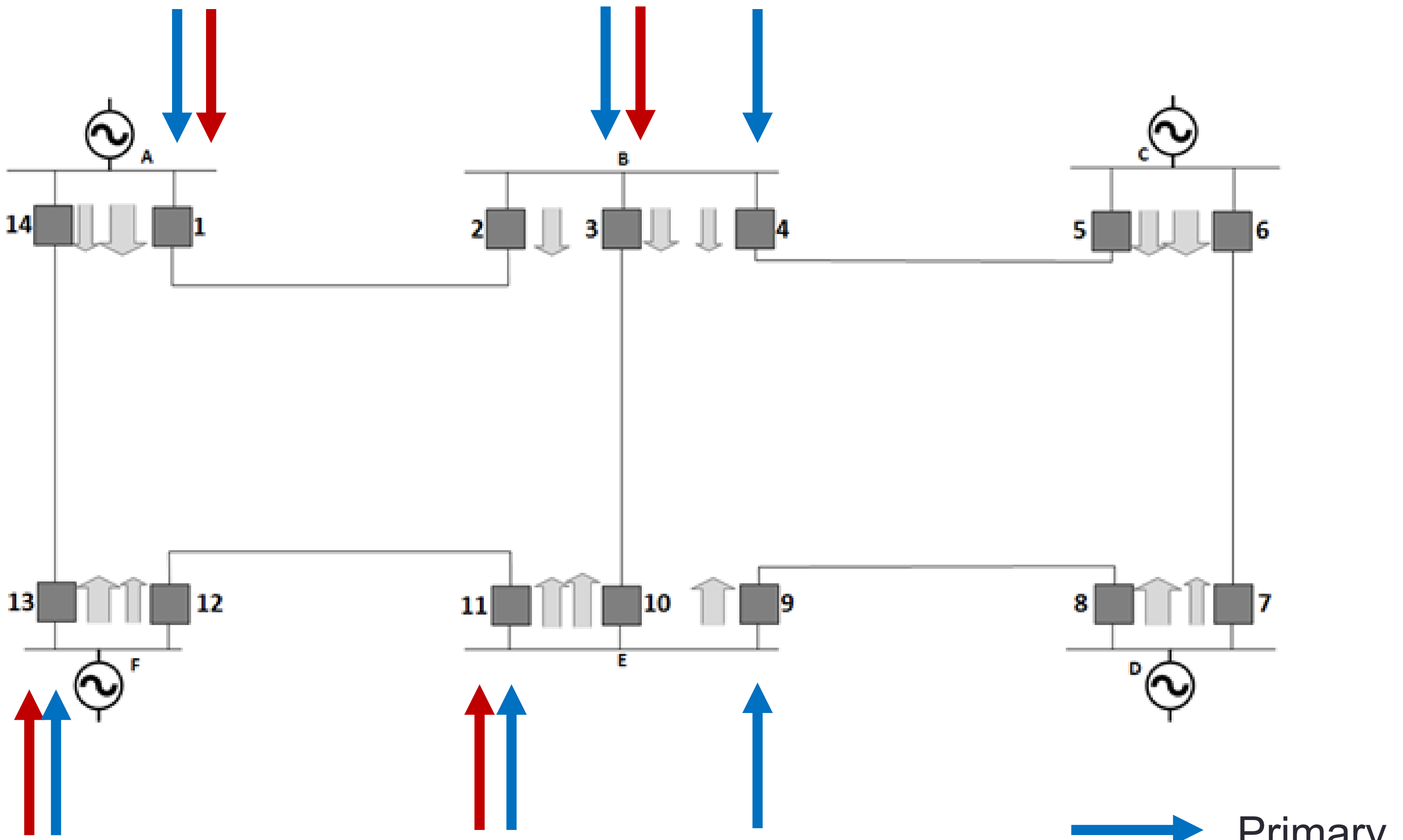
- Wide-area coordination is a labor intensive, difficult process.
- Automated tools to verify coordination exist, but less work has been done to automate development of coordinated settings to avoid (or fix) reported violations.
- PRC-027-1 is on the horizon! WAC must be performed with increasing frequency.

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

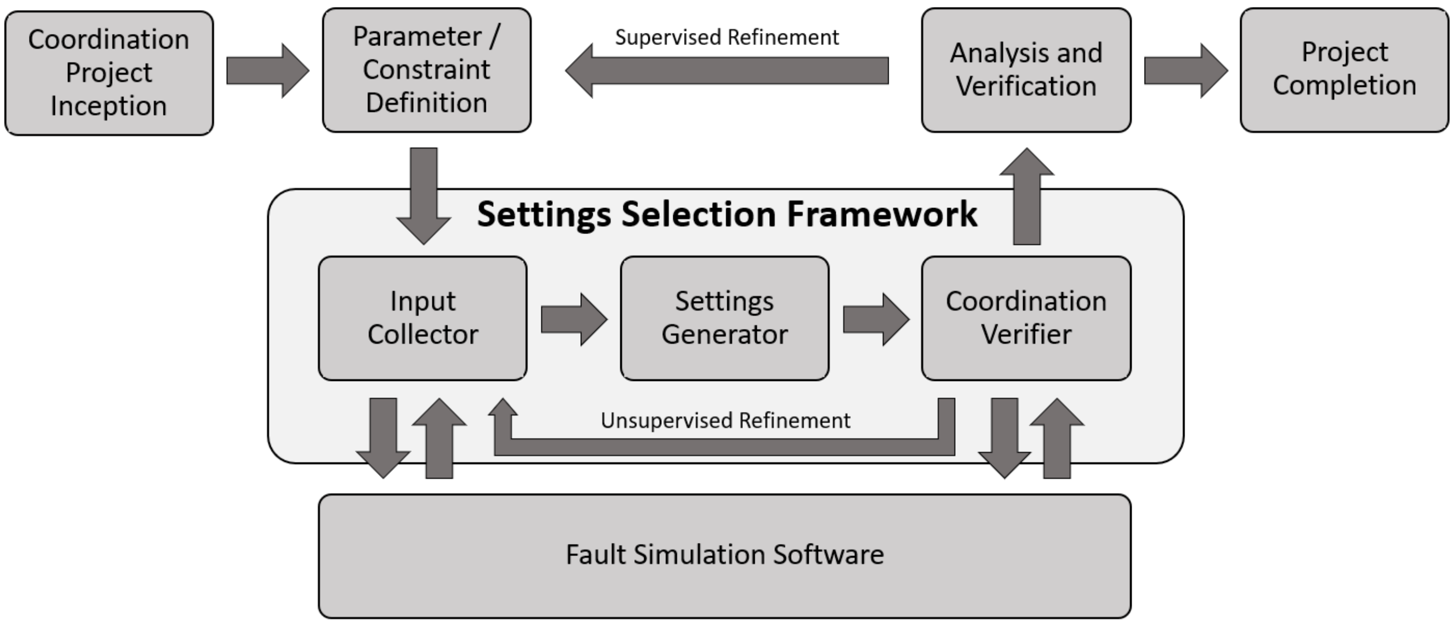
- Use an ***auto-tuner*** which can quickly create coordinated relay settings based on guidance from an engineer. Draw from academic literature. Extend for real world grids.
- Leverage our previous work for the automation workflow.
  - ✓Input collection (e.g., backup relay pairs, fault currents) from 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
  [Moirangthem 2011] & [Birla 2005]
- 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



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.

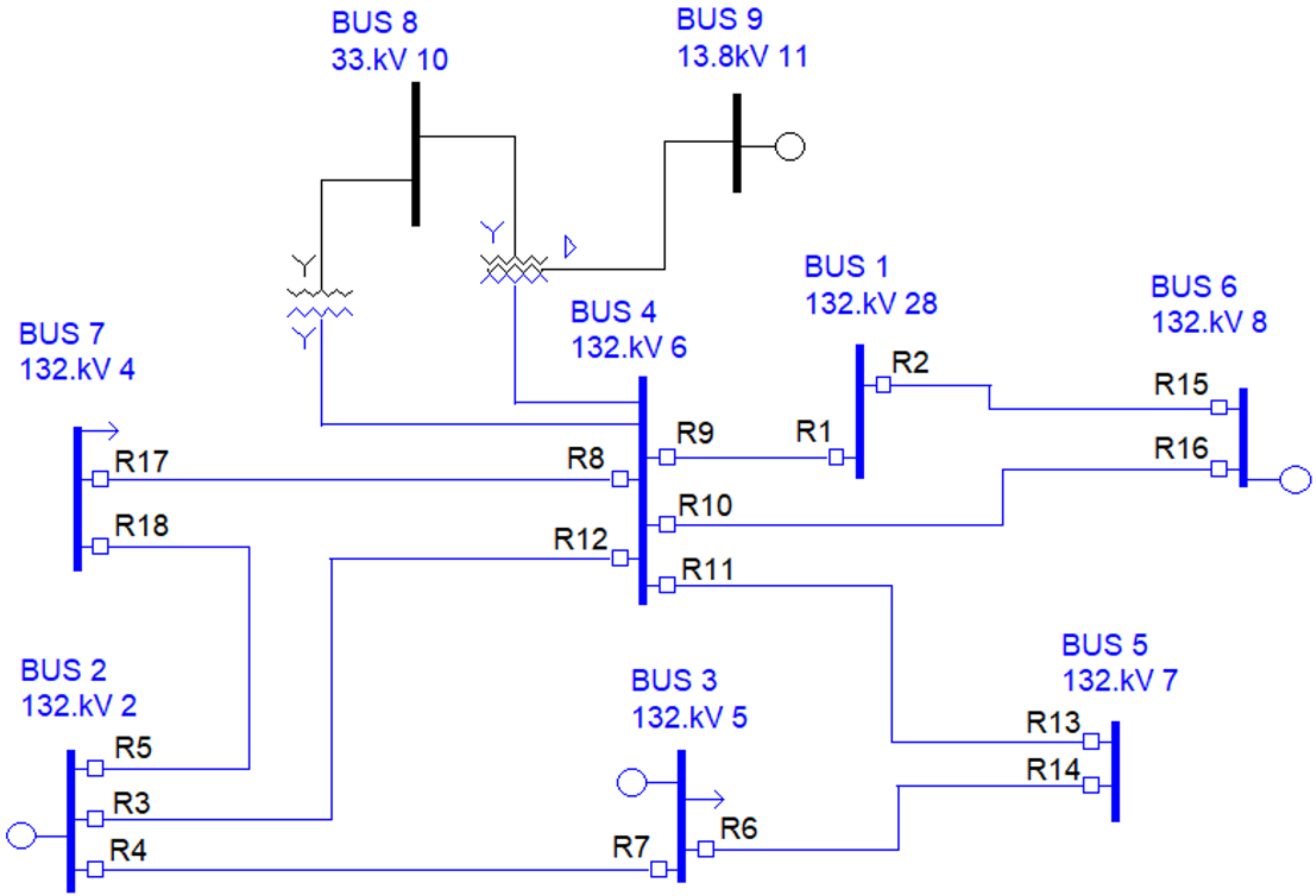
Experimental Setup

- 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



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.

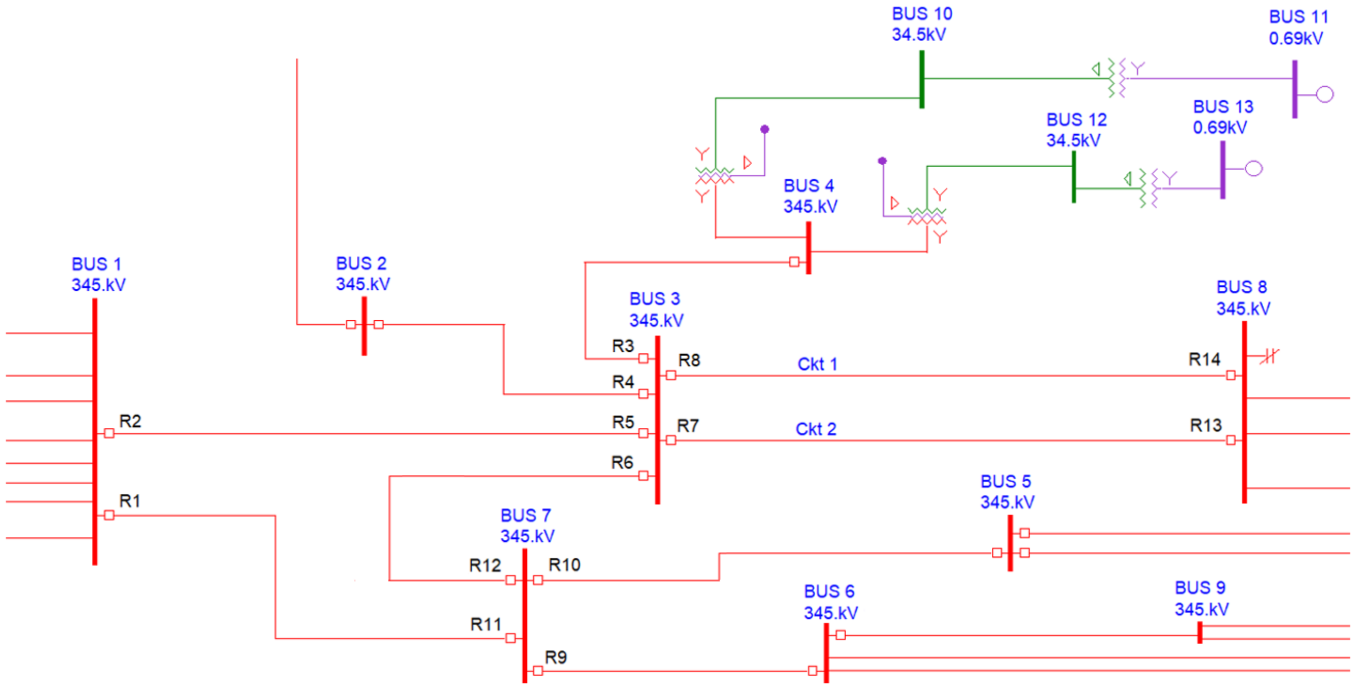
CACULATED SETTINGS AND RESPONSE FOR 9-BUS SYSTEM

Relay	I_{set}	TMS	T_{LE} (s)
R1	1.4059	4.1602	0.4779
R2	2.8317	0.8774	0.4610
R3	2.4526	0.5383	0.3302
R4	2.7968	0.5219	0.4155
R5	4.0043	0.5000	0.6830
R6	5.0245	0.5059	0.5838
R7	2.1344	0.8517	0.3568
R8	6.7189	0.5190	0.5435
R9	6.2713	0.5748	0.4715
R10	4.0927	0.9471	0.3364
R11	5.5285	0.5000	0.5382
R12	1.9652	0.9592	0.3238
R13	4.0366	1.0660	0.4193
R14	4.1494	0.9338	0.4113
R15	3.8561	0.5053	0.7861
R16	3.6525	1.1543	0.3068
R17	5.3283	1.2443	0.4269
R18	2.0971	1.5784	0.4628

Experiments – Real World System

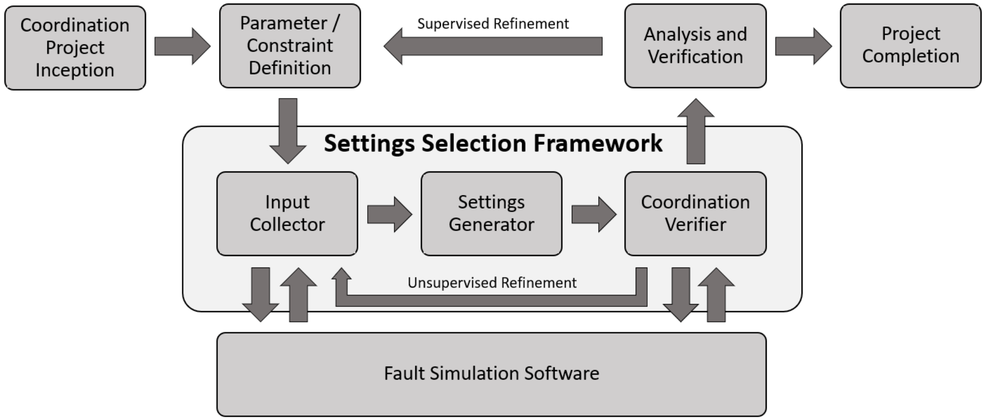
- Power System from customer whom wide area coordination was previously performed manually.
- More complex – parallel lines, each ~100miles long.
- Interconnected – Auto-tuner selected settings for backups in adjacent system (but did not consider their backups).
- Parameters (taken from SEL 421)
  - ✓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.

CALCULATED SETTINGS AND RESPONSE FOR REAL WORLD SYSTEM

Relay	I_{set}	TMS	T_{LE} **(s)**
R1	7.5871	0.5000	0.1355
R2	2.6634	1.3937	0.1616
R3	0.2500	0.5000	0.0482
R4	0.2500	0.5000	0.0486
R5	1.9895	1.2070	0.1478
R6	5.5834	0.5327	0.1801
R7	4.1376	4.3878	0.4701
R8	4.1309	4.4059	0.4718
R9	5.7930	0.5593	0.1686
R10	0.2500	0.5000	0.0483
R11	3.7933	0.5252	0.1581
R12	4.8413	0.5363	0.1737
R13	2.4660	0.9348	0.1031
R14	2.4612	0.9256	0.1020

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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