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A Graph Theory Approach for Placing Overcurrent Relays and Reclosers for Economical Protection of Meshed Transmission Networks

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Introduction

- Penetration of power grid by renewables becoming more widespread
  - Renewable energy resources
  - Distributed storage
  - Distributed generator
- Increased protection complications/concerns as direct result
  - Standard non-directional radial protection may be rendered useless
- Meshed networks useful for resilience
  - More expensive standard protection schemes required
- What if resources are limited?
  - Lower cost options need to be considered
  - Distance relay cost potentially 8-10 times more than overcurrent relays

Prior Work

In prior work, an algorithm was developed to determine a minimum breakpoint set (MBPS).

1. R. C. Matthews, M. J. Reno and A. Summers, "A Graph Theoretical Method for Identification of a Minimum Breakpoint Set for Directional Relay Coordination," Electronics: Control of Microgrids, pp. 1-19, 2019.

In prior literature, definitions for both the MPBS and its cardinality were found to be erroneous.

- A proof for establishing the cardinality of the MBPS was presented

The method laid out in [1] for determining a MBPS is built upon in the current work

Cost Consideration

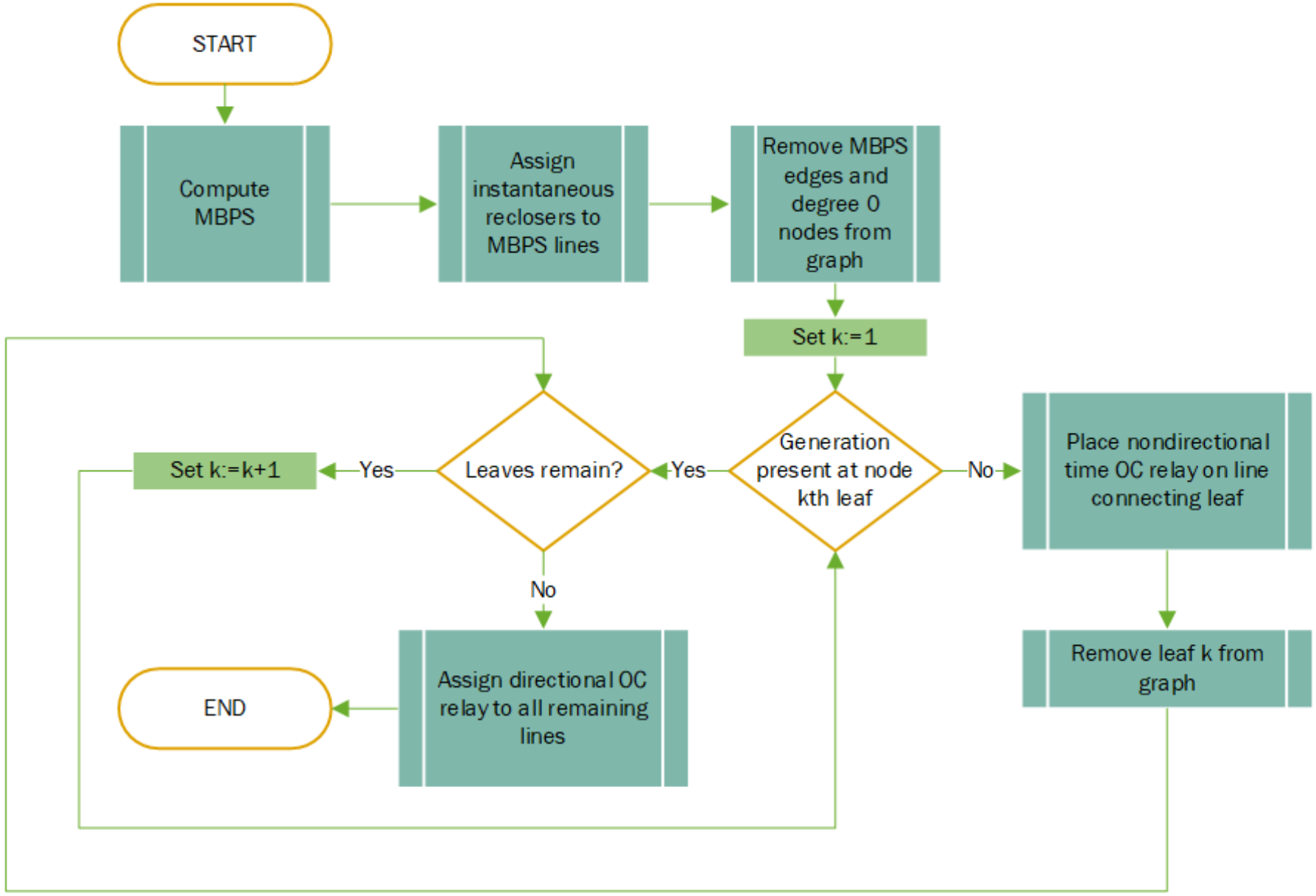
Relay	Type	Cost Range	VT Req.
SEL-321	Distance	$7390-8136	Yes
SEL-551	Nondirectional OC	$910	No
SEL-851	Directional OC	$910-1872	No

- Cheapest distance relay nearly 4 times as expensive as most expensive directional overcurrent relay
- Distance relay requires additional hardware component
  - Voltage Transformer (VT)

Proposed Method

1. Determine an MBPS using algorithm proposed in [1]
   a) Place instantaneous OC reclosers in MBPS locations
2. Remove MBPS from further consideration
3. Find all nodes in graph with degree 1 (leaves)
   a) If none exist, go to Step 5
4. For each leaf, determine whether generation is present
   a) If no, place nondirectional time OC relay on line
   b) If yes, return to Step 3.
5. Assign all remaining lines directional time OC relays

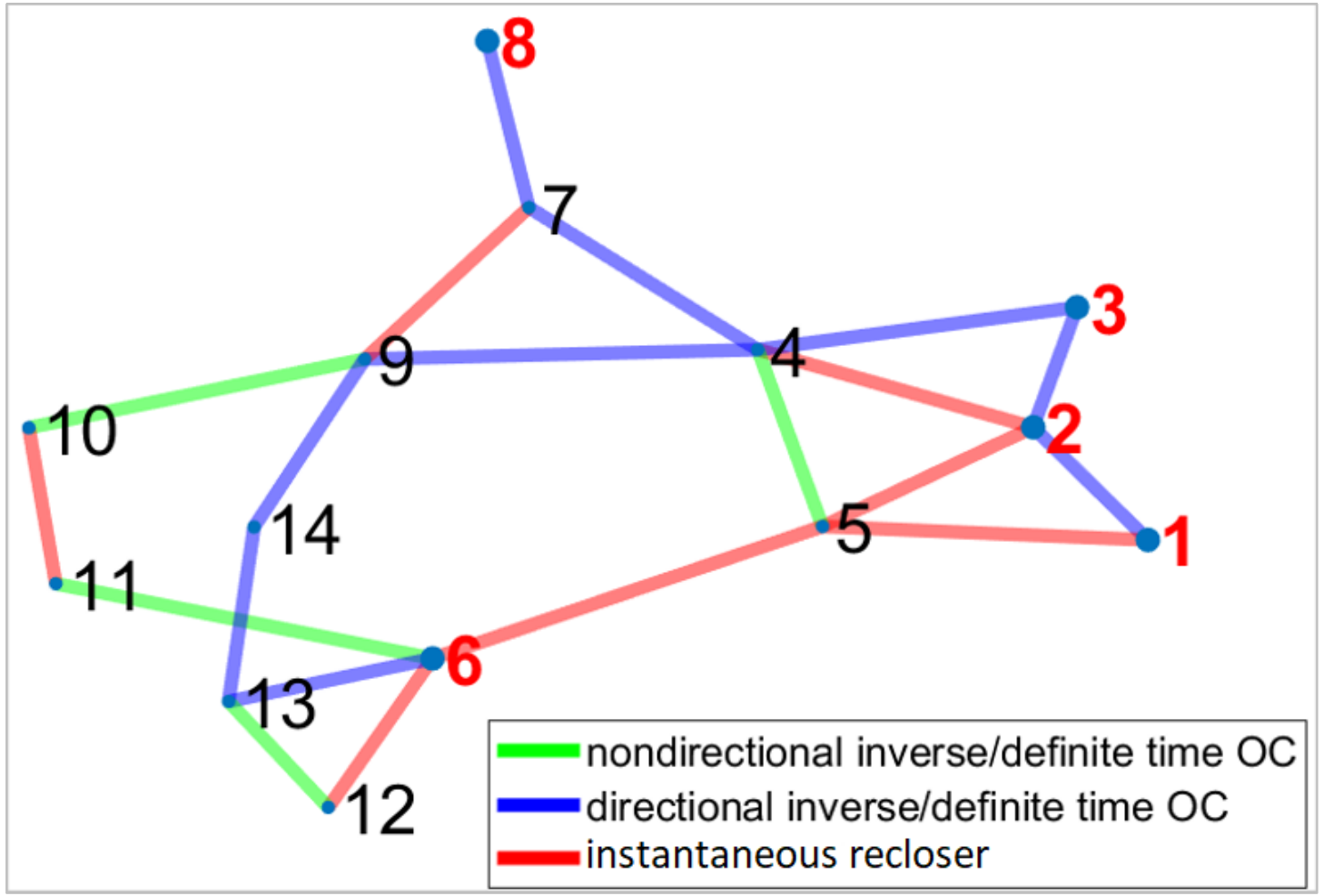
Proposed Method



Performance Notes

- Bus Fault
  - System will sectionalize to clear fault (weakness)
- Line Fault Not on MBPS line
  - Reclosers will instantaneously open when fault occurs
  - Relay on faulted line will subsequently trip after time delay
  - Network will remain unsegmented after fault clears
- Line Fault on MBPS Line
  - Reclosers will repeatedly shoot until the remain open
  - Remaining system will be radial (assuming all reclosers experience fault-level current)
- Oscillations
  - Multiple reclosers opening at once may cause substantial transients during trip/reclose processes.
  - Transient stability to be examined in future work

Results: IEEE 14-Bus (Device Placement)

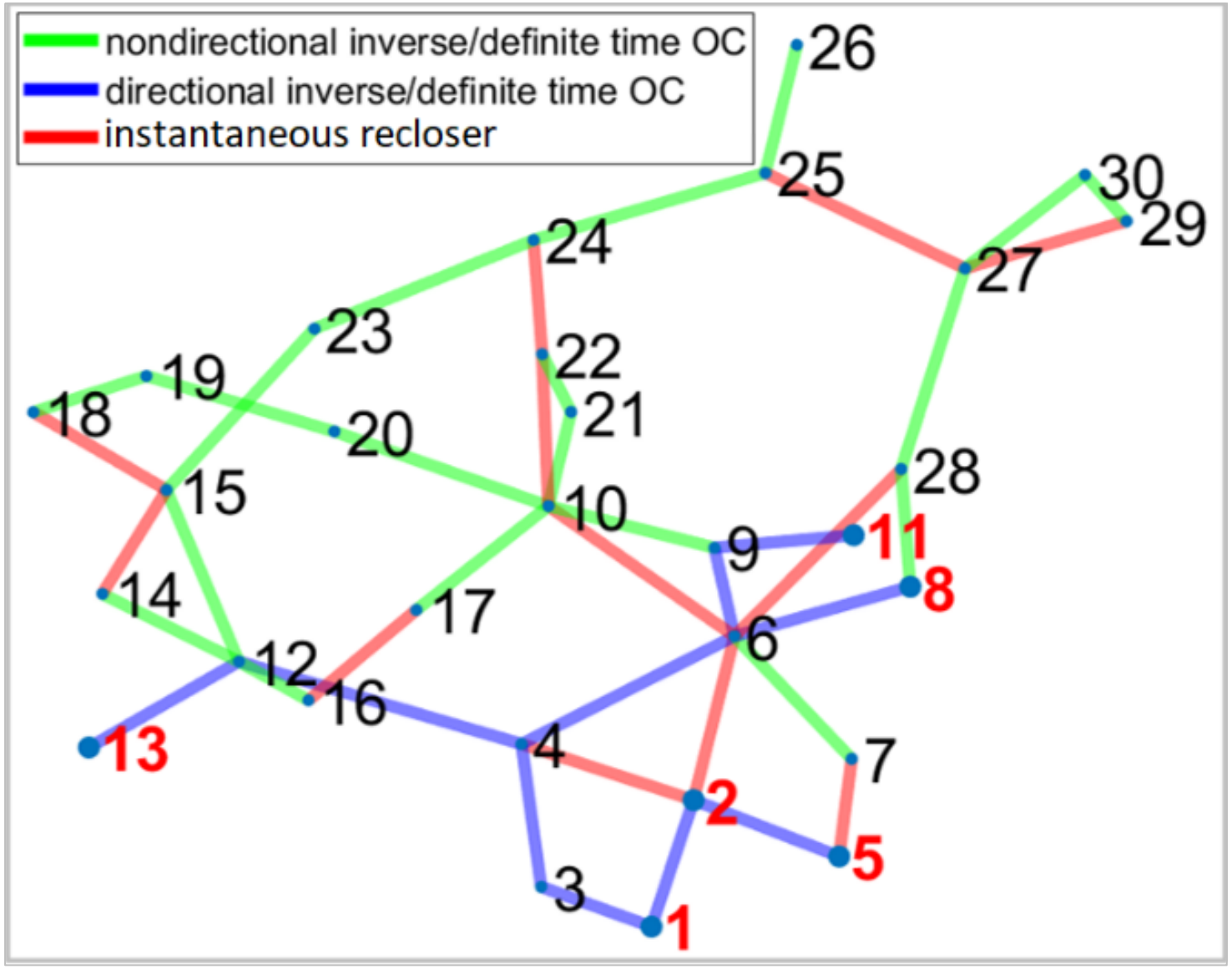


Results: IEEE 14-Bus (Phase and Ground Settings)

Location		Phase Settings			
From	To	Pickup (A)	TDS	Type	Description (US)
1	2	515.3	1.8	U4	Extremely inverse
2	1	352.5	0.1	DT	Definite time
2	3	597.5	1.9	U1	Moderately inverse
3	2	31.0	0.4	DT	Definite time
3	4	162.8	11.6	U5	Short-time inverse
4	3	150.4	0.7	DT	Definite time
4	5	40.8	4.3	U5	Short-time inverse
4	7	83.2	10.5	U5	Short-time inverse
7	4	393.0	1	DT	Definite time
7	8	83.2	2	U5	Short-time inverse
8	7	393.0	1.3	DT	Definite time
4	9	168.7	7.5	U4	Extremely inverse
9	4	30.0	1	DT	Definite time
9	10	56.6	1.6	U4	Extremely inverse
9	14	45.8	4.9	U1	Moderately inverse
14	9	68.8	1.3	DT	Definite time
13	14	68.9	5.6	U1	Moderately inverse
14	13	30.0	0.9	DT	Definite time
13	12	33.3	0.1	DT	Definite time
6	13	169.6	1.1	U4	Extremely inverse
13	6	30.0	0.6	DT	Definite time
6	11	39.5	3	U5	Short-time inverse
1	5	351	-	IT	Instantaneous
2	4	259	-	IT	Instantaneous
2	5	191	-	IT	Instantaneous
5	6	211	-	IT	Instantaneous
6	12	35	-	IT	Instantaneous
7	9	10	-	IT	Instantaneous
10	11	26	-	IT	Instantaneous

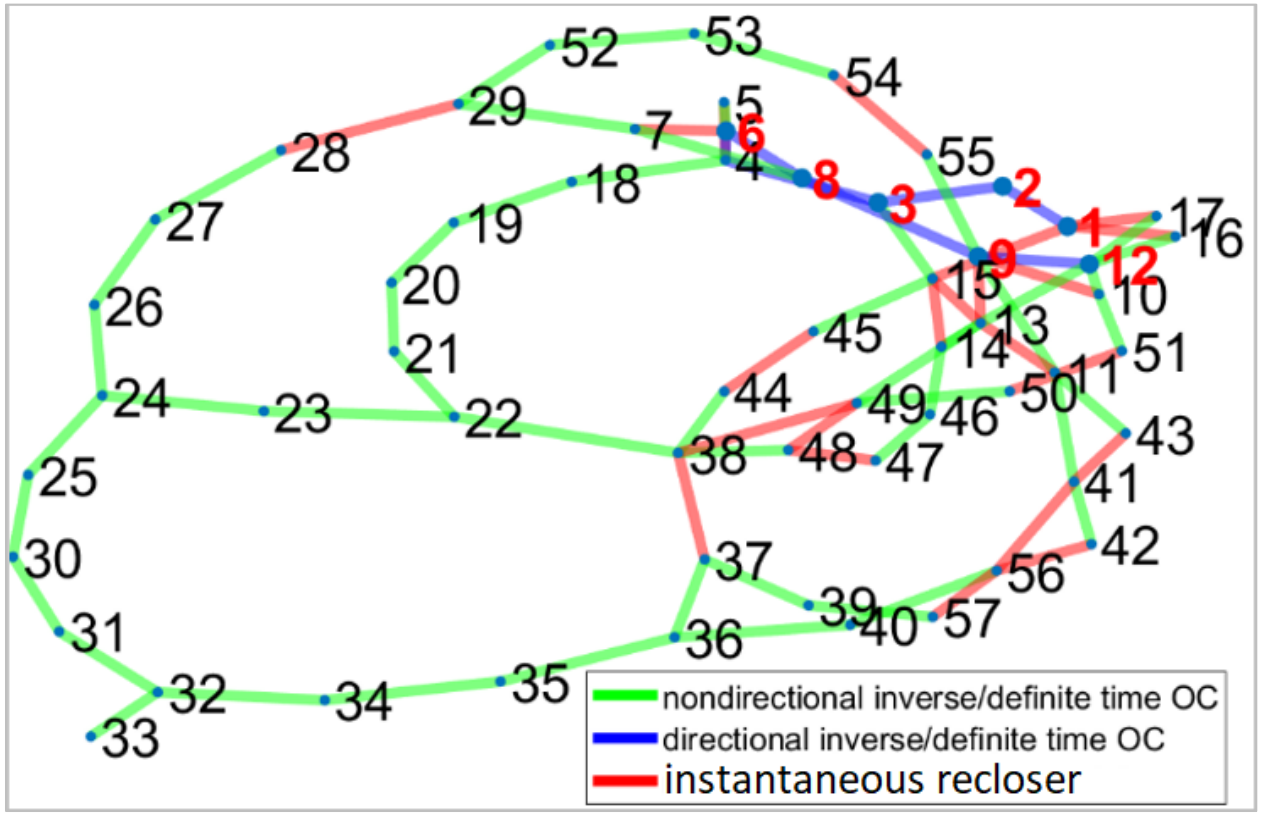
Location		Ground Settings			
From	To	Pickup (A)	TDS	Type	Description
1	2	25.4	10.2	U4	Extremely inverse
2	1	153.3	0.6	DT	Definite time
2	3	18.9	5.5	U4	Extremely inverse
3	2	6.0	0.6	DT	Definite time
3	4	5.0	5.8	U1	Moderately inverse
4	3	7.5	1	DT	Definite time
4	5	5.0	4.9	U4	Extremely inverse
4	7	68.9	7.7	U4	Extremely inverse
7	4	7.8	1.3	DT	Definite time
7	8	68.9	6.7	U4	Extremely inverse
8	7	8.0	1.9	DT	Definite time
4	9	8.4	5.9	U1	Moderately inverse
9	4	9.6	1	DT	Definite time
9	10	5.0	7.7	U4	Extremely inverse
9	14	45.8	5.4	U4	Extremely inverse
14	9	5.0	1.3	DT	Definite time
13	14	5.0	10.2	U1	Moderately inverse
14	13	5.0	1	DT	Definite time
13	12	5.0	0.3	DT	Definite time
6	13	5.0	9.4	U3	Very inverse
13	6	12.2	0.3	DT	Definite time
6	11	5.0	12.7	U2	Inverse

Results: IEEE 30-Bus (Device Placement)



Results: IEEE 57-Bus (Device Placement)

Nondirectional time OC relay locations		Nondirectional time OC relay locations		Nondirectional time OC relay locations	
from	to	from	to	from	to
6	5	26	24	43	11
8	7	27	26	44	38
11	9	28	27	45	15
12	10	29	7	46	14
13	12	30	25	47	46
14	13	31	30	48	38
15	3	32	31	49	13
16	12	33	32	50	49
17	12	34	32	51	10
18	4	35	34	52	29
19	18	36	35	53	52
20	19	37	36	54	53
21	20	38	22	55	9
22	21	39	37	56	40
23	22	40	36	57	39
24	23	41	11		
25	24	42	41		



Directional time OC relay locations		Directional time OC relay locations	
from	to	from	to
1	2	6	8
2	3	8	9
3	4	9	12
4	6		

Conclusions

- Proposed graph theory method successfully placed relays in proper locations
- Relay coordination was demonstrated for the IEEE 14-Bus
  - Genetic algorithm-based optimization
- Proposed method is only proposed for cases where cost/resources are limited
  - More expensive devices such as distance relays will allow for better selectivity in meshed networks
- **Future work**
  - Oscillations due to excessive switching of reclosers may leave system prone to instability
    - Further investigation/dynamic modeling required