TRANSMISSION & SUBSTATION DESIGN & OPERATION SYMPOSIUM

THE UNIVERSITY OF TEXAS AT ARLINGTON

A Cost Benefit Analysis of Faster Transmission System Protection Schemes and Ground Grid Design

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Agenda

- Example System And Clearing Times
- Ground Grid Design
- Cost Analysis
- Additional Conclusions

Example Systems And Clearing Times

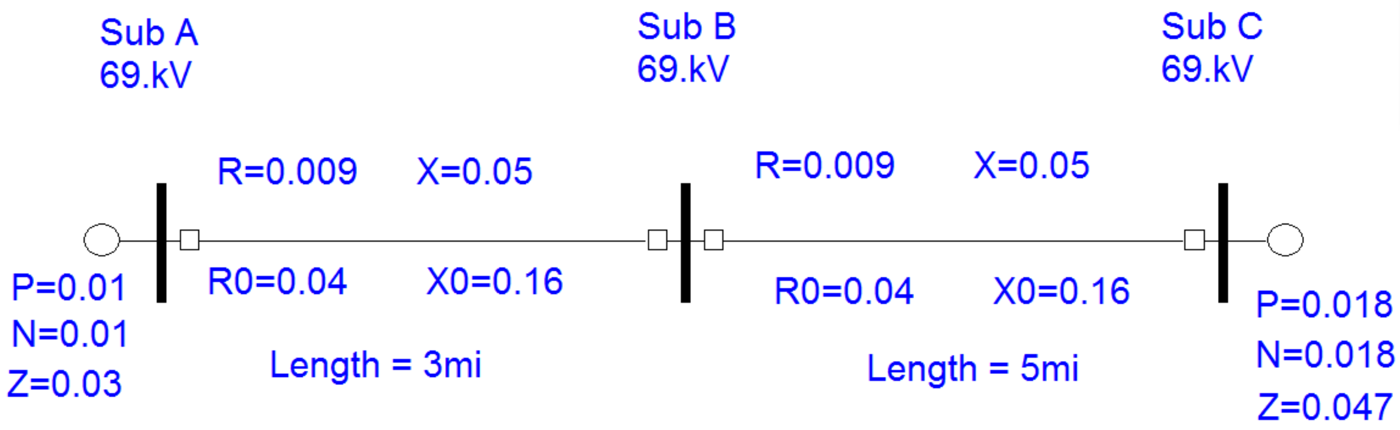
Fault Clearing Times

- Worst case clearing time depends on
  - Protection scheme (OC, Step Distance, DCB, differential)
  - DC system (single or redundant)
  - Breaker failure scheme
- A breaker failure scheme is assumed with a 3x breaker op time delay
- Single DC scheme clearing time is the worst case remote end clearing time (assumes DC system has failed)

Protection Costs to Reduce Trip Time

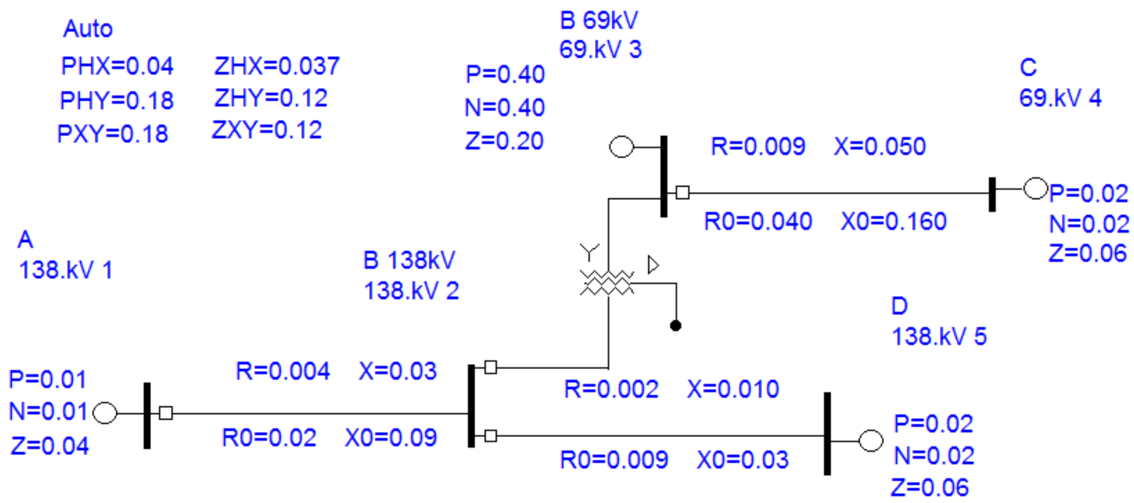
- The base cost assumed breakers and two CTs were installed per position (line, transformer, bus etc.)
- Additional relaying costs included:
  - PTs for distance protection
  - More expensive relays and panel equipment
  - Communications equipment installation
  - Redundant DC system installation

15kA Available Fault Current



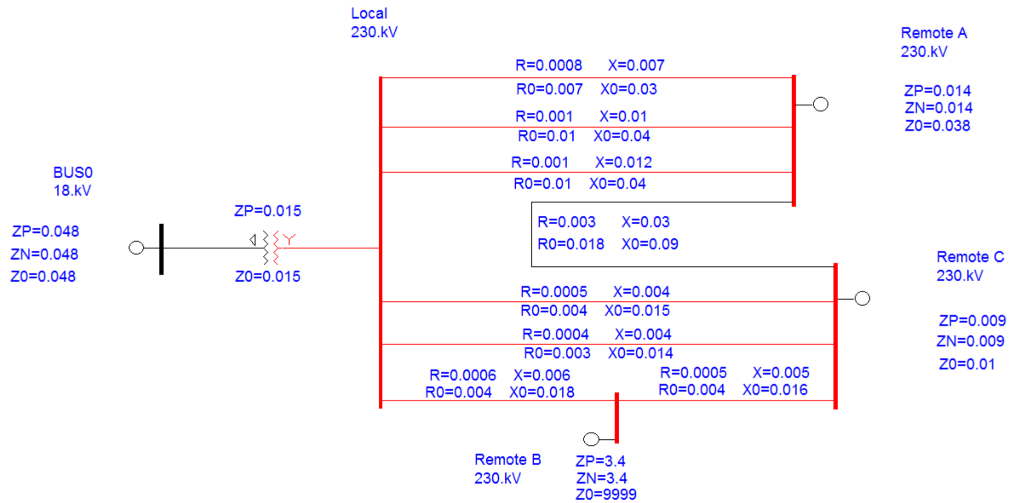
- 69kV Two Line Terminal Substation
- Distribution transformer
- Remote OC relaying trips at 32.7 cycles
- Remote distance relaying trips at 20 cycles

20kA Available Fault Current



- 138kV Three-terminal substation
- Autotransformer
- Remote OC relaying trips at 77.2 cycles
- Remote distance relaying trips at 20 cycles

40kA Available Fault Current



- 230kV Six-terminal substation
- Generation
- Remote OC relaying trips at 20 cycles
- Remote distance relaying trips at 20 cycles

Ground Grid Design

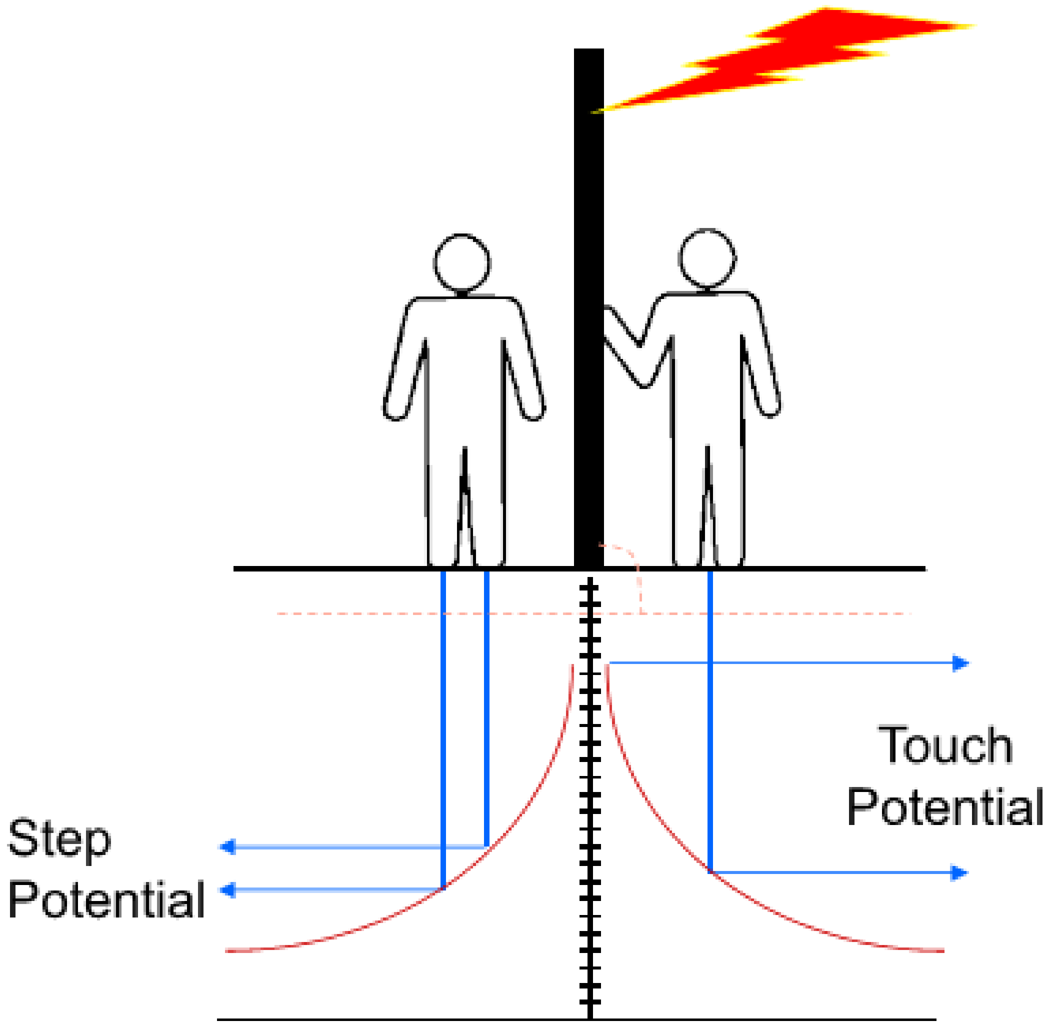
Cost of Ground Grid Design

- Three factors:
  - Soil
  - Fault current
  - Clearing time
- Cannot easily control soil or fault current
- Can control clearing time
- This allows a trade-off between relaying costs and ground grid costs

Step And Touch Potentials

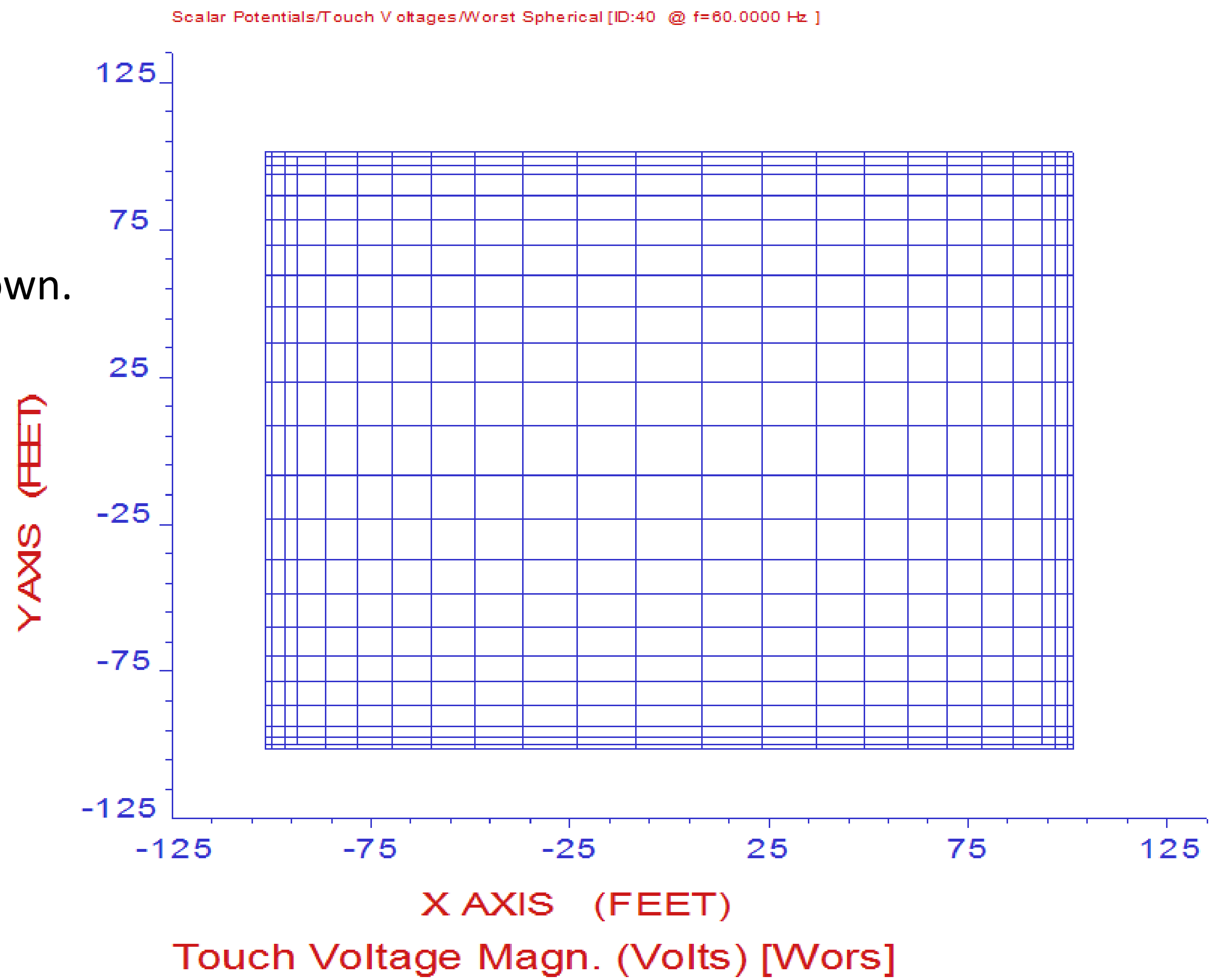
- Step potential occurs when a voltage gradient between a persons feet is sizeable enough to cause fatality
- Touch potential occurs when a voltage gradient between objects being touched and the person’s feet is sizeable enough to cause fatality
- This threshold is calculated using IEEE 80 and various parameters of the station

Step And Touch Potentials



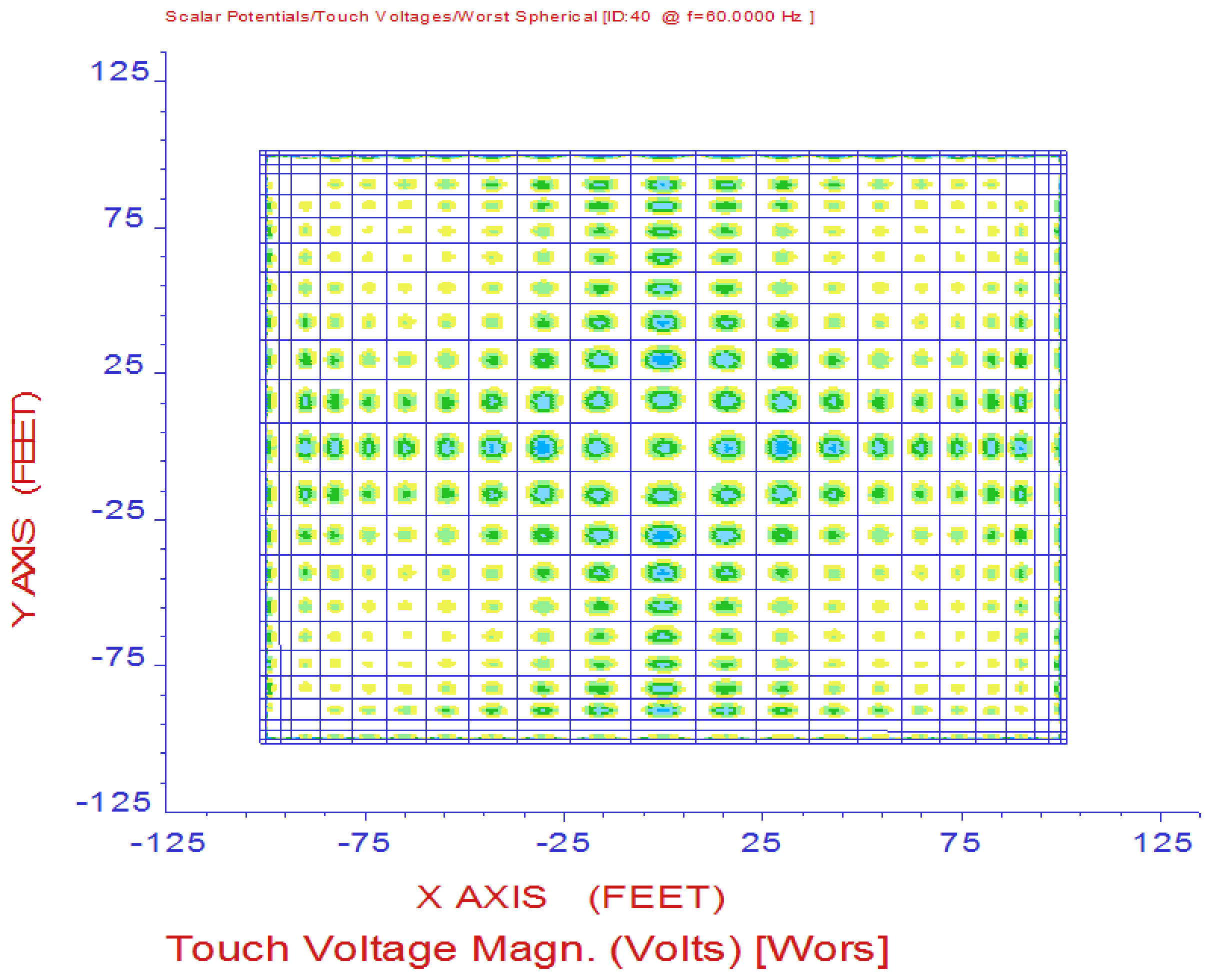
13.5 Cycle Clearing Times

Ground grid design is safe.
No touch potentials are shown.



35.5 Cycle Clearing Times

Ground grid design is unsafe
Touch potentials are shown.

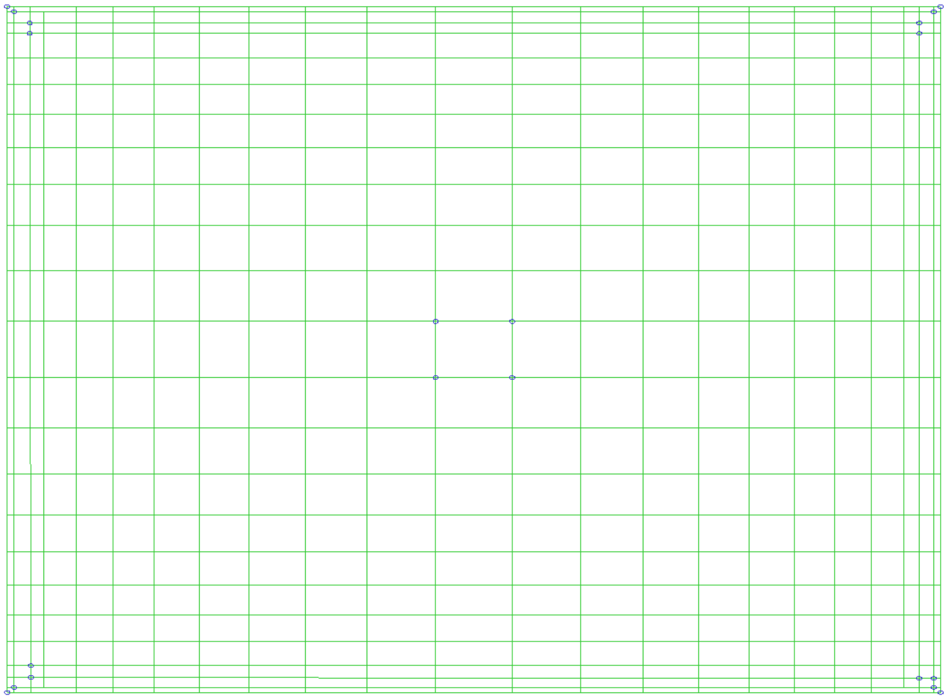


Ground Grid Assumptions

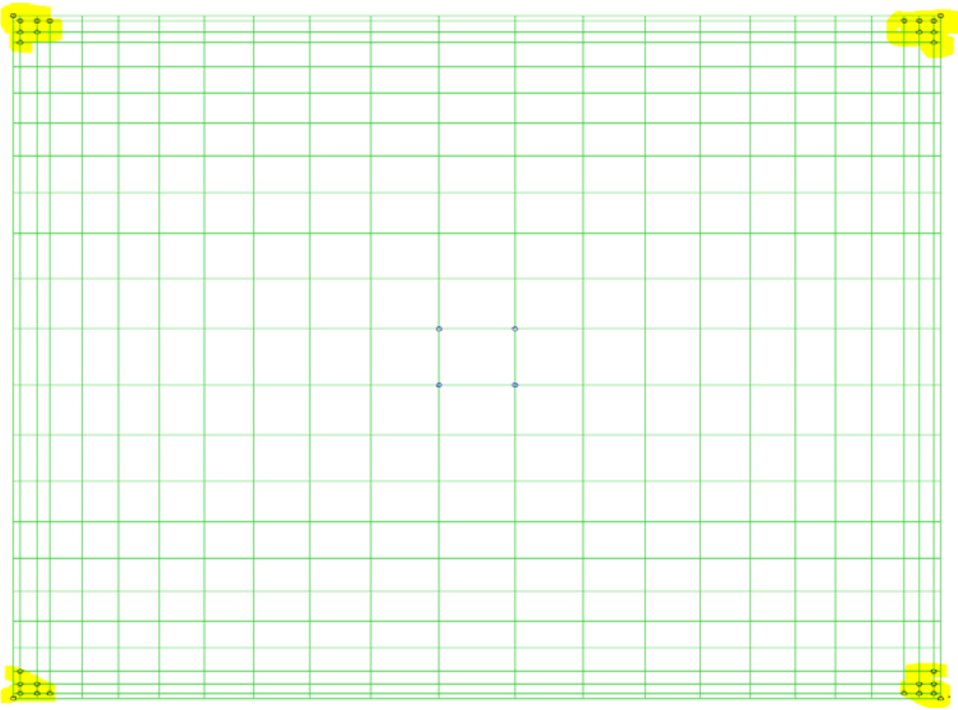
- Current injected is completely remote current (no split factor)
- X/R = 20
- 4/0 conductor sizing for all conductors
- 4 inches of 3000 Ohm-meter crushed rock to the extents of the tested area
- Uniform soil model
- 10 foot ground rods with 5/8 inch diameter

Ground Grid Voltage Potential Mitigation

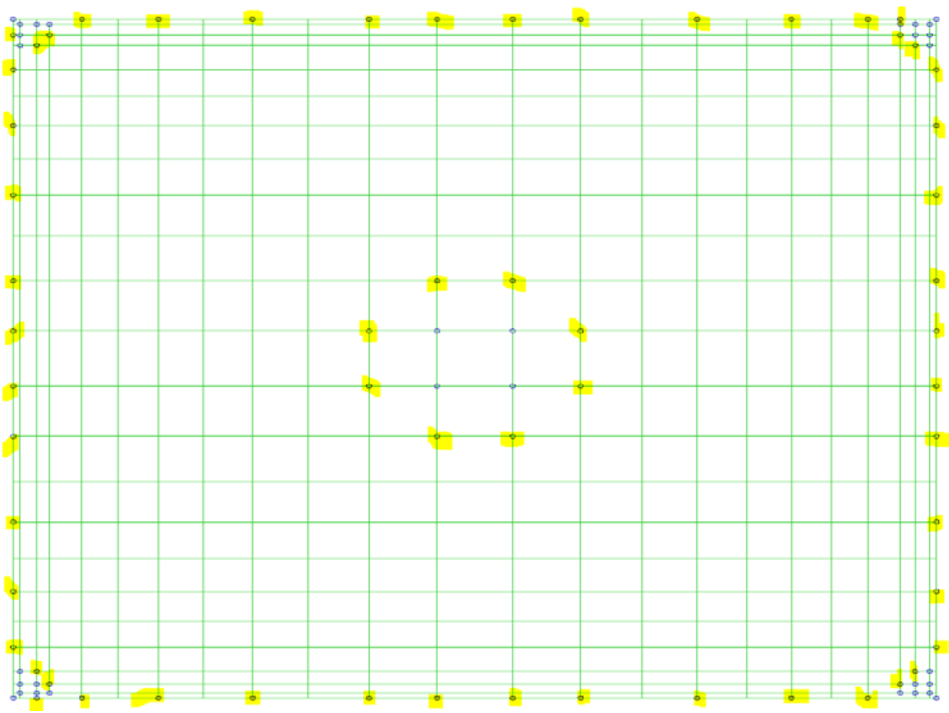
1. A square grid is modeled with even spacing and ground rods around outside border
2. Minimal conductors are added around corners to mitigate voltage potential issues there
3. A conductor is placed in an empty grid spacing where there is a voltage potential issue
4. If enough voltage potential issues exist, the entire grid is redrawn with a more dense spacing



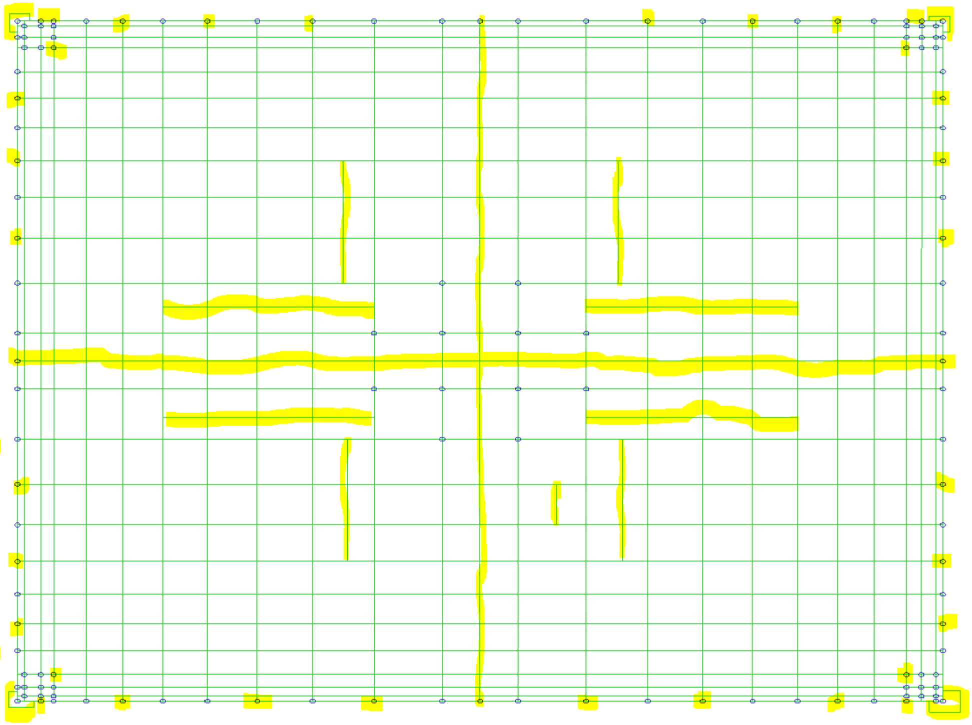
13.5 Cycle Clearing Time



17.0 Cycle Clearing Time



23.0 Cycle Clearing Time



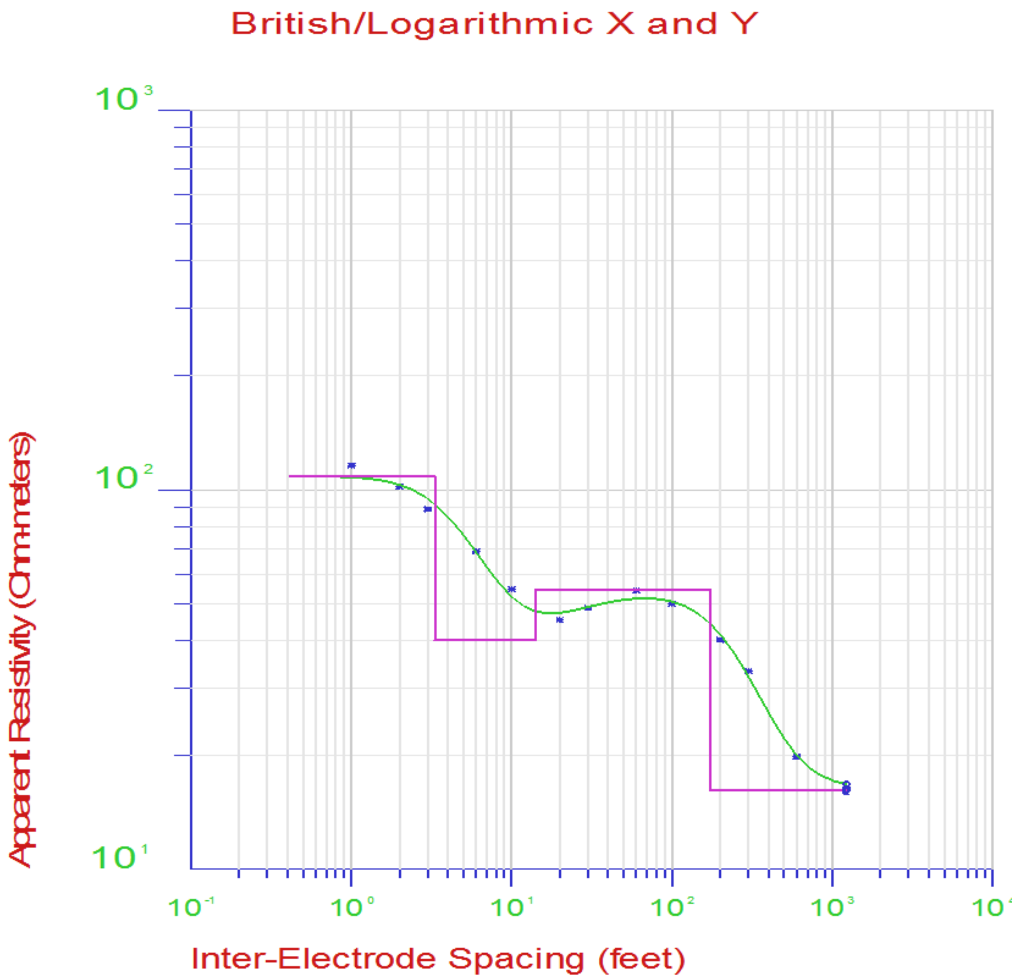
35.7 Cycle Clearing Time

Incremental Grid Cost

- Installation and material costs estimated at $50/foot
- The base cost of the grid is found at the fastest clearing time
- Increased cost as a result of clearing time is a comes from the conductors needed to make the grid safe.
- Base cost at the fastest clearing time does not give any useful information

Tested Grounding Scenarios

- Ground grids designed to each respective voltage/current level with 75 Ohm-meter uniform soil
- 69kV/15kA grid designed using 25 Ohm-meter, 75 Ohm-meter, and 225 Ohm-meter



Cost Analysis

15kA Grid Cost With 75 Ohm-Meter Soil

Clearing Time (cycles)	Conductor Required (feet)	Total Cost at $50 per foot	Incremental Cost Increase	Total Cost Increase From Fastest Clearing Time	Percent Increase From Fastest Clearing Time
13.5	4,538	$226,900			
17	4,853	$242,650	$15,750	$15,750	6.94%
18.5	4,853	$242,650	$0	$15,750	6.94%
23	5,298	$264,900	$22,250	$38,000	16.75%
25	5,298	$264,900	$0	$38,000	16.75%
35.7	5,620	$281,000	$16,100	$54,100	23.84%
37.7	5,719	$285,950	$4,950	$59,050	26.02%

- Maximum cost savings of $59k
- Right two columns show savings when decreasing clearing time to the fastest
- Incremental Cost column shows savings updating your protection scheme to match installed equipment/relaying

20kA Grid Cost With 75 Ohm-Meter Soil

Clearing Time (cycles)	Conductor Required (feet)	Total Cost at $50 per foot	Incremental Cost Increase	Total Cost Increase From Fastest Clearing Time	Percent Increase From Fastest Clearing Time
13.5	5,433	$271,650			
17	5,611	$280,550	$8,900	$8,900	3.28%
18.5	5,789	$289,450	$8,900	$17,800	6.55%
23	6,233	$311,650	$22,200	$40,000	14.72%
25	6,391	$319,550	$7,900	$47,900	17.63%
80.2	9,260	$463,000	$57,050	$191,350	70.44%
82.2	9,260	$463,000	$57,050	$191,350	70.44%

- Maximum cost savings of $191k

40kA Grid Cost With 75 Ohm-Meter Soil

Clearing Time (cycles)	Conductor Required (feet)	Total Cost at $50 per foot	Incremental Cost Increase	Total Cost Increase From Fastest Clearing Time	Percent Increase From Fastest Clearing Time
13.5	12,794	$639,700			
17	12,917	$645,850	$6,150	$6,150	0.96%
18.5	13,645	$682,250	$36,400	$42,550	6.65%
23	14,476	$723,800	$41,550	$84,100	13.15%
25	14,642	$732,100	$8,300	$92,400	14.44%

- Maximum cost savings of $92k

How Much of an Impact Does Soil Have?

TABLE VII. GROUND GRID DESIGN COSTS AT 40KA

Clearing Time (cycles)	Soil Model: Total Cost 25 ohm-m	Total Cost 75 ohm-m	Total Cost 225 ohm-m	Cost Increase over 13.5 cycles 25 ohm-m	Cost Increase over 13.5 cycles 75 ohm-m	Cost Increase over 13.5 cycles 225 ohm-m
13.5	$113,800	$226,890	$497,000			
17	$113,800	$242,650	$503,000	$0	$15,760	$6,000
23	$125,800	$264,900	$532,000	$12,000	$38,010	$35,000
35.7	$145,800	$281,000	$587,000	$32,000	$54,110	$90,000

- Increasing soil resistivity increases the cost difference between slow and fast clearing times
- Not a large difference between the 25 ohm-m and 225 ohm-m soil models

How Fault Current Influence Costs

	23 Cycle Clear Time	
Fault Current	Total Cost	Cost Increase over 13.5 cycles
15kA	$264,900	$38,000
20kA	$311,650	$40,000
40kA	$723,800	$92,400

- The benefit of reducing trip time from 23 cycles to 13.5 cycles varies with fault current
- Decreases from $92,400 at 40kA to $38,000 at 15kA

Should Cheaper Relay Schemes Be Used?

- Ground grid cost increase between 5 cycle and 3 cycle breakers did not justify the installation of new breakers
- Step distance relaying allows for clearing times that are generally fast enough for most situations
- Installations that have low fault current and will not have slow trip times due to coordination might be able to use overcurrent relaying
- These are only general trends, some exceptions will occur with more complex soil models

Additional Conclusions

Additional Considerations

- The relationship between grid installation cost and relay tripping speed is weak
- This means that other limitations will likely require faster tripping such as system stability or equipment damage concerns
- Grid savings is then a just an additional benefit
- Significant capital costs could be saved by reducing clearing time to match installed relaying and equipment

Additional Considerations

- Benefit could be gained by reducing worst case clearing times through breaker failure trip time delay reduction
- Reducing breaker failure time delay allows for a faster remote end clearing time for single DC systems
- This could potentially increase breaker failure trip events – system impact will vary by breaker reliability.

Process Improvements

- Moving some engineering analysis to the scoping phase of a project
- Soil testing can be performed before relay selection to determine situations where upgraded relaying is worth the additional price

Q&A