Ames Substation

Derek Elkins, Patrick Musoy, Mackenzie Ray,
Nathan Tegeler, Matthew Wells

Client: Burns and McDonnell
Advisor: Hugo Villegas Pico
Team: SDDec-24-02
Website Url: Link

Task Responsibility/Contributions

- Kenzie:
  - Meeting Notes
  - Bus configuration design/report
  - DC I/O relay assignments
- Nathan:
  - Piloting schemes
  - Relaying selection
  - AC equipment sizing
  - DC I/O relay assignments
- Matthew:
  - PLC frequencies and equipment
  - Piloting schemes
  - Relaying selection
- Derek:
  - Team Lead
  - Bus configuration design/report
  - Site layout design
- Patrick:
  - Piloting schemes
  - Relaying selection
  - DC I/O relay assignments

Project Overview - Ames Substation

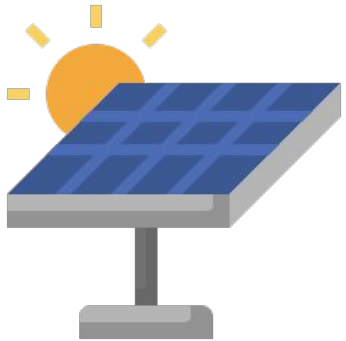
Primary Goal: Design a robust substation that will integrate the Ames Solar Farm into the existing transmission line infrastructure.

Ames Substation Requirements

- Interface a 69kV, 2 MW solar farm
- Accommodate three existing 138 kV lines (Boone, Ankeny, Nevada)
- Implement redundant fault protection schemes

Design Scope

- Physical layout and bus configuration
- Protection scheme coordination



What is a Substation?

- The facilities for electrical equipment
- A node in the power grid
- Transforms voltage (up or down)
- Monitors and controls the power grid
- Protects the grid and connected equipment

Conceptual Sketch

Boone

- 15 miles, 138kV

Ankeny

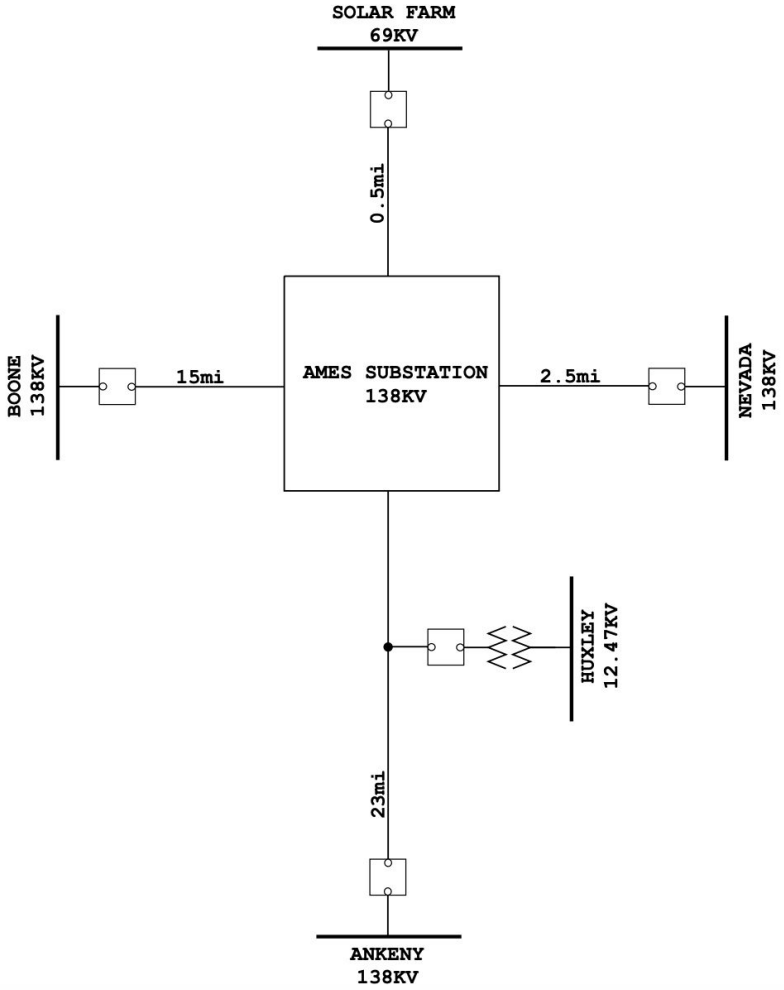
- 23 miles, 138kV
- Huxley tap-off 12.47kV

Nevada

- 2.5 miles, 138kV

Ames Solar Farm

- 0.5 miles, 69kV



Substation Requirements

Functional

Transform the voltage

Interconnect four transmission lines

Monitor system operation

Respond to faults

Safe Operation

Non-Functional

69/138 kV transformer

Ring bus configuration

Current and voltage transformers

Pilot schemes

Adhere to ANSI, IEEE standards

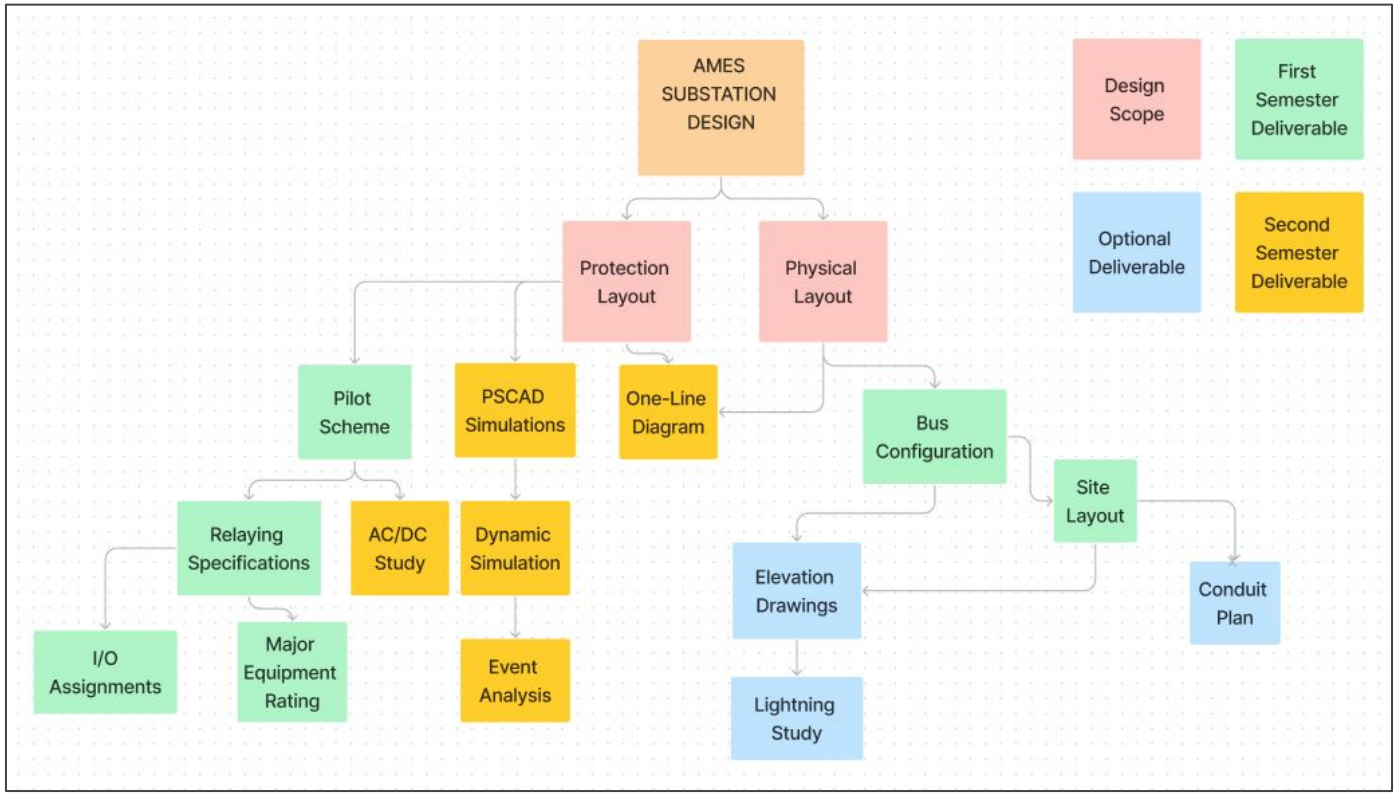
Potential Risk & Mitigation

Risk	Outcome	Mitigation
Equipment Ratings	Overspending, component failure, or both.	Complete research. Consult with the advisor or client.
Relay Selection	Compound negative effect on future reports and simulations.	Consult IEEE standards. Peer review the selections. Review the selections with the client.
I/O Assignments	Failures in the pilot scheme coordination.	Peer review to verify the connections.
Calculations	Discrepancies in electrical equipment ratings.	Peer review the procedure and calculation. Verify final results with the client.
File Management	Significant burden on our project timeline.	Save files diligently. Backup any significant process.

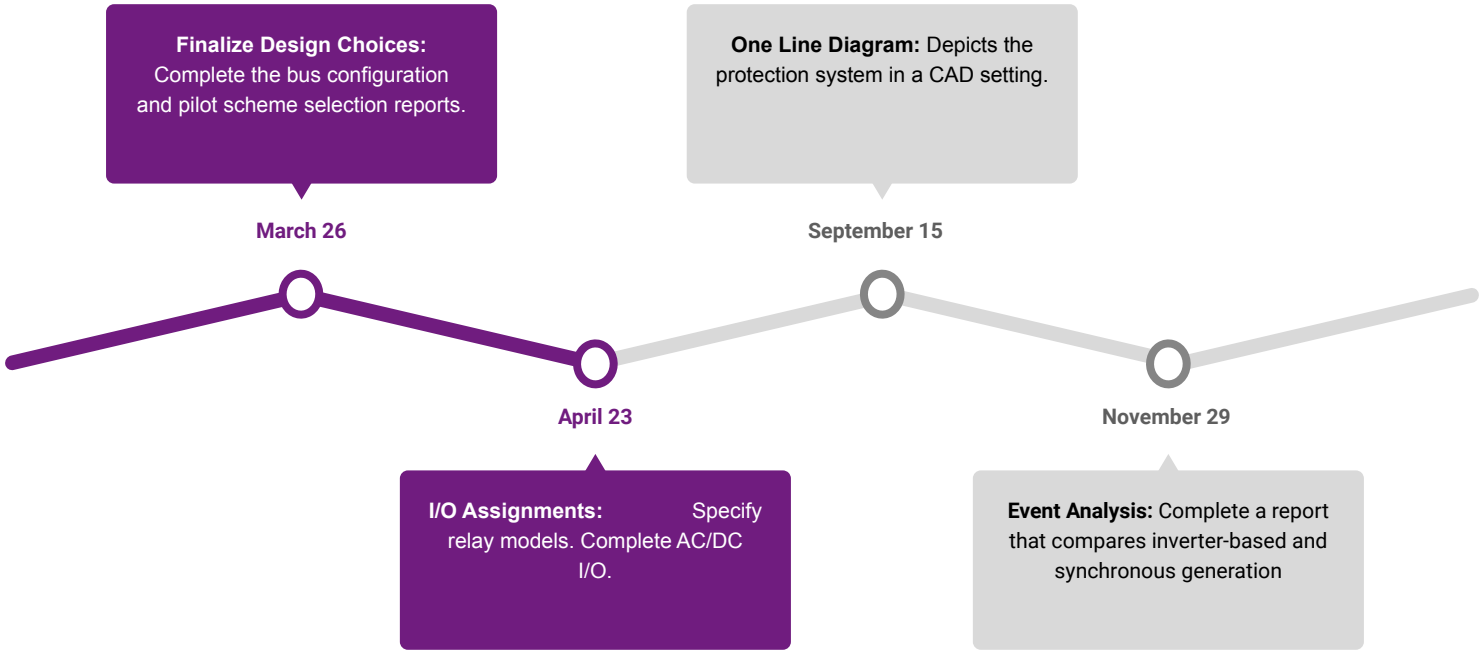
Resources

- Substation design guide: *Design Guide for Rural Substations* National Rural Electric Cooperative Association
- Example substation set: One-line, schematics, wiring diagrams, and site layouts.
- Short circuit study
- Relay specification report
- Software (AutoCAD and PSCAD)

Project Workflow



Project Milestones & Schedule



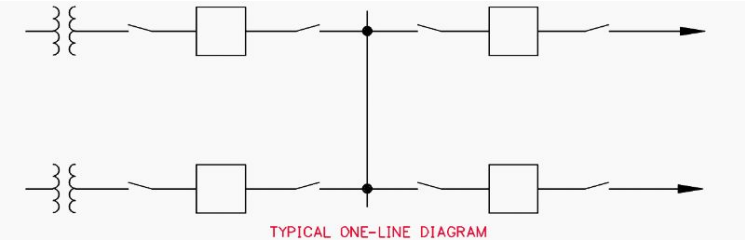
Bus Configuration

Overview

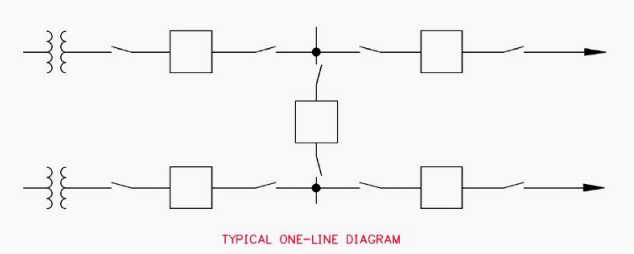
- Bus configuration - Arrangement or layout conductors within a substation that connects different pieces of electrical equipment
- 6 main bus configurations
  - Radial
  - Sectionalized
  - Main and Transfer
  - Breaker and a Half
  - Double Breaker Double Bus
  - Ring Bus

Radial/Sectionalized Configuration

- Commonly used in rural areas
  - Low power levels
    - 11 kV to 66 kV
- One source feeding the load
- Low level of reliability

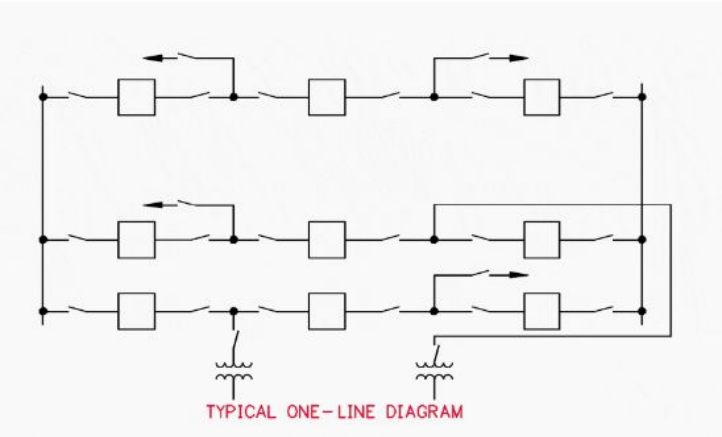


- Similar to radial configuration
  - Two radial configurations separated by a breaker instead of a bus
- Typically used for low power level stations



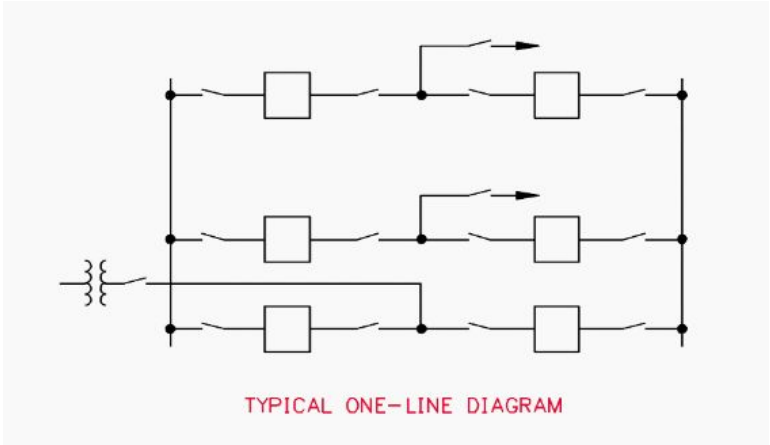
Breaker and a Half Configuration

- Two main buses connected with three independent circuit breakers
  - Effectively a breaker and a half associated with each line
- High level of reliability
  - If one line goes out others can remain on
- Maintenance issues
  - Complex layout due to number of breakers



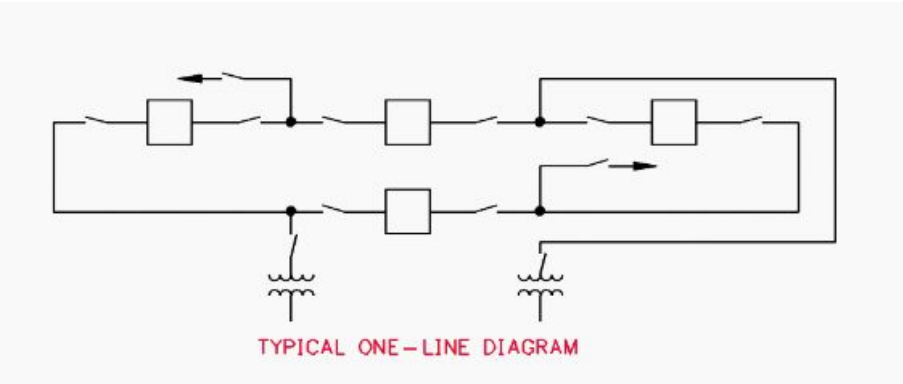
Double Breaker Configuration

- Most commonly seen in high power level stations
  - Above 220 kV
- High cost
  - Each line has 2 breakers
- Complex maintenance due to the high number of breakers



Ring Bus Configuration

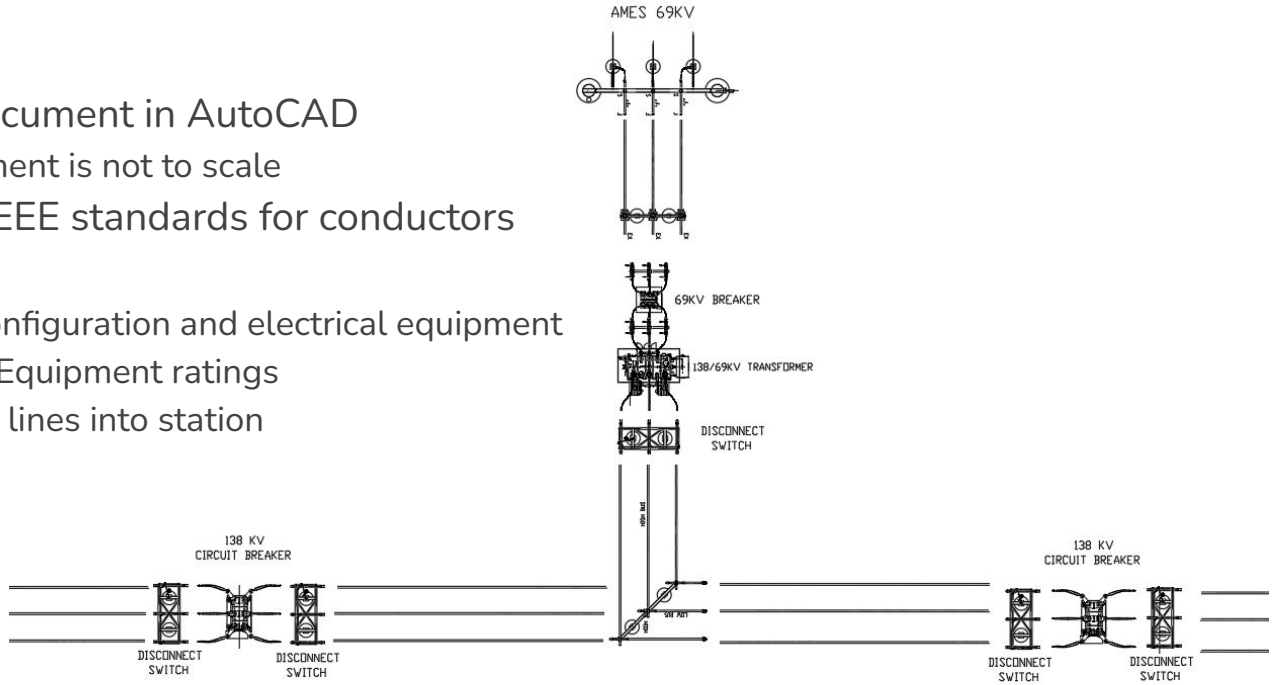
- Most common for mid-level power stations
  - 66 kV - 220 kV
- Two open ends of line with a breaker
  - Separate each input line off with two breakers
  - If one line experiences a fault others remain energized



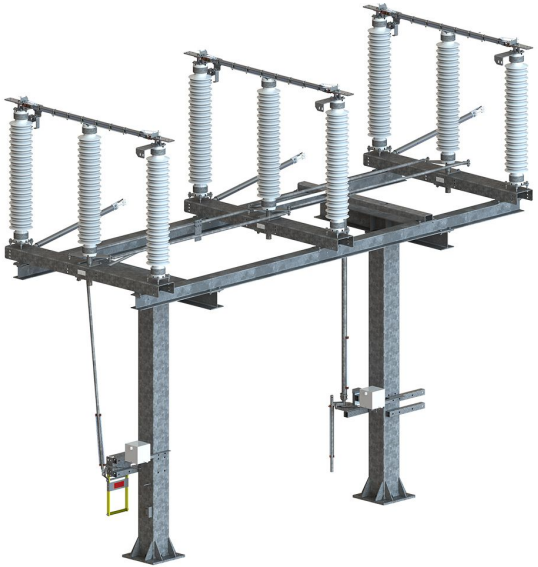
Site Layout

Site Layout

- Created document in AutoCAD
  - Document is not to scale
- Followed IEEE standards for conductors
- Includes
  - Bus configuration and electrical equipment
    - Equipment ratings
  - Power lines into station



Major Equipment



Disconnect Switch

Circuit Breaker (CB)

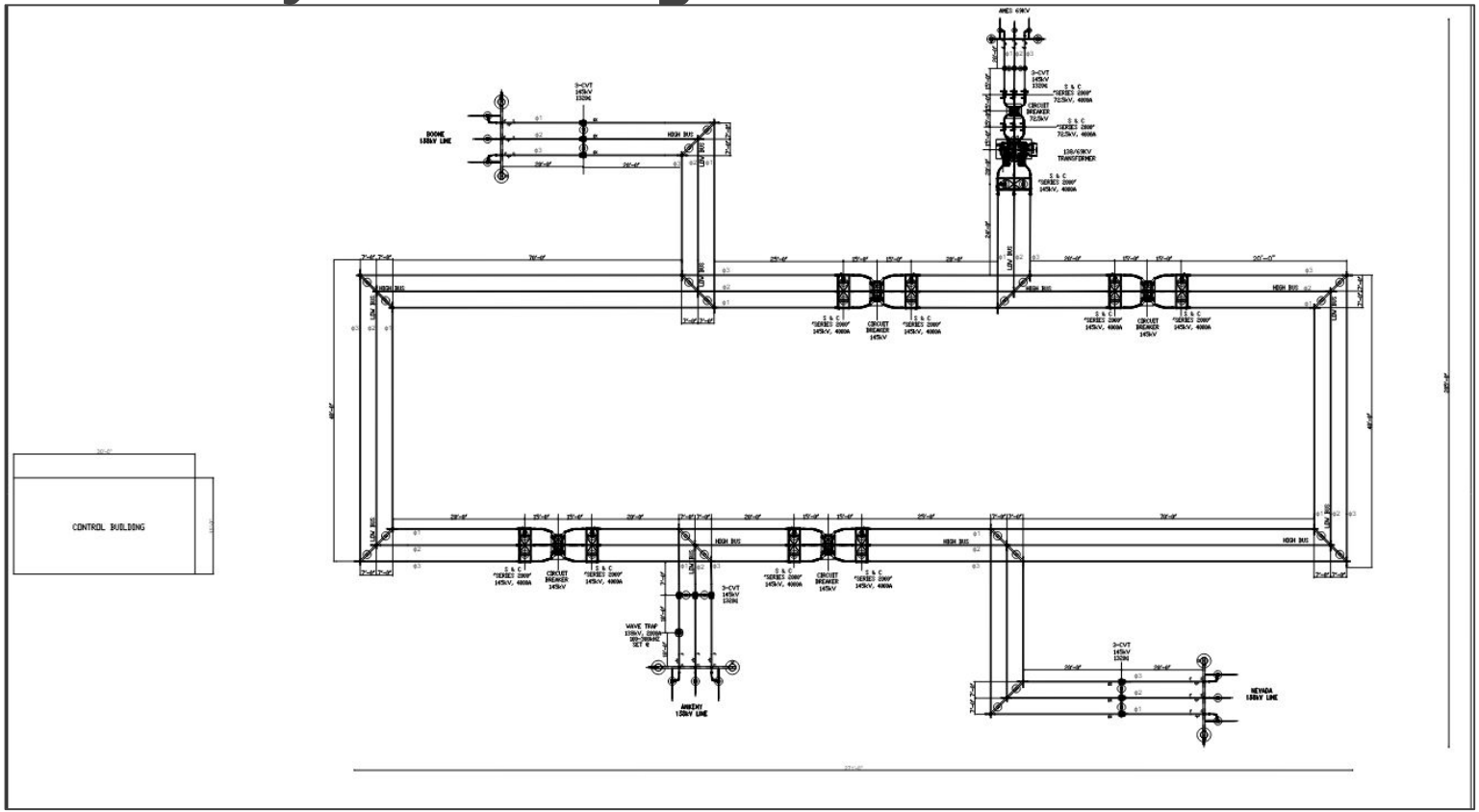
Capacitive Voltage Transformer (CVT)

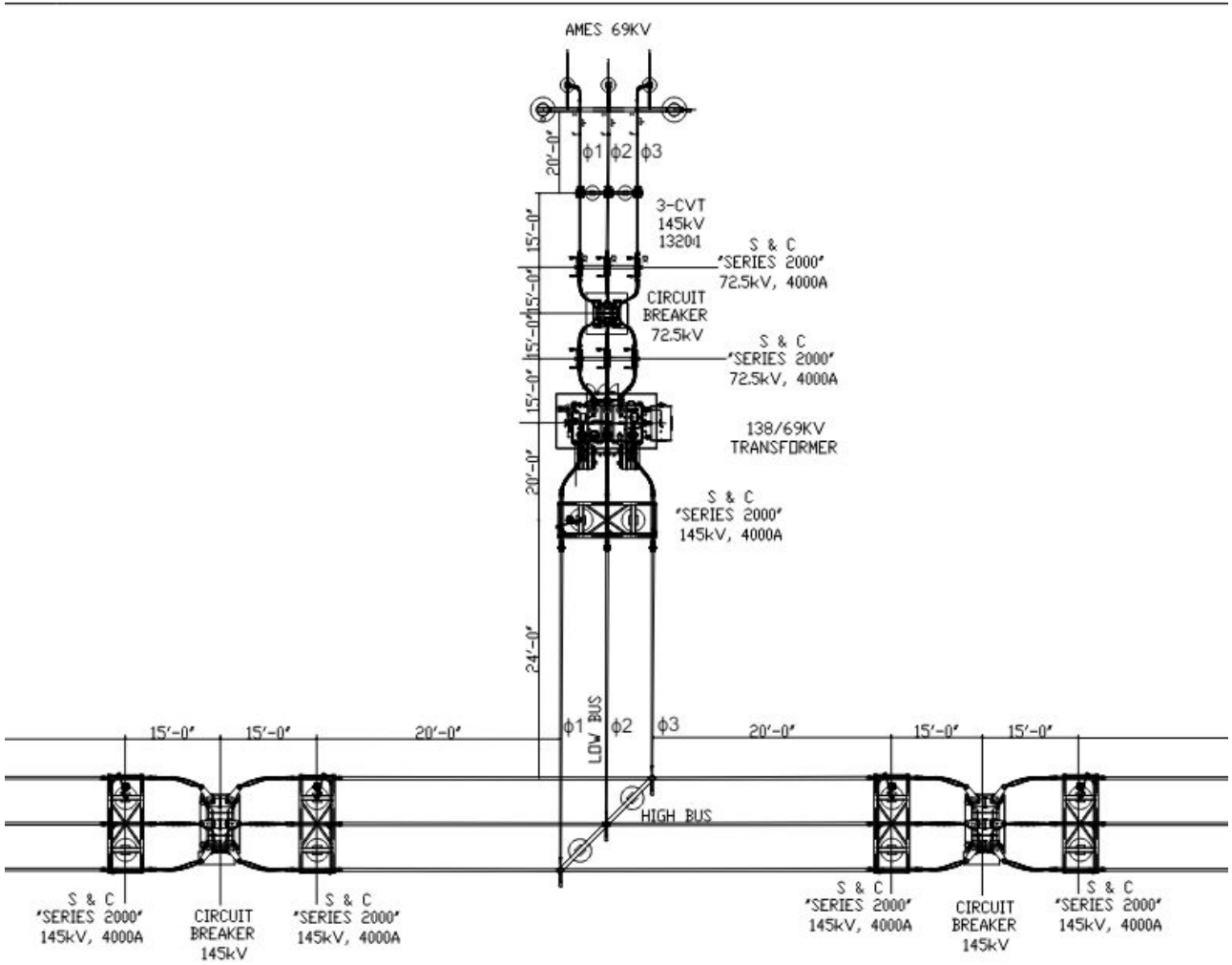
Major Equipment Continued

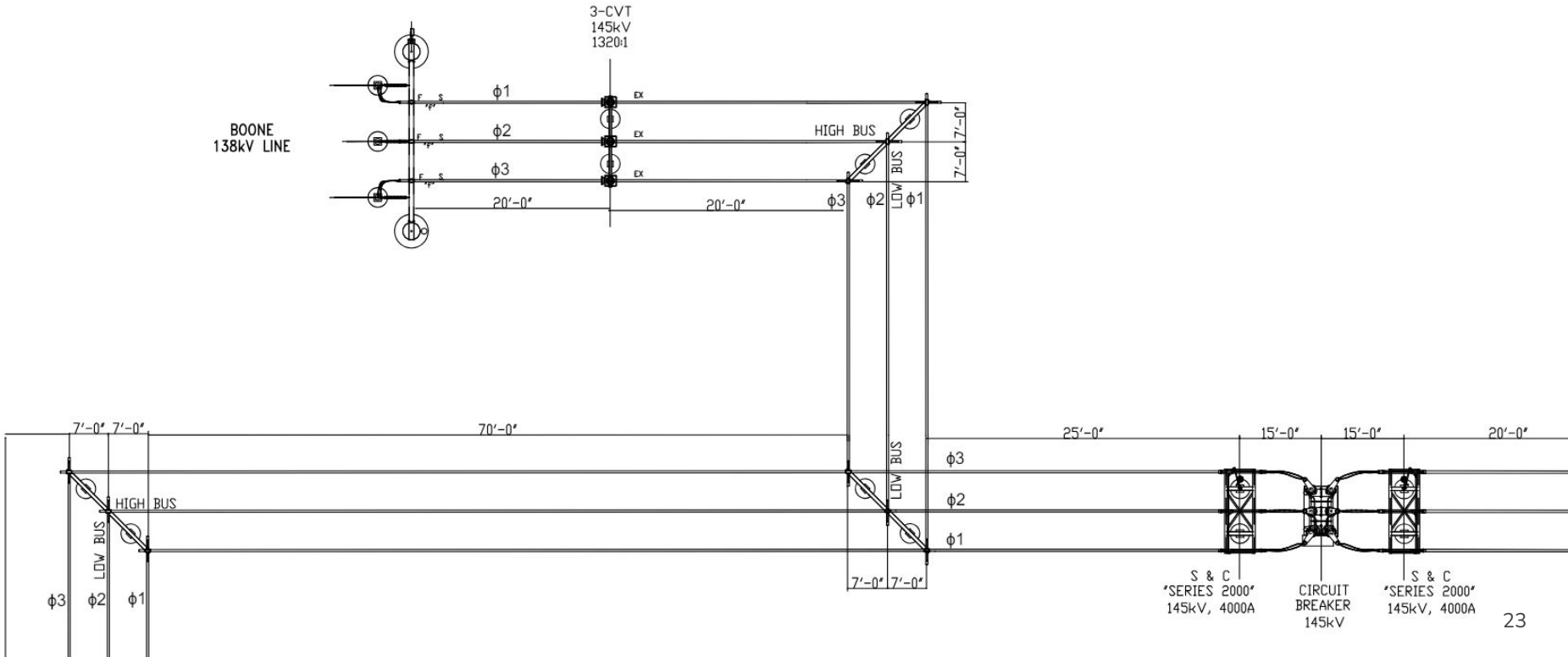
Transformer

Wave Trap

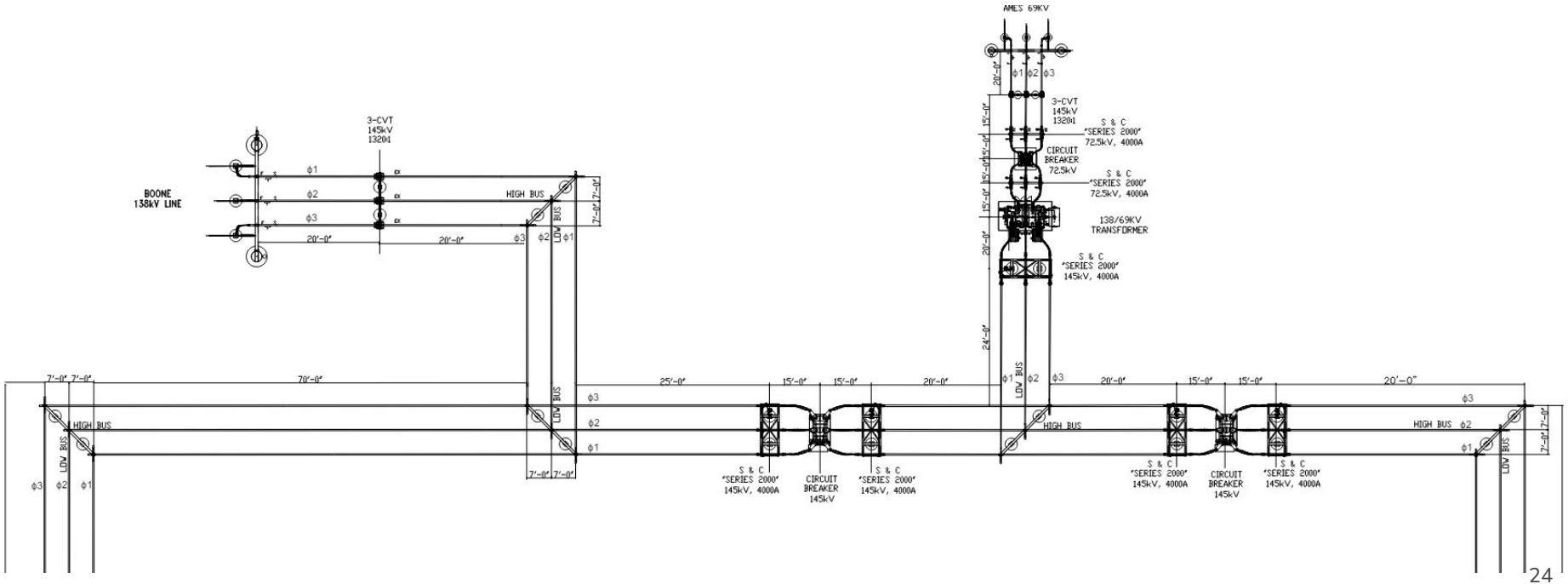
Site Layout - Design

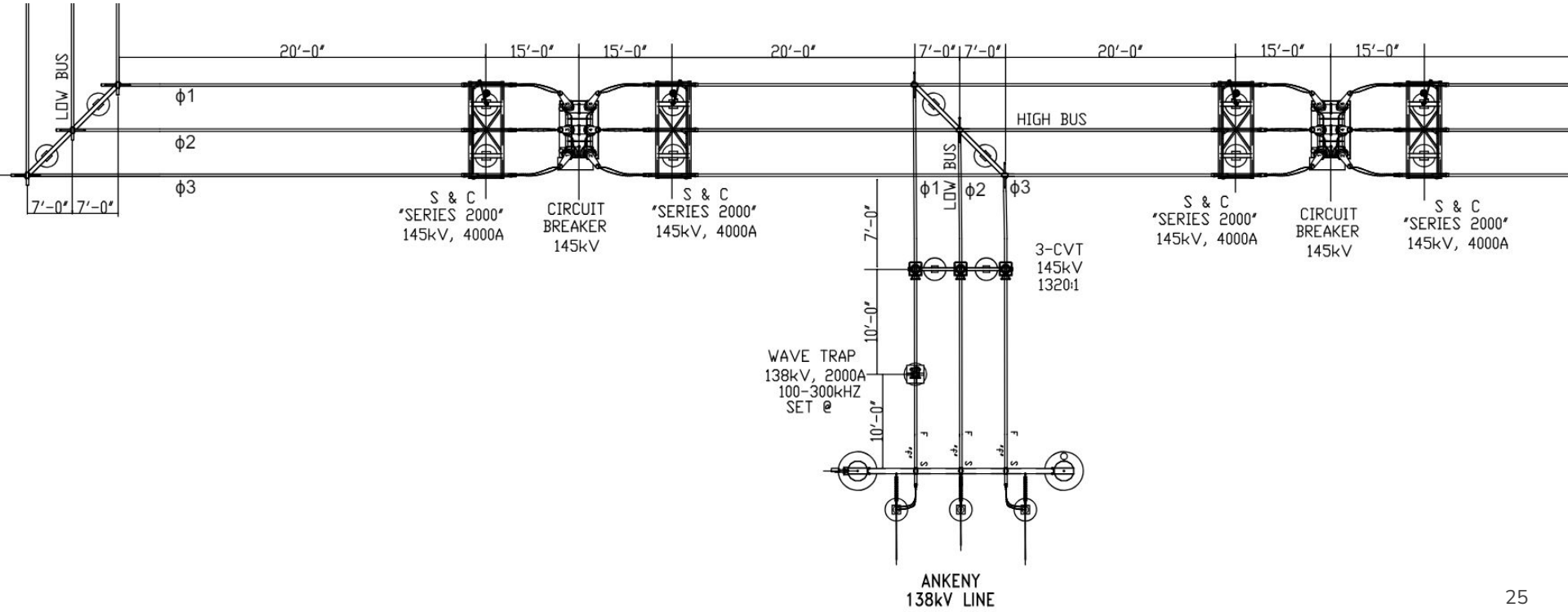


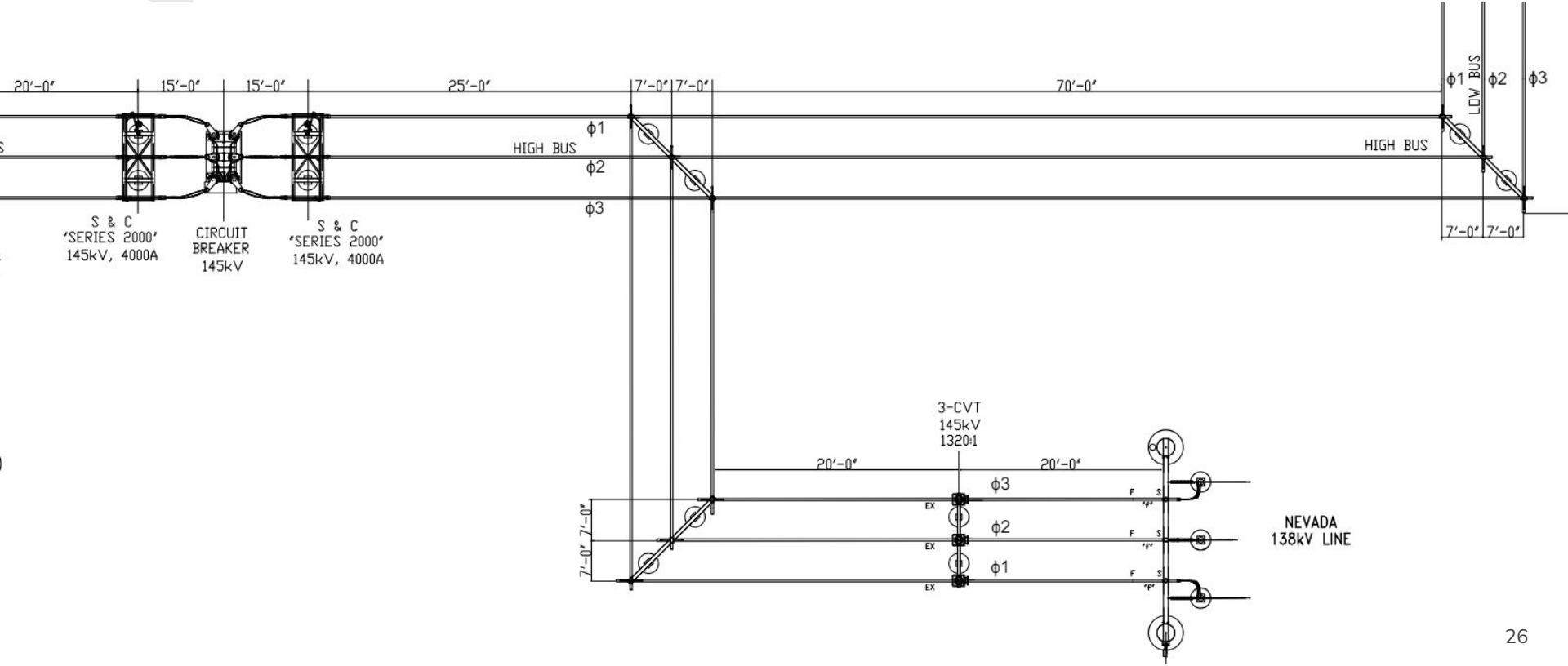

AMES 69KV
20'-0"
ϕ1 ϕ2 ϕ3
3-CVT
145kV
13201
15'-0"
S & C
'SERIES 2000'
72.5kV, 4000A
CIRCUIT
BREAKER
72.5kV
15'-0"
S & C
'SERIES 2000'
72.5kV, 4000A
138/69KV
TRANSFORMER
20'-0"
S & C
'SERIES 2000'
145kV, 4000A
24'-0"
15'-0"
15'-0"
20'-0"
ϕ1
ϕ2
ϕ3
LOW BUS
20'-0"
15'-0"
15'-0"
HIGH BUS
S & C
'SERIES 2000'
145kV, 4000A
CIRCUIT
BREAKER
145kV
S & C
'SERIES 2000'
145kV, 4000A
S & C
'SERIES 2000'
145kV, 4000A
CIRCUIT
BREAKER
145kV
S & C
'SERIES 2000'
145kV, 4000A


3-CVT
145kV
1320:1
BOONE
138kV LINE
ϕ1
ϕ2
ϕ3
EX
HIGH BUS
LOW BUS
7'-0"
20'-0"
20'-0"
7'-0" 7'-0"
70'-0"
25'-0"
15'-0"
15'-0"
20'-0"
S & C
"SERIES 2000"
145kV, 4000A
CIRCUIT
BREAKER
145kV
S & C
"SERIES 2000"
145kV, 4000A

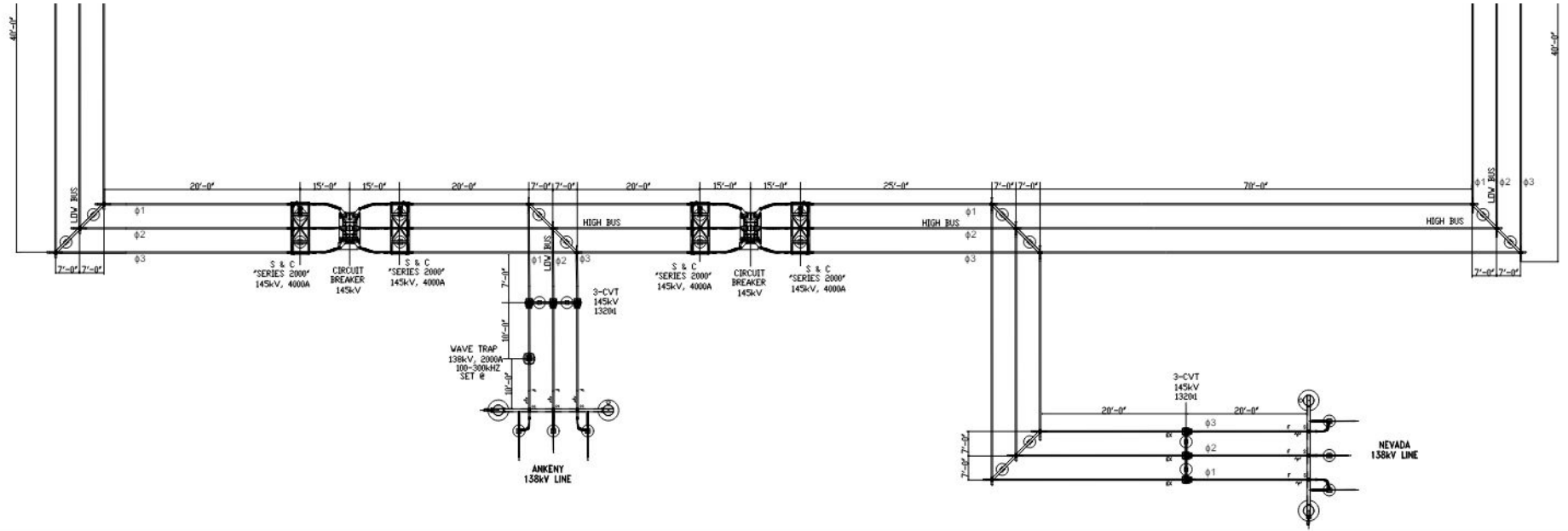
Northern Section




LOW BUS
20'-0"
15'-0"
15'-0"
20'-0"
7'-0"
7'-0"
20'-0"
15'-0"
15'-0"
ϕ1
ϕ2
ϕ3
HIGH BUS
7'-0"
7'-0"
S & C
"SERIES 2000"
145kV, 4000A
CIRCUIT
BREAKER
145kV
S & C
"SERIES 2000"
145kV, 4000A
LOW BUS
ϕ1
ϕ2
ϕ3
S & C
"SERIES 2000"
145kV, 4000A
CIRCUIT
BREAKER
145kV
S & C
"SERIES 2000"
145kV, 4000A
7'-0"
3-CVT
145kV
1320:1
10'-0"
WAVE TRAP
138kV, 2000A
100-300kHZ
SET @
10'-0"
ANKENY
138kV LINE


20'-0"
15'-0"
15'-0"
25'-0"
7'-0"
7'-0"
70'-0"
ϕ1
ϕ2
ϕ3
LOW BUS
HIGH BUS
HIGH BUS
ϕ1
ϕ2
ϕ3
7'-0"
7'-0"
S & C
"SERIES 2000"
145kV, 4000A
CIRCUIT
BREAKER
145kV
S & C
"SERIES 2000"
145kV, 4000A
3-CVT
145kV
1320:1
20'-0"
20'-0"
ϕ3
ϕ2
ϕ1
7'-0"
7'-0"
EX
F
S
NEVADA
138kV LINE

Southern Section



Piloting Schemes

Pilot Relaying Schemes

Pilot Scheme: The communication between the terminals of a transmission line, coordinated to effectively isolate the system from faults. Coordination between zones

- DTT: Direct Transfer Trip
- POTT: Permissive Overreaching Transfer Trip
- DCB: Directional Comparison Blocking
- DCUB: Directional Comparison Unblocking
- 87L: Current Differential

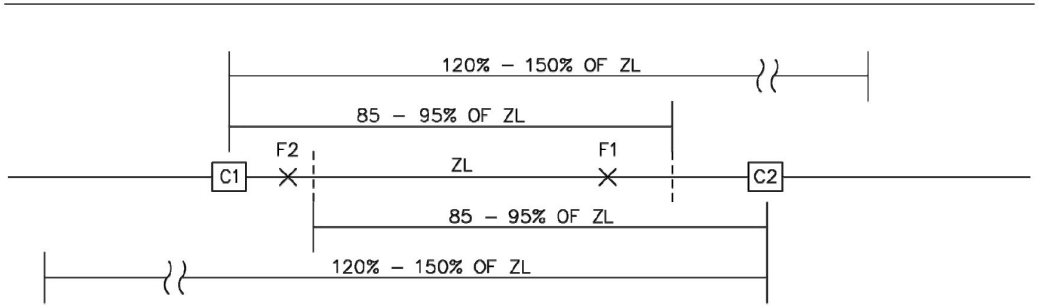
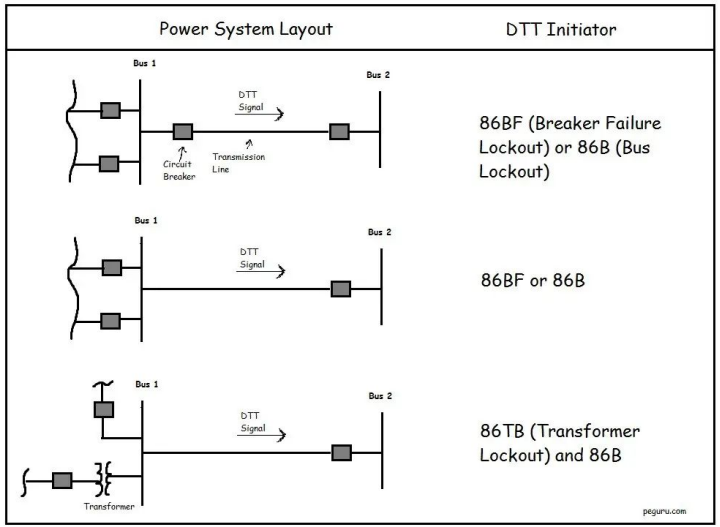


FIGURE 12.6: Distance Relay Zones 1 and 2

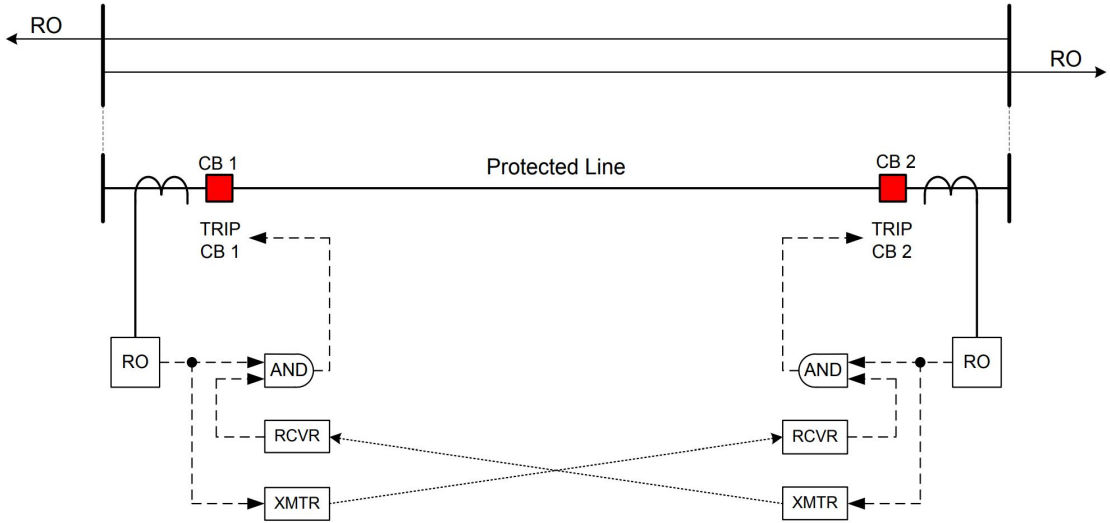
Direct Transfer Trip (DTT)

DTT trips the remote breakers if a local breaker failure, transformer failure, or bus fault occurs.



Permissive Overreaching Transfer Trip (POTT)

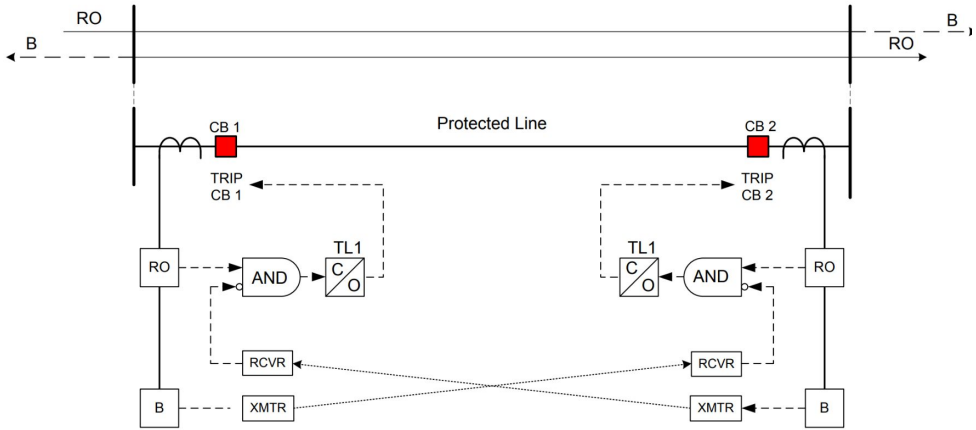
- Overreaching zone of protection.
- “Guard” and “Trip” signals.
- Ground fiber cable communication.
- Requires remote permission to trip.

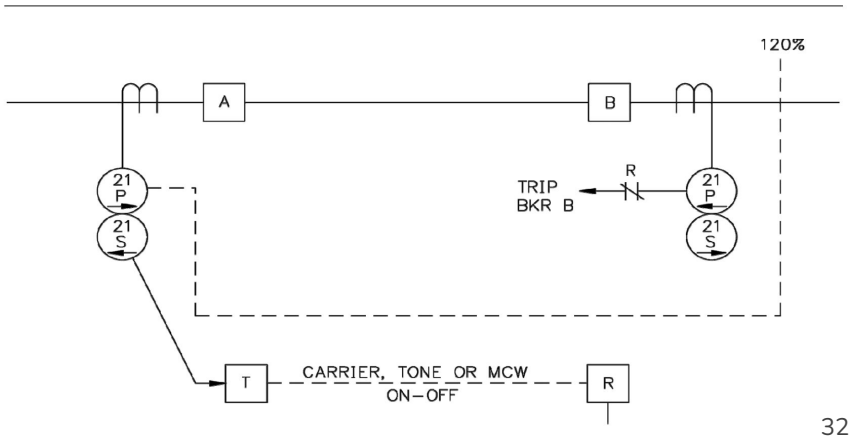


RO – overreaching trip function, must be set to reach beyond remote end terminal.

Directional Comparison Blocking (DCB)

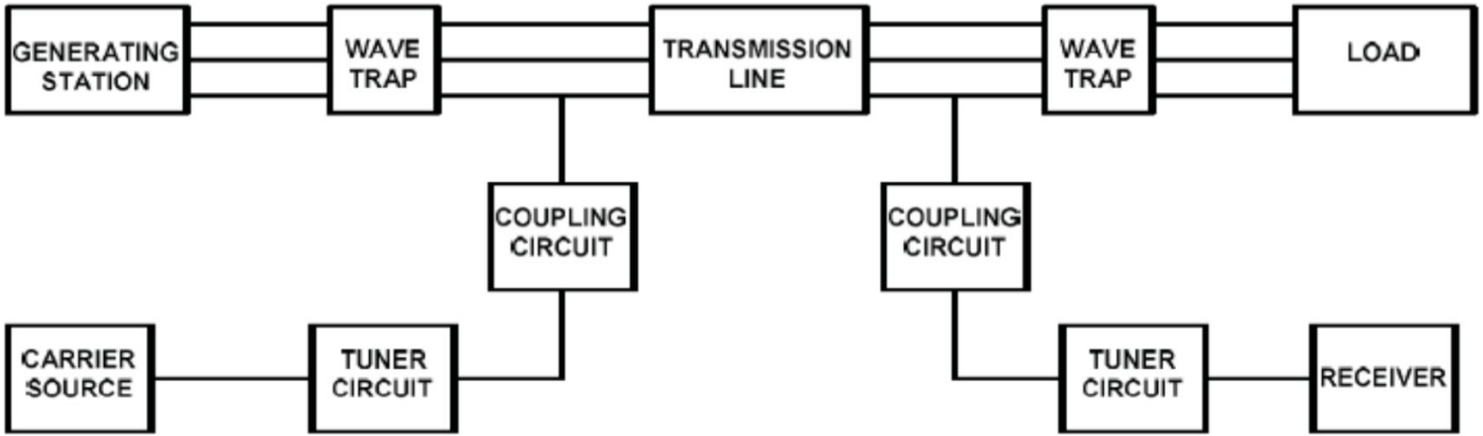
- Backwards and overreaching forward relay zones
- Relays trip on forward faults unless a remote blocking signal is received
- Power line carrier (PLC) communication channel





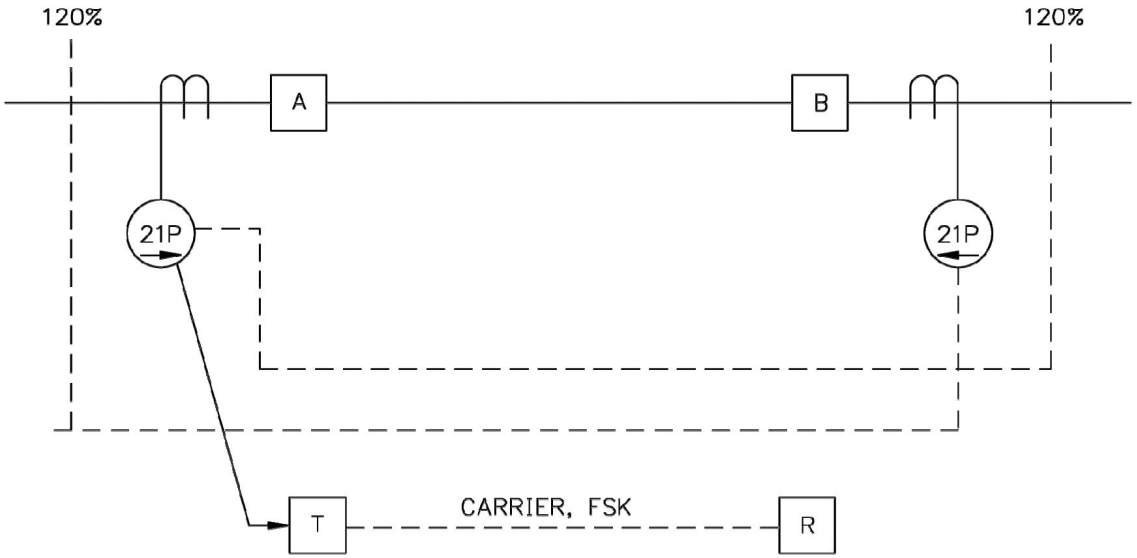
PLC Communication

- Couples carrier frequencies onto the power line for relay communication

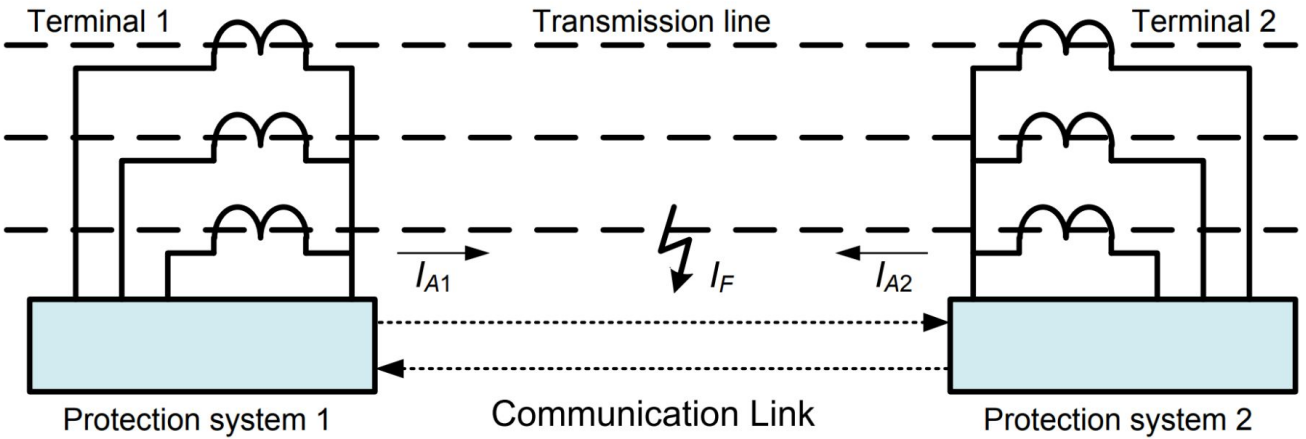


Directional Comparison Unblocking (DCUB)

- Same permissive logic as POTT
- PLC communication channel



Line Differential (87L)

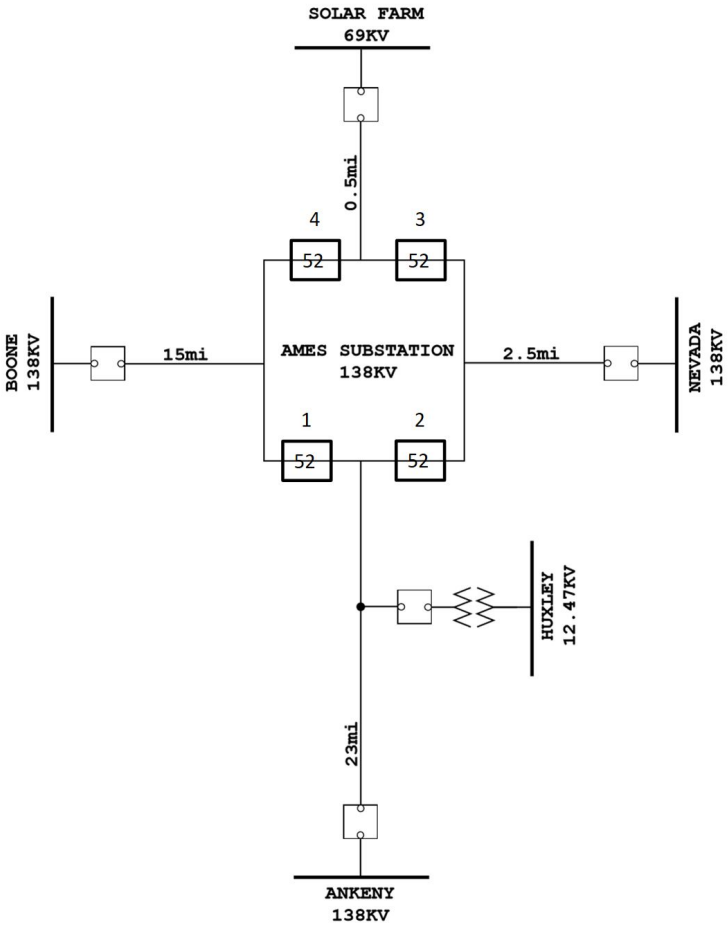


$I_{A1} + I_{A2} = 0$; no fault on the line

$I_{A1} + I_{A2} \neq 0$ ($= I_F$); fault on the line

Pilot Selection

- Ankeny 23 mile line and Huxley connection
  - Primary DCB, Secondary DCUB
- Nevada 2.5 mile line
  - Primary and secondary 87L
- Boone 15 mile line
  - Primary 87L, secondary POTT
- Ames Solar Farm 0.5 mile
  - Primary and secondary 87L



Relay Selection

Relay

- Is an electrical circuit component, serving as switches controlled by electrical signal.
- It consists of a set of input terminals for a single or multiple control signals
- Commonly used to control high-power circuit with low-power signals

Relays Function

- SEL 387E
  - Current Differential and Voltage Relay provides protection to two- or three-winding power transformers
- SEL 411L
  - Advanced Line Differential Protection, Automation, and Control System which provides differential and distance protection with both phase- and sequence-based
- SEL 421
  - Protection, Automation, and Control System
  - Serve for high-speed distance and directional protection and complete control of a two-breaker bay.
- SEL 487E
  - Transformer Protection Relay
- SEL 352: Breaker Failure Relay
  - Breaker failure protection, control, and monitoring.

Relays Function cont.

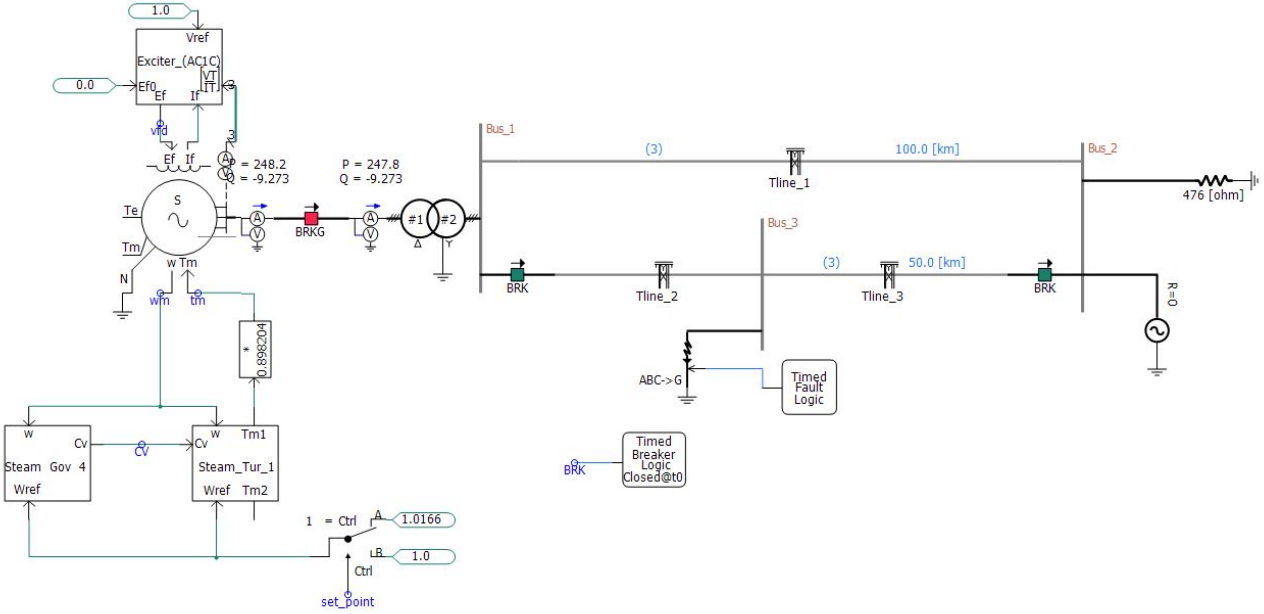
- SEL 387
  - Current Differential and Overcurrent Relay 4 current inputs for current differential calculations
  - Can be used for 87L and ring bus configurations
- SEL 401L
  - Ultra-High-Speed Line Relay provides 5 zones of protection
  - Provides directional and distance relay options

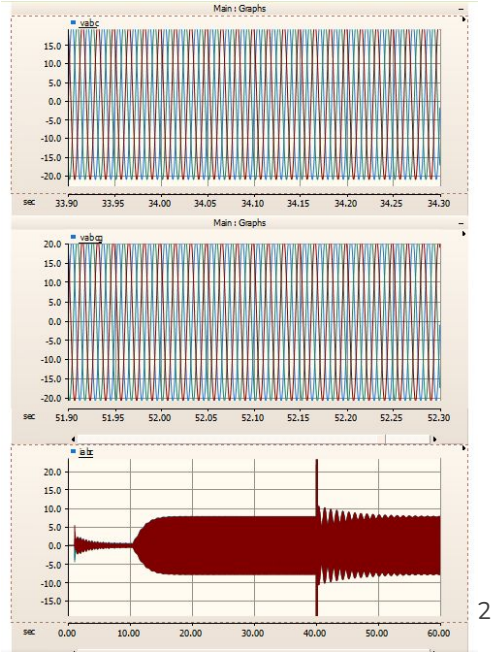
Relay Selections

- Ames – Ankeny (138 kV) – 23 miles
  - Primary: SEL 401L
  - Backups: SEL 421
  - Breaker Failure: SEL 352
  - Huxley connection: SEL 421
- Ames – Boone (138 kV) – 15 miles
  - Primary: SEL 411L
  - Backups: SEL SEL 421
  - Breaker Failure: SEL 352
- Ames – Nevada (138 kV) – 2.5 miles
  - Primary: SEL 411L
  - Backups: SEL 387
  - Breaker Failure: SEL 352
- Ames Solar Farm (69kV) – 0.5 miles
  - Primary: SEL 411L
  - Backups: SEL 387
  - Breaker Failure: SEL 352
- Transformer Breaker
  - Primary: SEL 487E
  - Backups: SEL 387E

Test Plan

- Implement design using PSCAD to test fault conditions
- Generate report to determine the differences between IBR and synchronous generation





Current Project Status/What's Next?

Completed this semester

- Bus Configuration
- Pilot Scheme Selection
- Site Layout
- Relay Selection

Next semester

- One-Line Diagram
- Dynamic Simulation
- Event Analysis Report
- Elevation Design
- Lightning Study

Questions?