138kV Cyclone Substation Design

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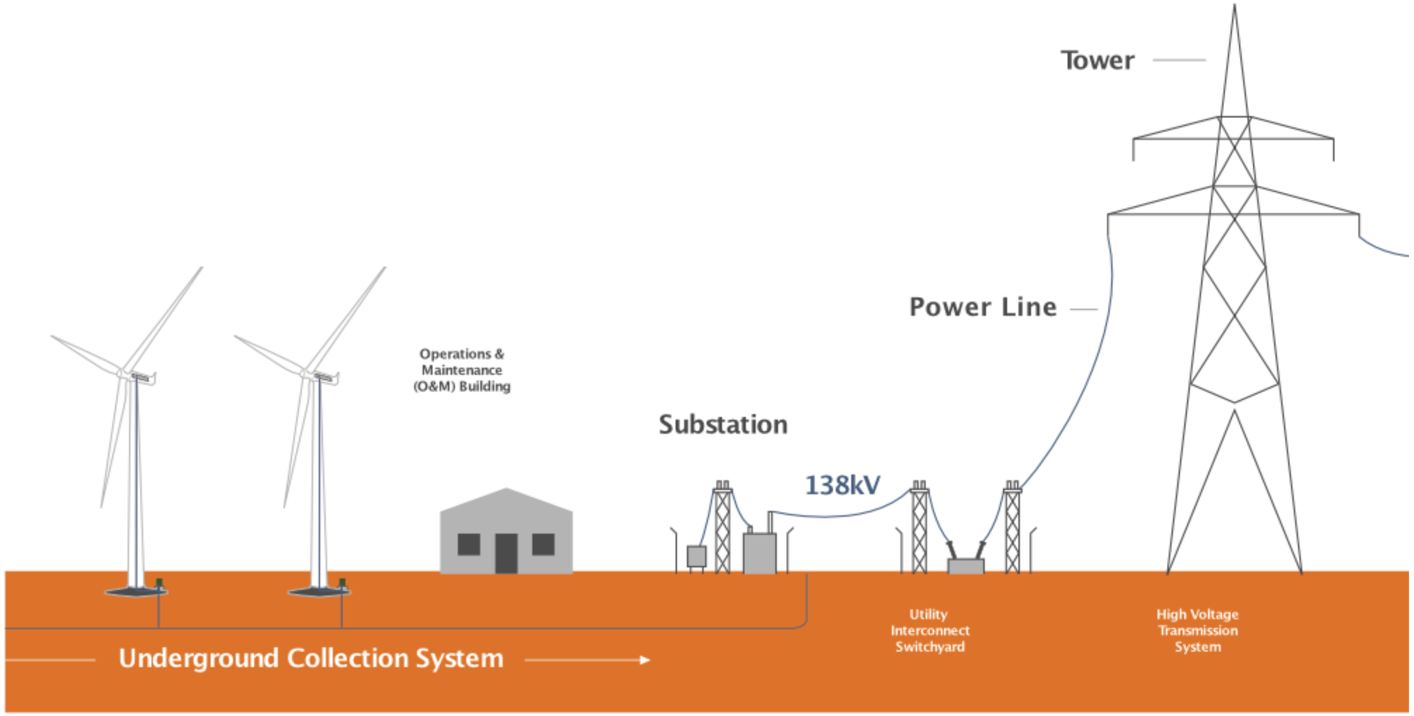
Sponsor: Burns & McDonnell – Riley O'Donnell & Tom Kelly

Advisor: Dr. McCalley

Scope and Project Need

Design a substation to interconnect a 69 kV wind farm in Ames, IA to Cedar Falls, IA and Des Moines, IA via 138 kV transmission lines.

The substation will bring renewable energy into the homes and businesses of residents in Cedar Falls and Des Moines reducing the need for the consumption of fossil fuels.



https://nmreta.com/transmission-lines/

Physical Components & Non-Functional Reqs.

Figure: Power Transformer

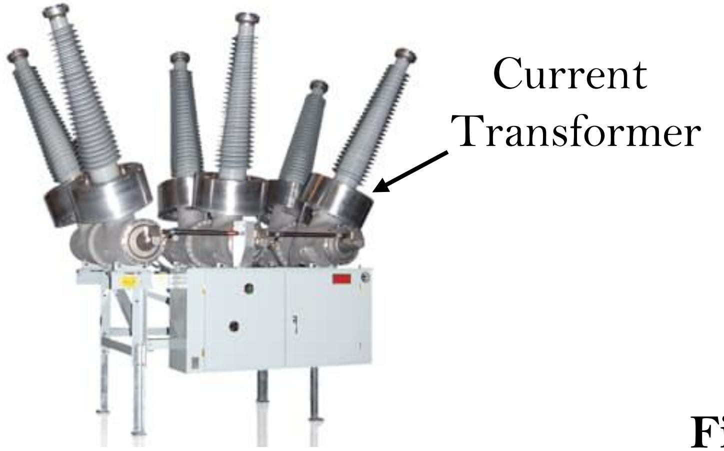


Figure: Circuit Breaker

Figure: Capacitively coupled voltage transformer

Figure: Wave Trap

Figure: Station service voltage transformer

Figure: Motor operated air break switch

Substation Configuration Requirements

- Initial breaker configuration: 3-position ring-bus
- Future breaker configuration: 6-position breaker-and-a-half

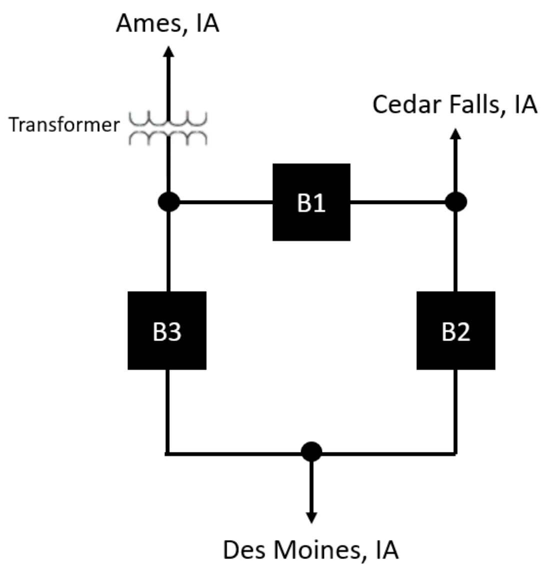


Figure: 3-position ring-bus

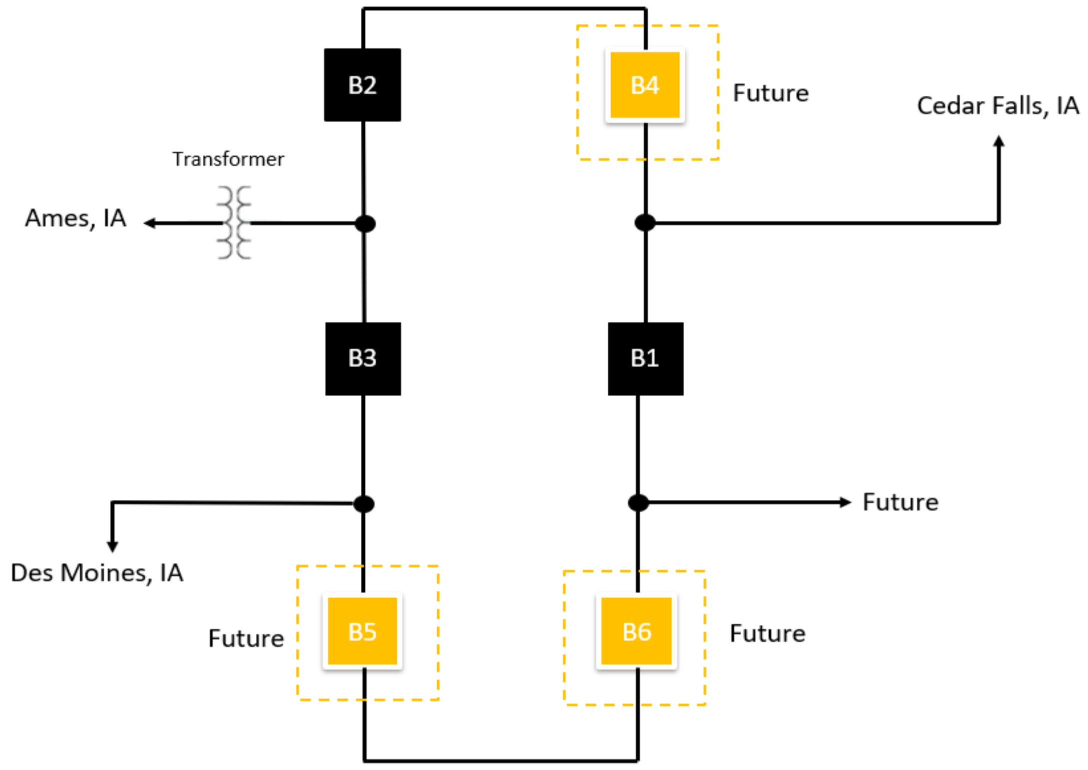
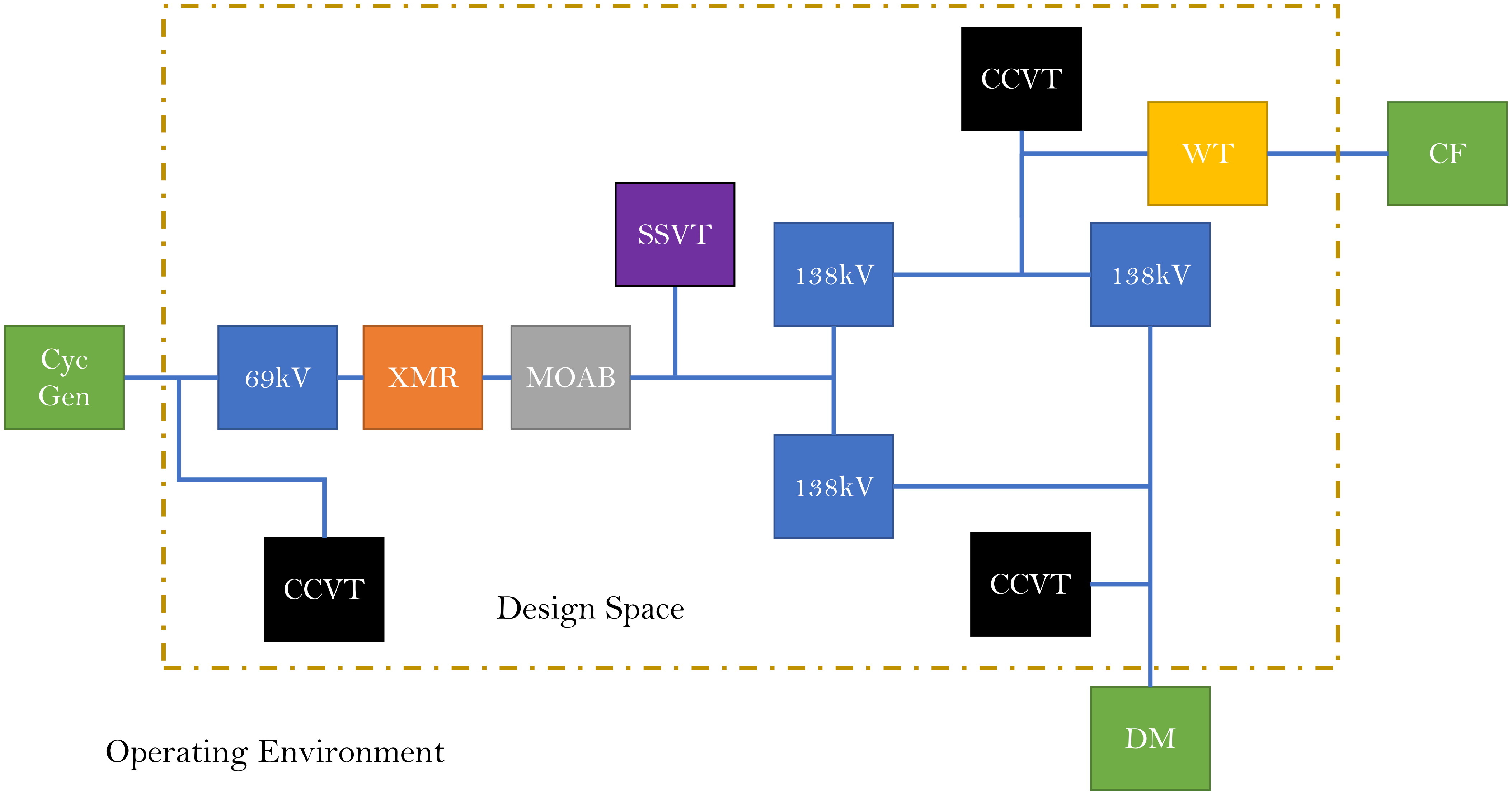


Figure: 6-position breaker-and-a-half

Conceptual/Visual Sketch



Conceptual Design Diagram

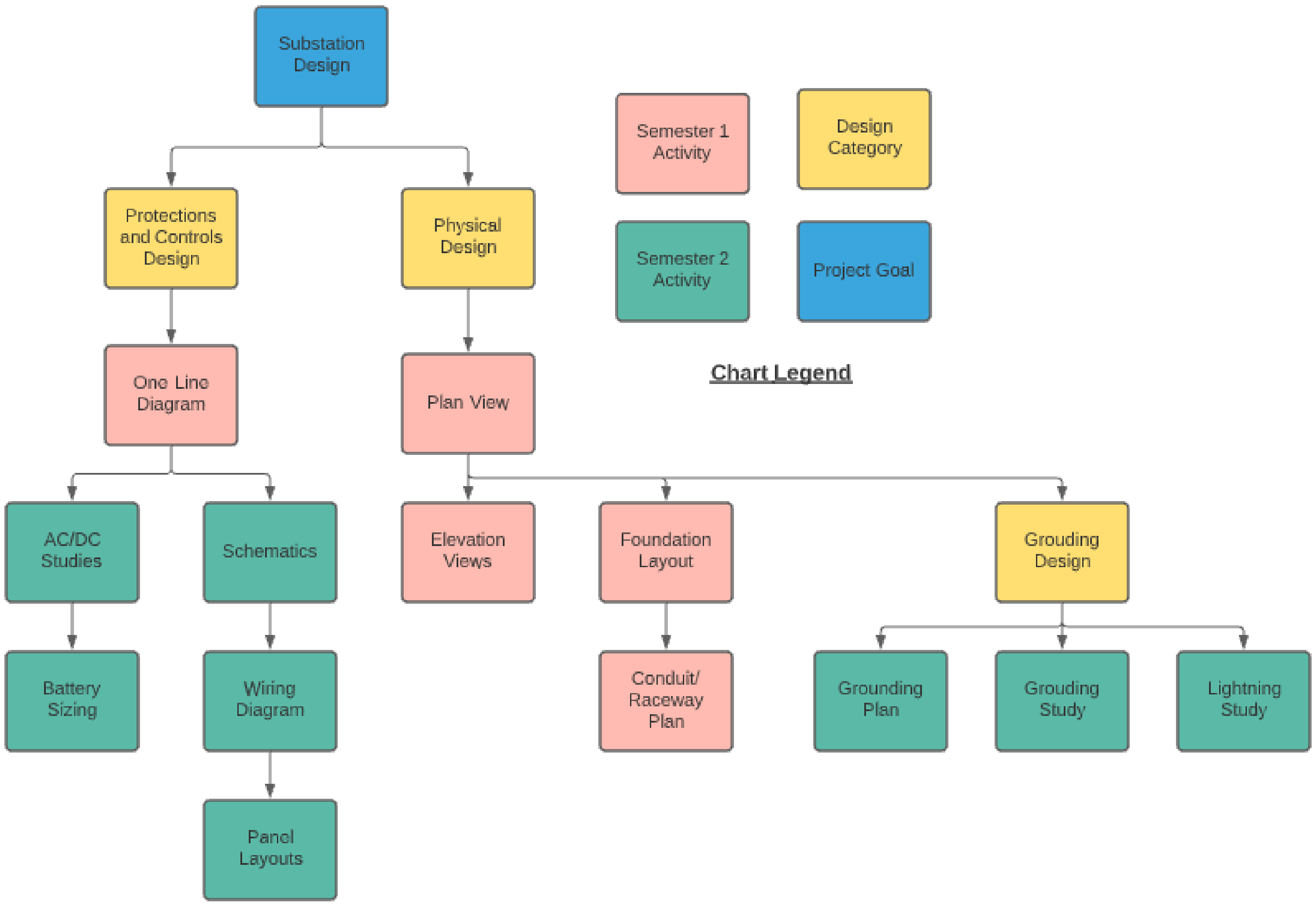
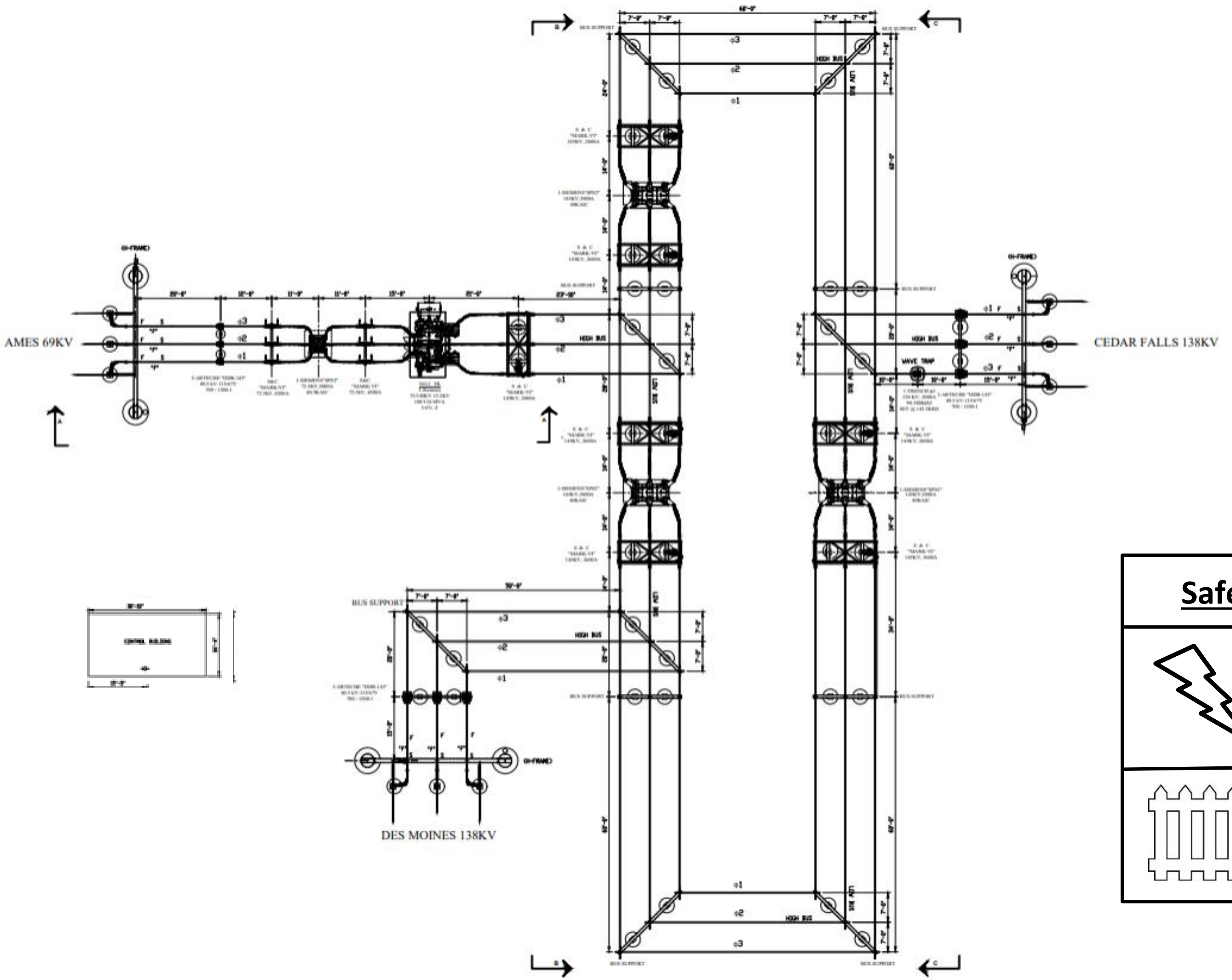
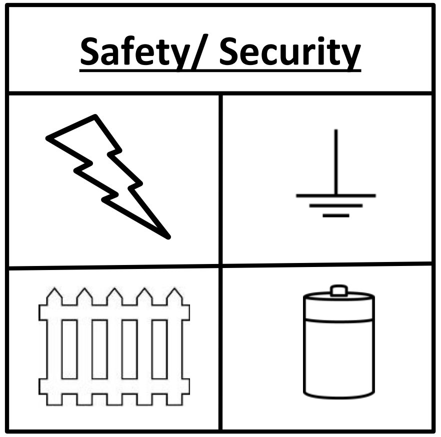


Figure: Design workflow

System Design - Plan View





System Design - Relay Specification

BURNS McDONNELL **Relay Specification**

Project ID:	**Iowa State EE Senior Design Project**
Description:	**Substation Design**
Author:	**Tom Kelly & Riley O'Donnell**
Revision Date:	**7/21/2020**

PROJECT SCOPE

The new Cyclone Substation will be a 138kV three breaker ring bus with a 138/69kV transformer (XFMR1) and a single 69kV line exit with a breaker. The station should be physically designed for the future expansion to a breaker-and-a-half arrangement.

Primary (DCB over Power Line Carrier) line protection for the 138kV Des Moines line exit will use a SEL-321 relay. Backup line protection for both the line exits will use a SEL-311B relay.

Primary and Backup line protection for the 69kV Cedar Falls line exit will be SEL-311L relays. Fiber optic cable will be used for relay communication between substations for both primary and backup relays.

SEL-352 relays shall be used for breaker failure protection on the 138kV ring bus breakers as well as the 69kV exit breaker. Separate primary and backup DC protection paths should be used to for all 138kV breakers and all protection schemes.

MAJOR EQUIPMENT

1. Install three (3) 138 kV circuit breakers (B1, B2 & B3), to be used for the transformer high-side.
   - The standard short circuit rating is sufficient.
   - Four (4) sets of 1200/5 ampere, MR, C800 accuracy class, rf=2.5 CT's per breaker (two (2) CT's per bushing)
2. Install one (1) 69 kV circuit breaker (B4), to be used for the transformer low-side.
   - The standard short circuit rating is sufficient.
   - Four (4) sets of 1200/5 ampere, MR, C800 accuracy class, rf=2.5 CT's per breaker (two (2) CT's per bushing)
3. Install three (3) Coupling Capacitor Voltage Transformers (CCVT's) (one per phase) on all three of the ring bus exits.
   - CCVT's to be rated 80.5,500V phase-to-neutral on the primary.
   - CCVT's to have two (2) secondary windings rated at 115/67V.
4. Station surge arrester specification to be determined by substation engineer.
5. All substation equipment and bus should be rated for at least 2000A. All line conductor and equipment should be rated for at least 750A.
6. Install one (1) station service transformer on the 138 kV bus side of the 138/69kV transformer MOAB to provide AC station service and relaying potentials.
   - 40250 – 120/240V, 100 kVA.

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138 kV Breaker B3 (XFMR1/Des Moines) Breaker Failure-to-Trip Relay

1- Schweitzer SEL-035210325HXX4XX, (BFR/B3) Breaker Failure relay, suitable for use at 125V DC. To be used for 138 kV Breaker B3 failure-to-trip protection.

1. Access to back of Schweitzer relays is required for PC connection.
2. Appropriate test/disconnect switches are required to provide connections for relay testing and isolation.

CT – 138 kV Bkr B3, XFMR1 side, top CT (Backup line Relay CT), 1200/5 (240/1)
PT – Wire the potential circuit of the SEL-352 relay to the 138 kV Des Moines line CCVT Y-Winding, 1200/1

One-Line

Output Contact Assignments:
OUT101 – Trip 138kV Bkr B3 86BFT aux relay
OUT102 – Re-trip Bkr B3
OUT103 – Enable Bkr B3 Close (Sync Check)
OUT104 – Init Send TT (Des Moines Line)
OUT105 – spare
OUT106 – spare
OUT107 – spare

Input Contact Assignments:
IN101 – Bkr B3 Breaker Failure Initiate
IN102 – Bkr B3 Status – 52/a contact
IN103 – spare
IN104 – spare
IN105 – spare
IN106 – spare

Schematic

Electroswitch series 24 switch to be used as a Failure to Trip cutoff switch (FT/CO). This switch shall be utilized to disable the Failure to Trip relaying for testing and maintenance. Escutcheon to read "ON" and "OFF" with the "ON" position to be in the twelve o'clock position.

Electroswitch Series 24 Lock-Out Relay (86BF/B3)

Contacts to be utilized as follows:

- Trip Bkr B1 and Block Close
- Trip Bkr B2 and Block Close
- Trip Bkr B4 and Block Close
- Block Close Bkr B3
- Send DTT to Des Moines via primary SEL311L
- Send DTT to Des Moines via backup SEL311L
- SCADA Indication (closed in "OFF" position)

Panel

Design Analysis/ Testing

Three major reviews are conducted:

- **Individual review –** Sub-team reviews deliverable
- **Peer review** - Whole design team reviews deliverable
- **Acceptance testing –** Client reviews the deliverable

In each review, the following tests are conducted:

- **Unit testing** - Review the deliverable against itself ensuring it meets design requirements
- **Interface testing** – Review how the deliverable references others

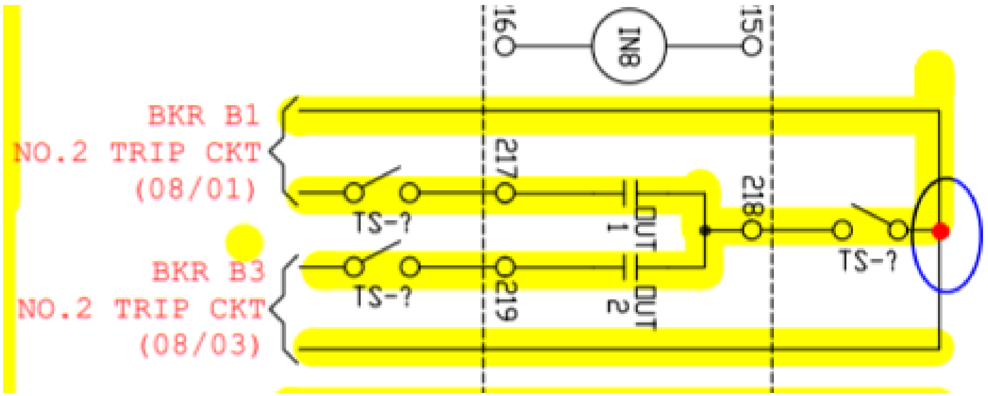


Figure: Unit Testing

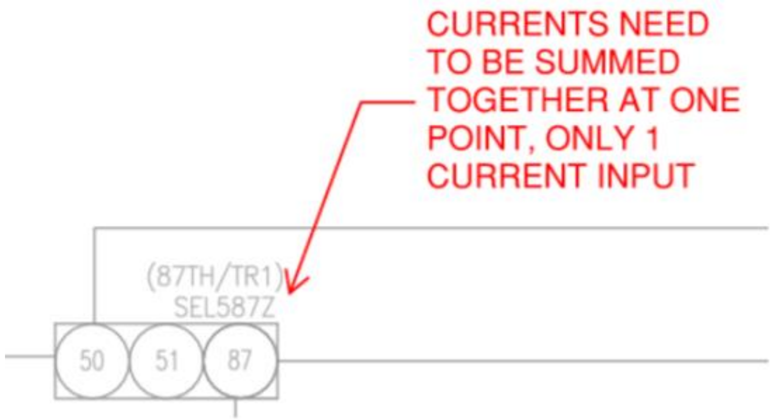


Figure: Acceptance Testing

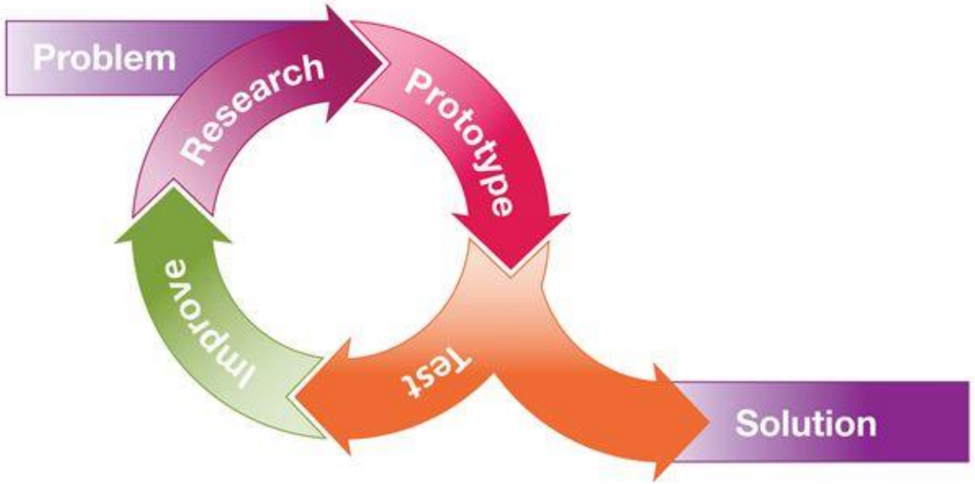
Measuring Success

Physical Design

- Does the design meet configuration and equipment requirement?
- Does the design allow for future expansion?

Protections and Controls Design

- Does the design implement the relay functions specified by the client?



Year-End Accomplishments

We **designed** a substation:

- Physical design (first semester)
- Protections and Controls (second semester)

Design Strategy	
Physical Design	**Protections and Controls**
Conduct various studies	Become familiar with relay specification
Review component specifications	Interact with the client to gain insight
Understand client requirements	Focus on protection of electrical assets
Focus on physical and electrical safety	

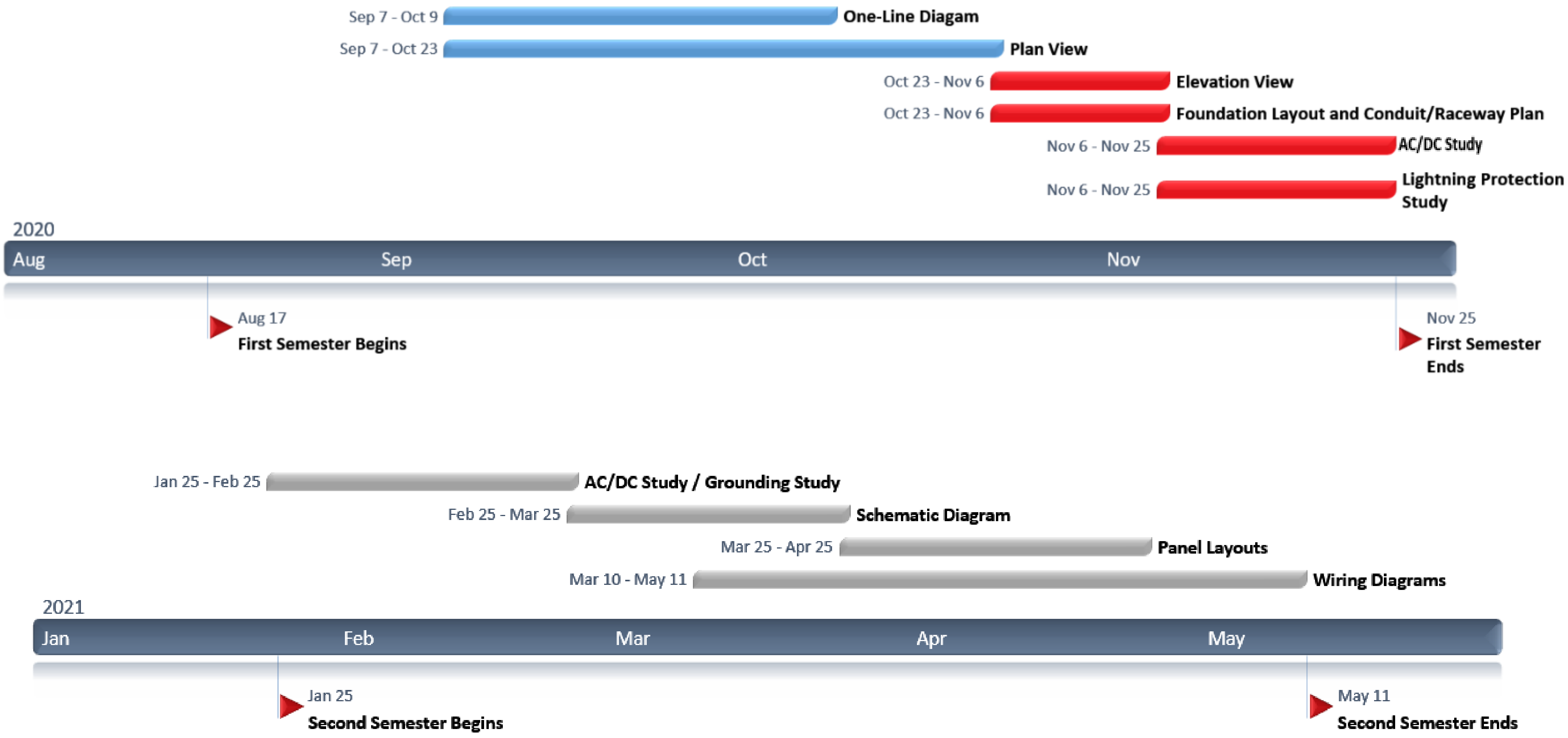
Conclusion

- Designed a substation through a set of deliverables
- Implemented industry standards in the design
- Added an emphasis on safety
- Created and carried out a testing strategy for our deliverables

https://sdmay21-04.sd.ece.iastate.edu/docs.html

Slide Appendix

Project Schedule



Limitations and Future Work

Limitations:

- Lack of electrical testing for protection system
- Focus purely on design over construction

Future Work:

- Procure materials and construct the substation
- Design the SCADA system
- Simulate the substation and controls via PLECS/ PSCAD/ SKM

Outcomes of Testing

One-Line

- Contradictions in the protection specification identified
- Currents enter relays on the left and potentials on the top

Plan-View

- Additional bus supports were required for long bus runs
- Move control building

Foundation Layout

- Drawing title block needed updating

Conduit/Raceway

- Add conduit for future expansion

Standards and Aiding Materials

Standards

- IEEE 80 - Substation grounding standard
- IEEE 998 - Substation lightning protection standard
- IEEE 450, 484, 485, 1187, 1188 - Battery Sizing

References

- Client protection specification
- *Design Guide for Rural Substations* - Prepared by BMcD

Industry Grade Software

- AutoCAD
- Bluebeam
- CDEGS

Component Selection

The following equipment is specified by the design team under the criteria that it meets client requirements and publicly available documentation is present:

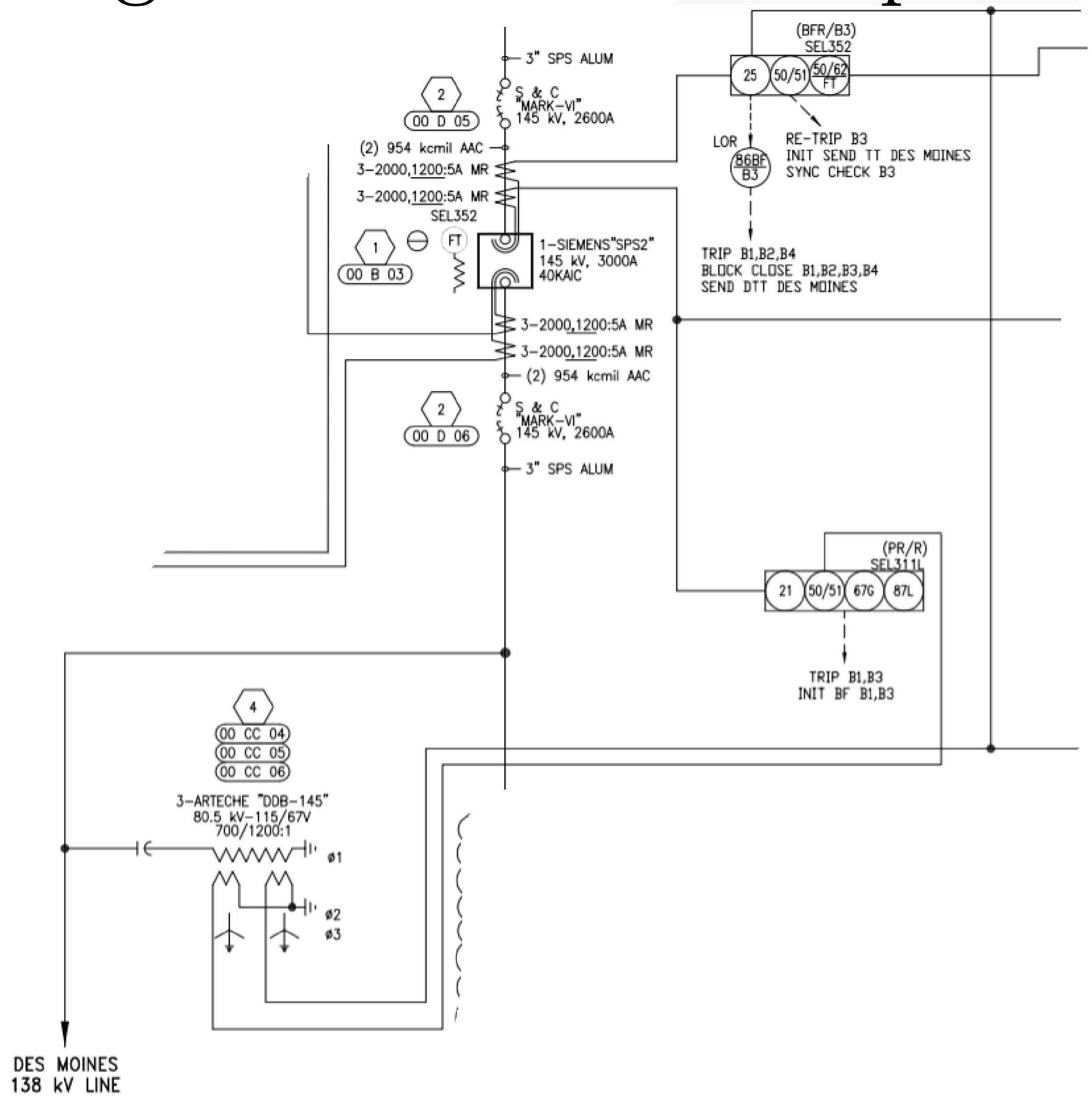
- Capacitor Coupled Voltage Transformers - Arteche DDB 145
- Bus Conductor - AFL Global 3-inch Schedule 80
- Wave Trap - Trench
- Station Service Voltage Transformer - ABB Kuhlman

Figure: Wave Trap

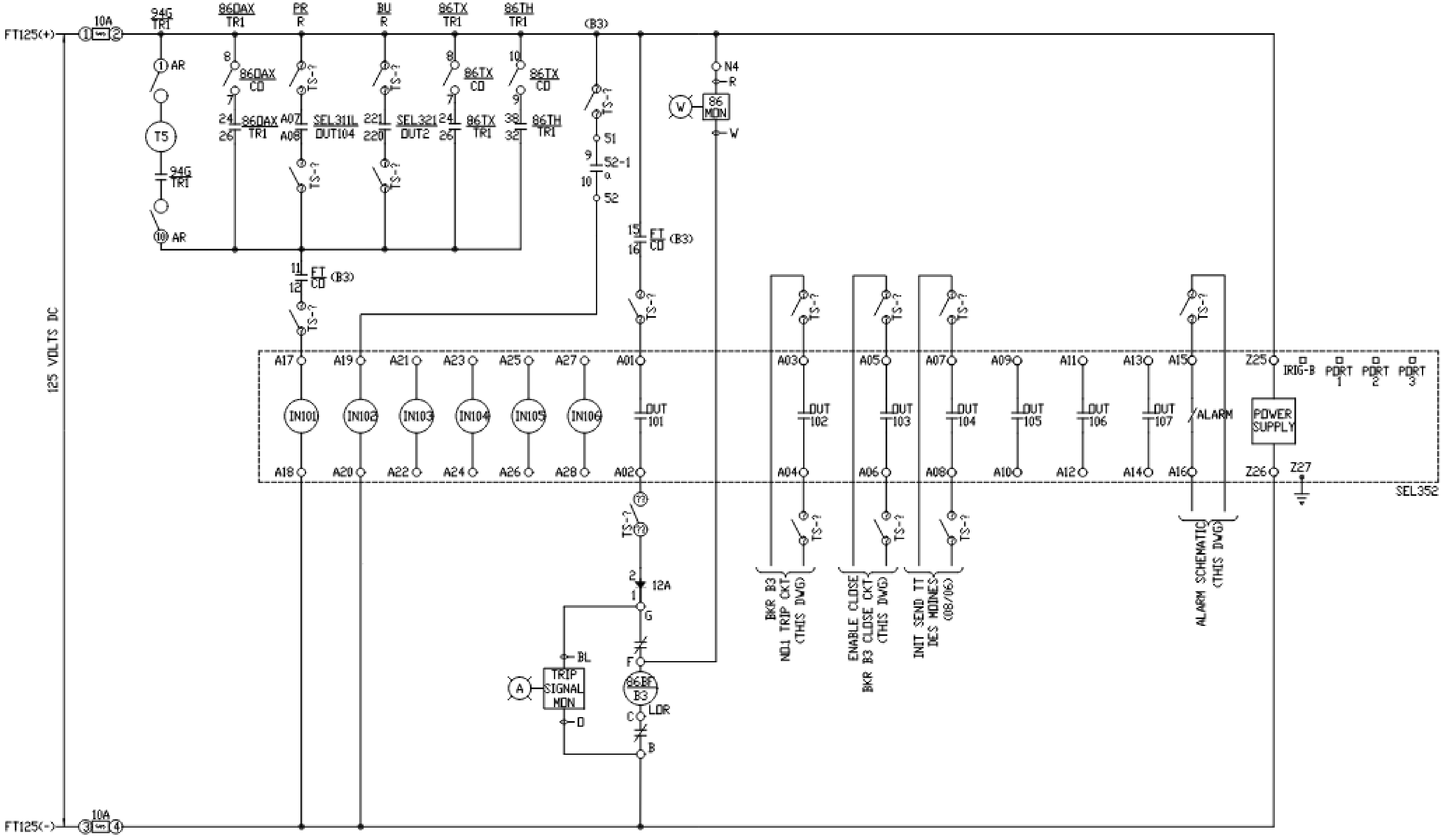
Figure: DDB 145

Drawing Stockpile

System Design - One Line Representation

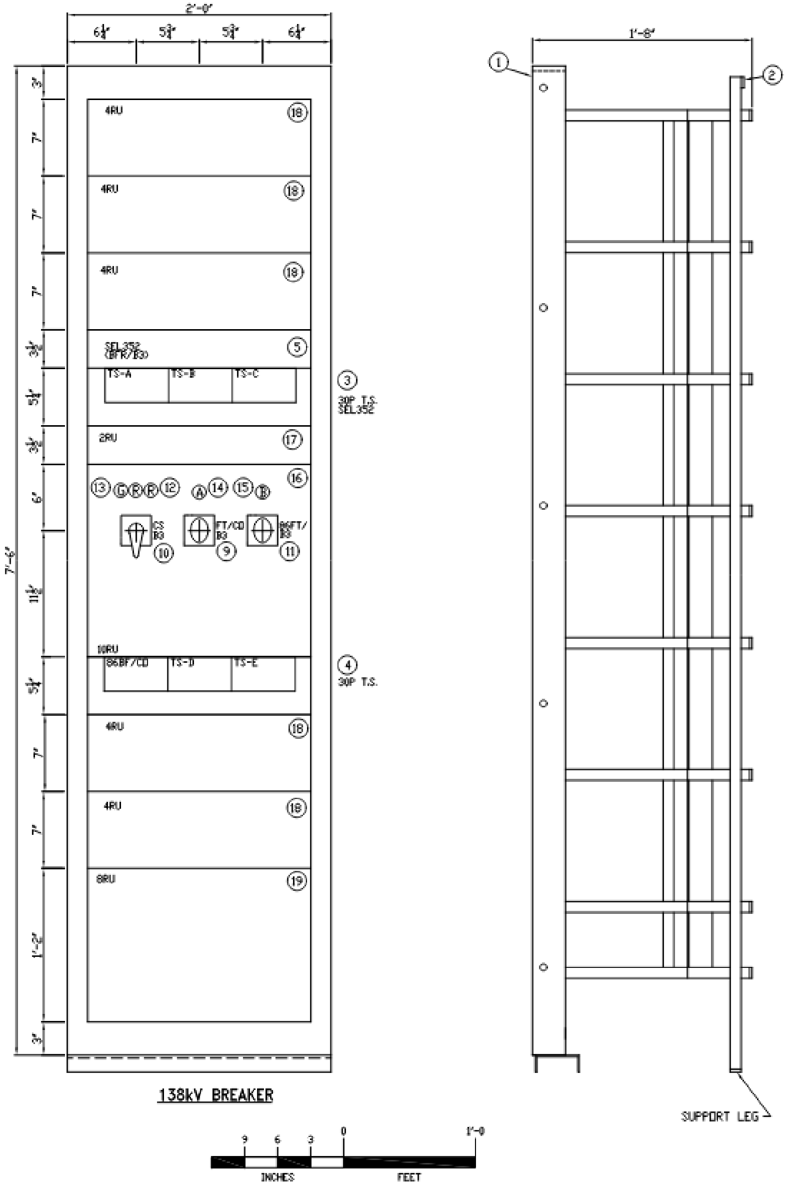


System Design - Schematic

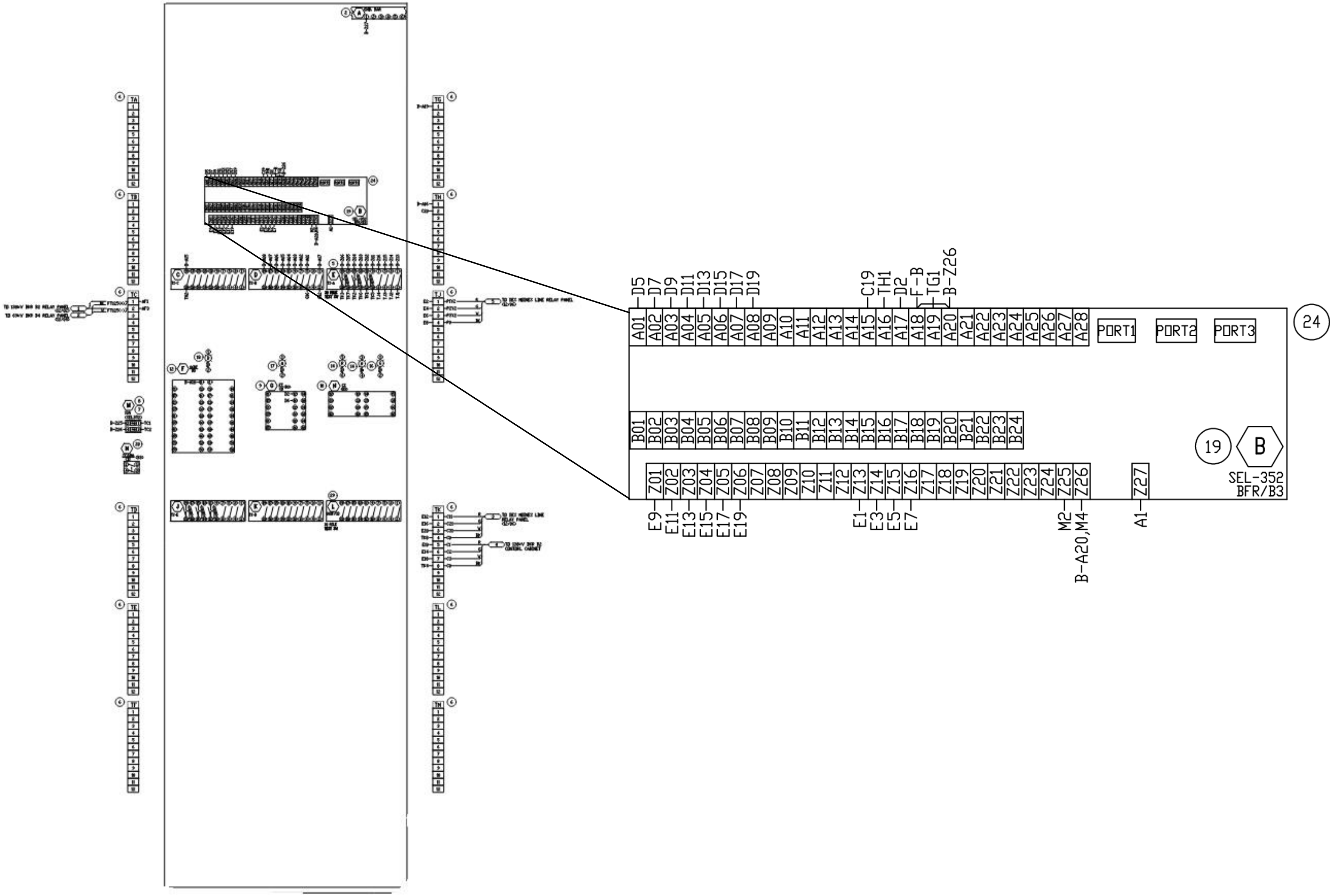


BREAKER FAILURE RELAYING (BFR/B3)

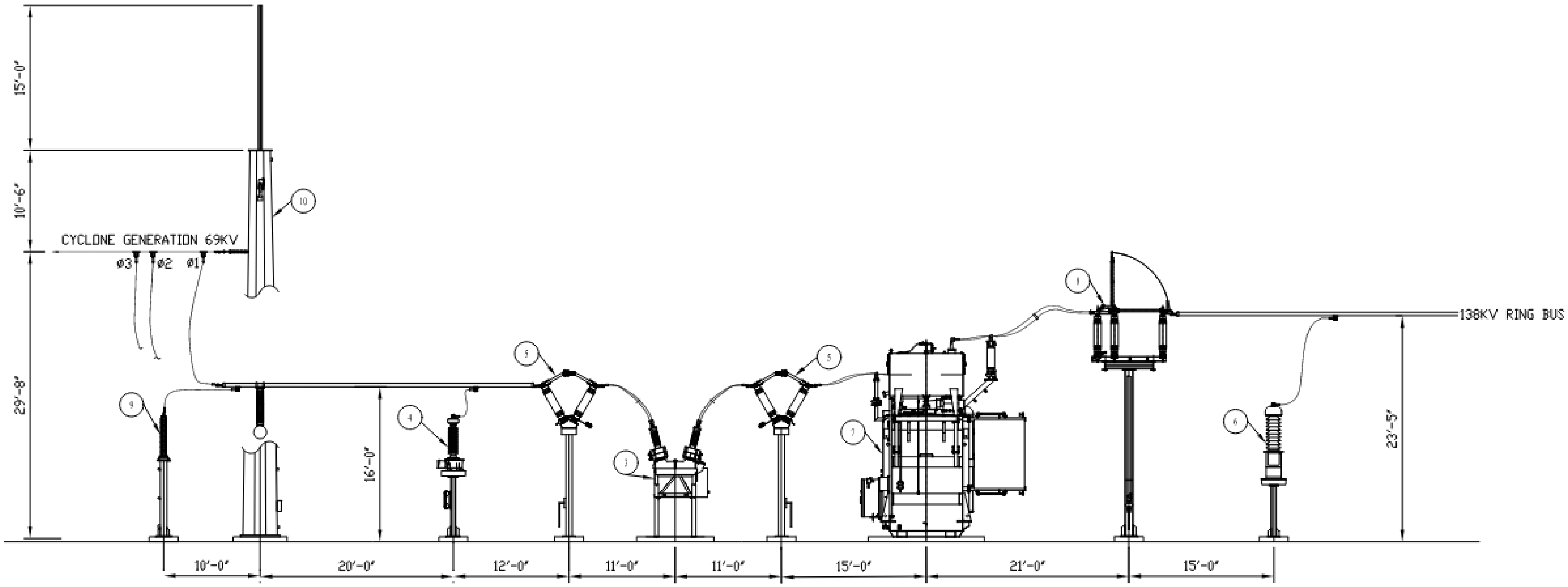
System Design - Panel Layout



System Design - Wiring



System Design - Elevation View

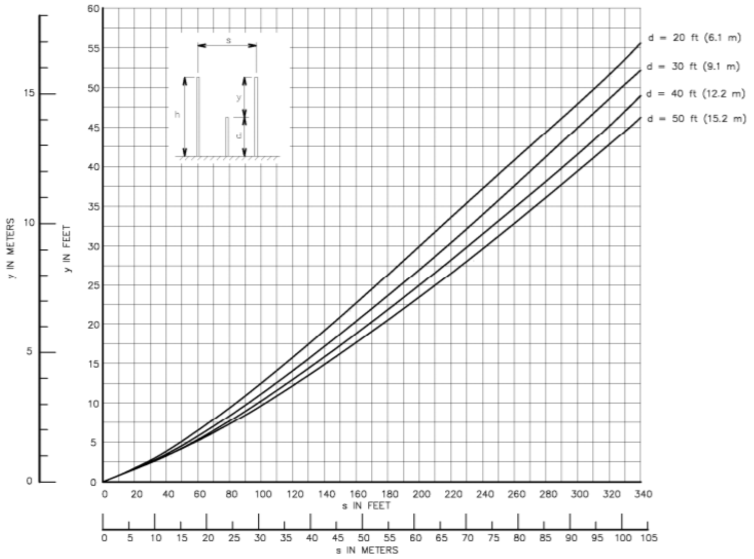


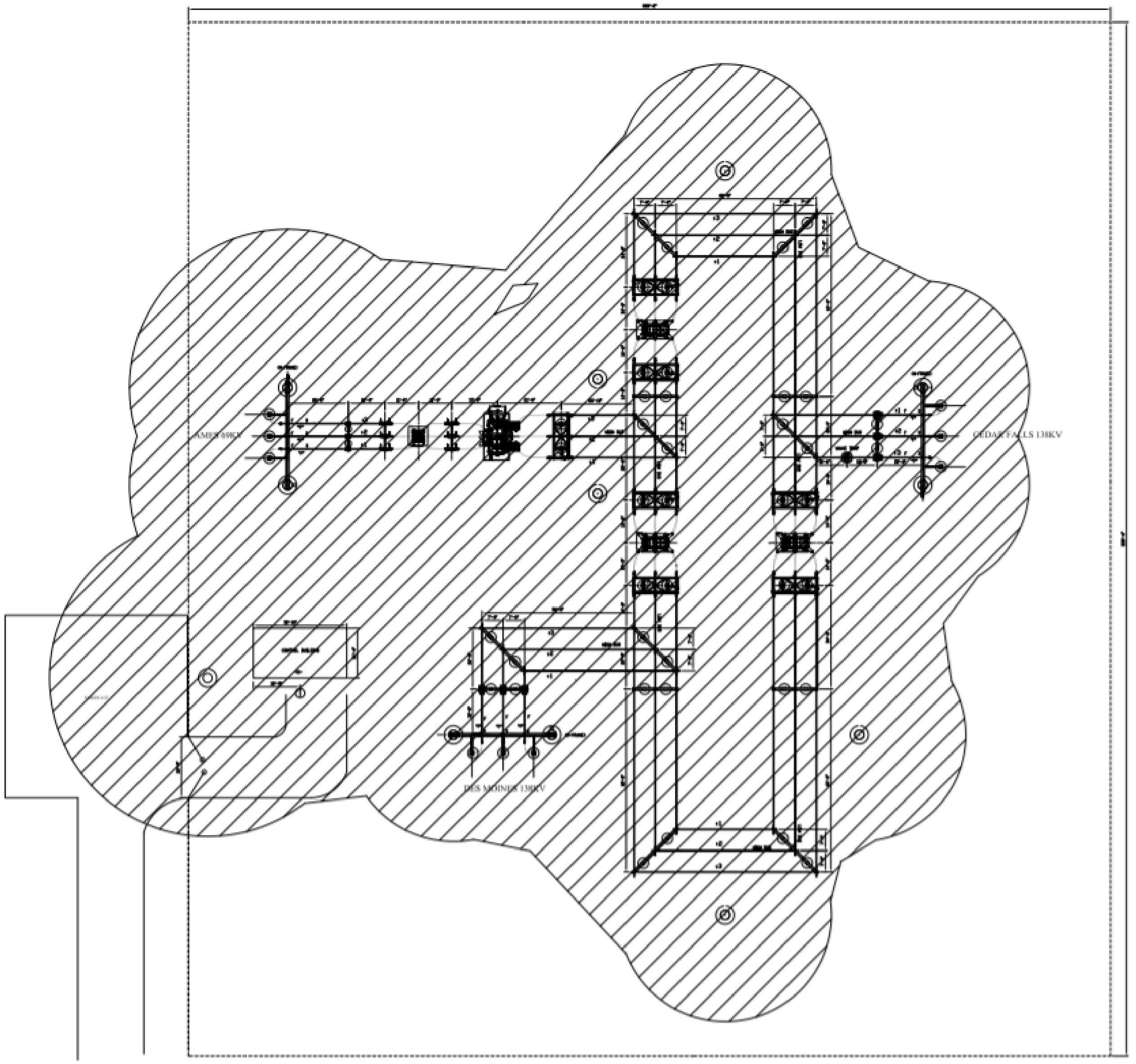
SECTION A TRANSFORMER ELEVATIONS

System Design - Lightning Protection

Standard Alert:

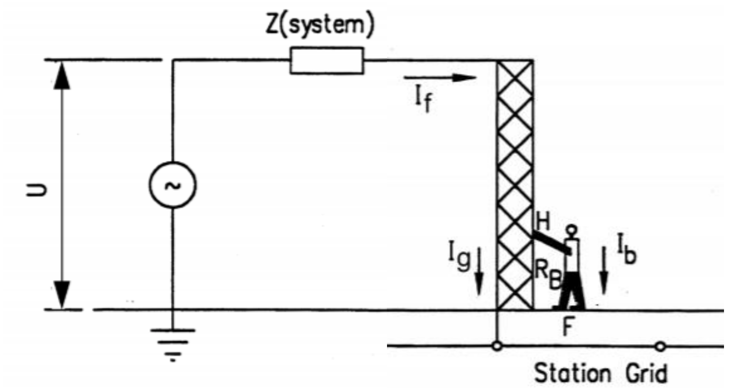
IEEE 998 - Guide for Direct Lightning Stroke Shielding of Substations

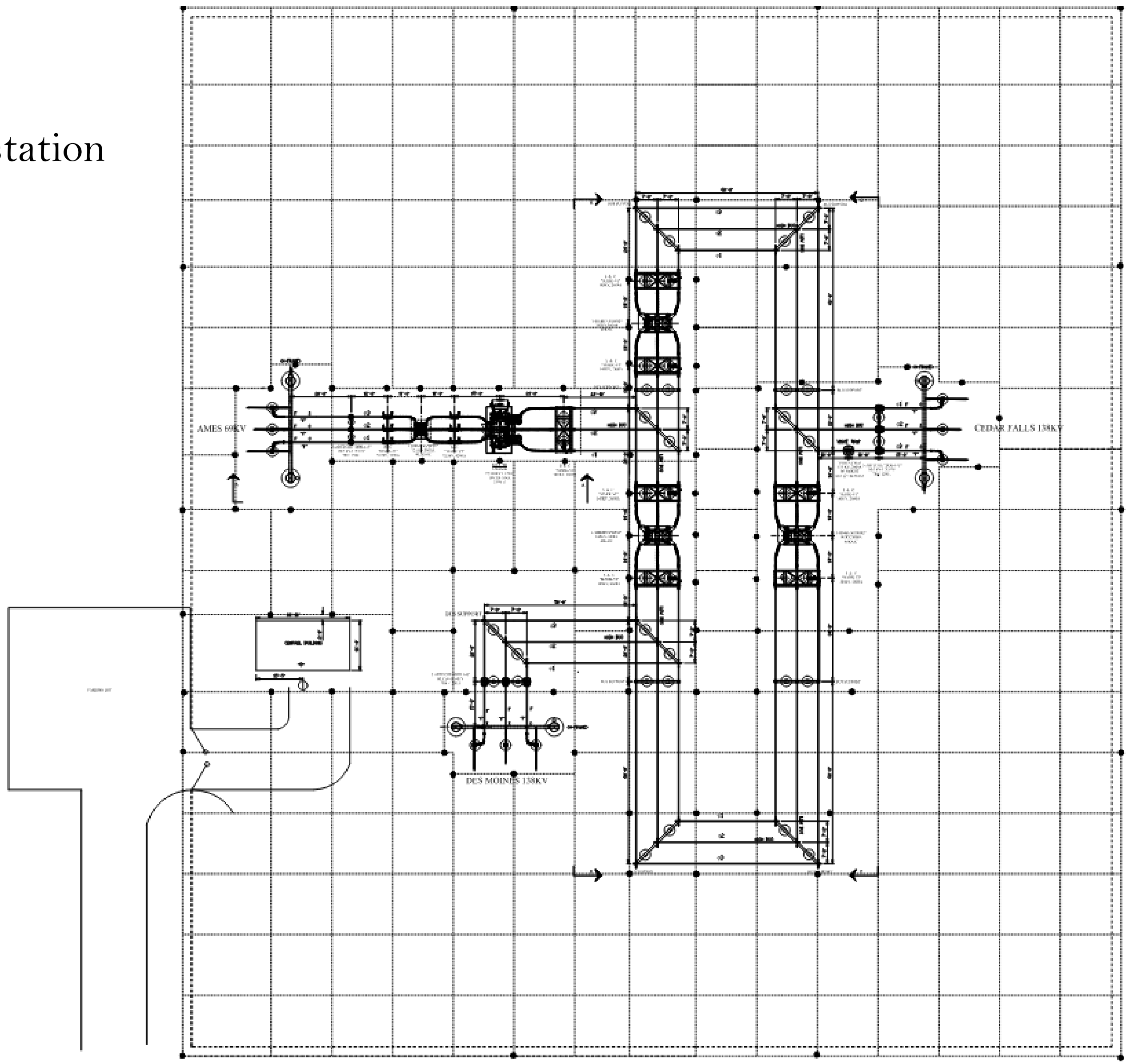




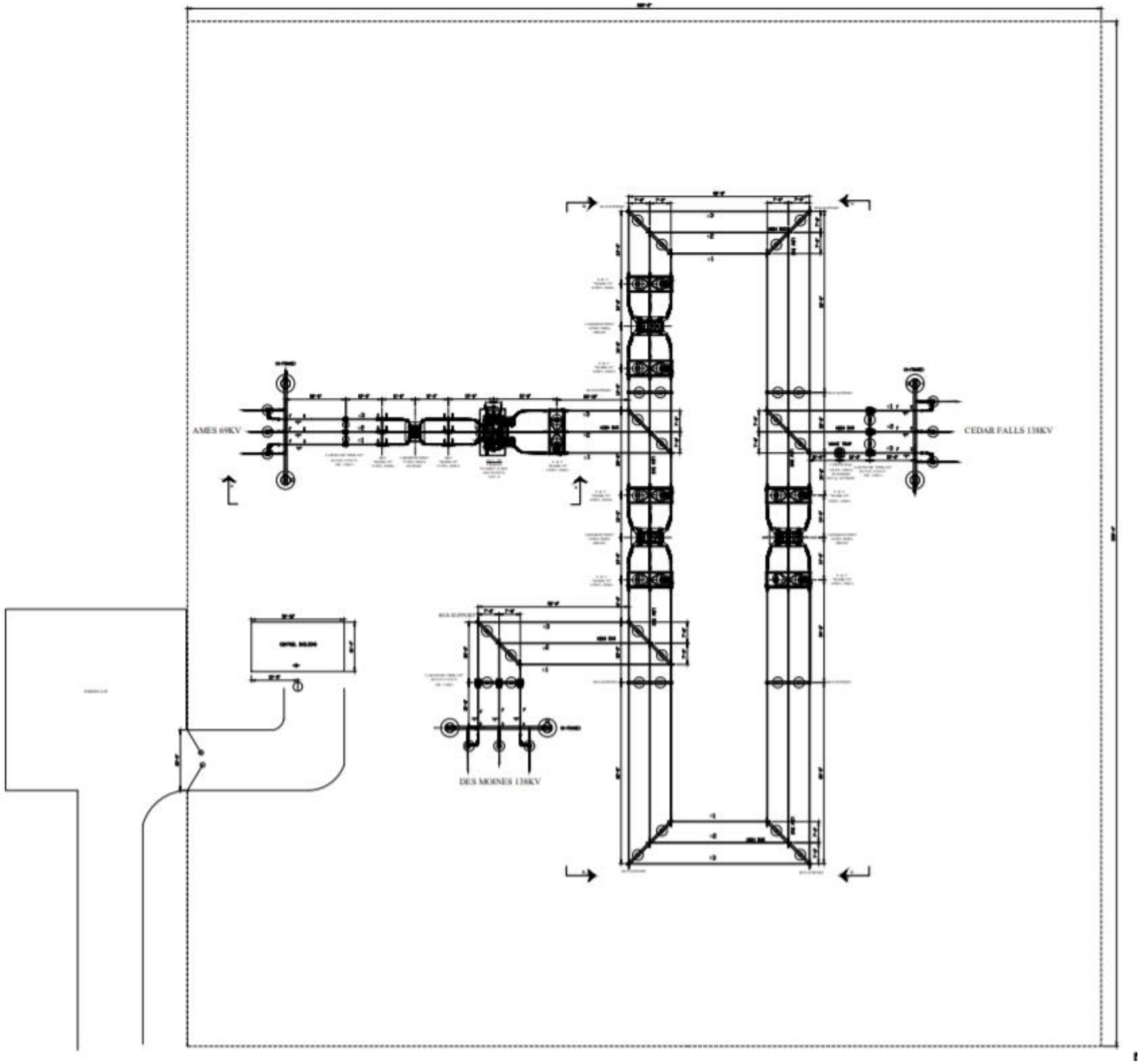
System Design - Grounding

Standard Alert:
IEEE 80 - Guide for Safety in AC Substation Grounding



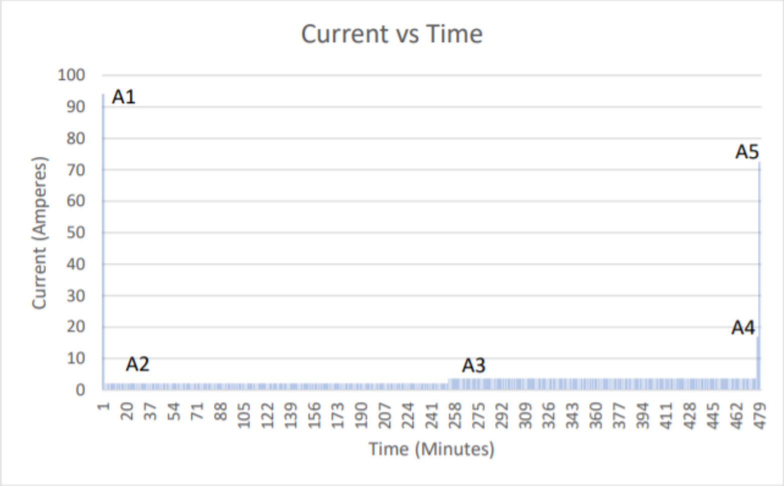


System Design - Fence



System Design - DC Study

Standard Alert:
IEEE 485 - Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications



Continuous Loads			
Quantity	**Device**	**DC Load Current (A)**	**Total (A)**
12	Relay & Meter Load	2.0776	24.931

Momentary Loads			
Quantity	**Device**	**DC Load Current (A)**	**Total (A)**
6	Emergency Lightning	0.256	1.536
7	Start Breaker Motors	9.8	68.6
7	138 kV and 69 kV Breaker Trip Coil #2 (Close)	1.9	13.3