Final Report for May 1611
Lamoni Municipal Utilities Upgrade

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Project Plan

Background

Lamoni is a growing community of 2,300 people in southern Iowa that is served by a municipal utility providing electricity, gas and water to the community. Lamoni would like to work with a team of students to help the utility choose the most cost-effective way to upgrade its distribution system to the east by looping a distribution feeder that is currently providing radial service. Among the design elements are: route selection, space constraints, design optimization, interconnection with existing feeders, and cost considerations of the updated system. Lamoni Municipal Power will provide one-line diagrams of current feeder configurations, data on power flows, design specifications of existing system and telephone support for questions from students.

Project Statement and Constraints

Lamoni's substation is rated for a maximum capacity of 10 MW, and is usually running around half of its capacity. The feeder our project is concerned with directs power out to the east end of Lamoni and is predicted to have reliability issues if more customers are added to the line. In order to relieve this issue, a radial line will be looped with an existing overhead line to help distribute power. This will add redundancy to the system and help prevent future blackouts. The power line specifications and load data will be supplied by Lamoni Municipal Power for us to verify that the lines will be able to support the full load through a power flow analysis. The project team will also need to locate a viable route for the new underground radial line and come up with a cost estimate and payment plan. Lamoni Municipal Power would also like to see several design options for a system that minimizes cost to the city and maximum reliability to allow for future commercial growth. Due to city ordinances, any distribution lines that are built within Lamoni city limits will need to be routed underground. The upgraded system will be designed to supply power to a 2 MW peak load on the east side of Lamoni.

Deliverables

1) A report suitable for presenting to the utility governing body detailing the design recommendations, power flow analysis, cost analysis (net present worth of alternatives) and payment plan.
2) Suitable one-line diagrams, distribution line routing plan, and equipment specifications

Design Option One:

This option is a combination of underground and overhead lines. A breaker cabinet will be added to the new generator site located across from the Lamoni Municipal Power building. Roughly 4500 feet of underground cable will run from the new breaker to Smith Street. The line will then be converted to an overhead line and run another 9000 feet to the interstate. The new overhead line will run parallel with the existing overhead line from the Municipality building to the interstate, where they will be looped together.

To improve reliability, we will need to have the two overhead lines on separate poles and different sides of the road. This will prove to be difficult because of easement issues. Although this option is more reliable than the existing system, it is less reliable than the other option because of the exposed overhead lines. This is because the overhead lines are very close together, and thus susceptible to the same fault conditions. For example, if high winds were to take down one line, there is a high probability that it would also take down the parallel line. This option is also less visually appealing since there will be parallel overhead lines surrounding the road. However, it would be the most cost effective way of providing reliability to the system.

Design Option Two:

This option uses underground lines to loop the east feeder. A breaker cabinet will be added to the new generator site located across from the Lamoni Municipal Power building. An underground cable of roughly 13,500 feet will run from the new breaker cabinet to the interstate. This underground line will be ran parallel to the existing overhead line. Once the two lines reach the interstate, they will be looped together. The load on the overhead line will be split with the underground line through a normally open switch. This will be the most expensive option but also the most reliable. If the overhead line were to fault, the underground line will be able to feed most of the load. Underground lines have the advantage of not needing any additional easements since the lines can be placed under the existing overhead lines. A possible issue with this route is that it may be difficult to place the underground cable without affecting the pre-existing distribution lines of the east feeder.

System Analysis

Currently, there has been some worry that the east feeder will begin experiencing reliability issues if the commercial end of Lamoni continues to grow. With the existing system, the load has a peak around 2MW during the summer months. In both design options, the load would be split between the parallel lines which would add to the total capacity of the system. This is desirable for future growth of the load. For both of these options, we would be installing a new breaker and monitoring equipment in the new generator site. Both options would provide greater reliability than the current system.

Diagrams

Current system:

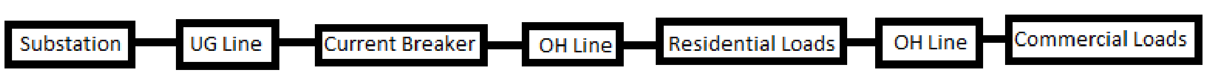


Diagram of design option one:

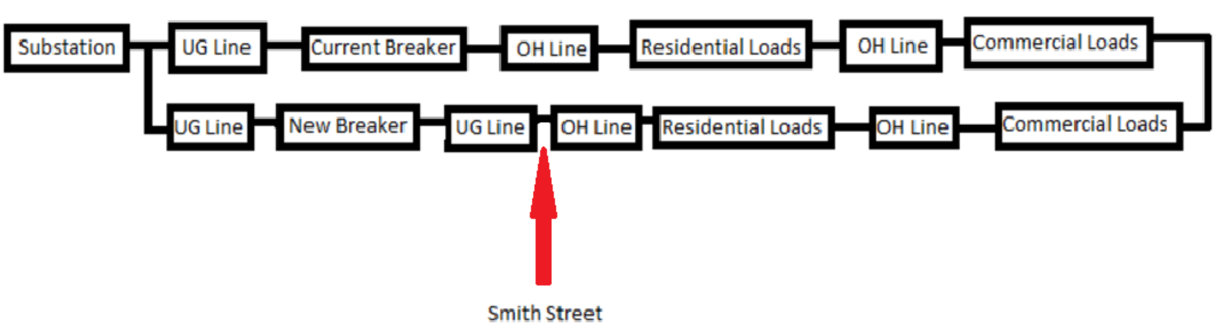
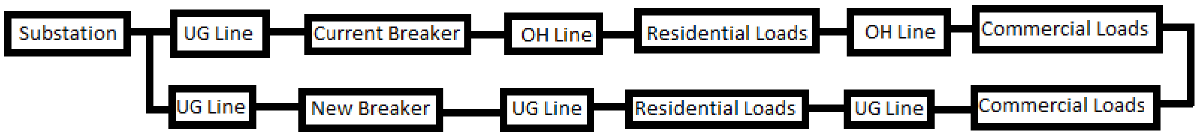
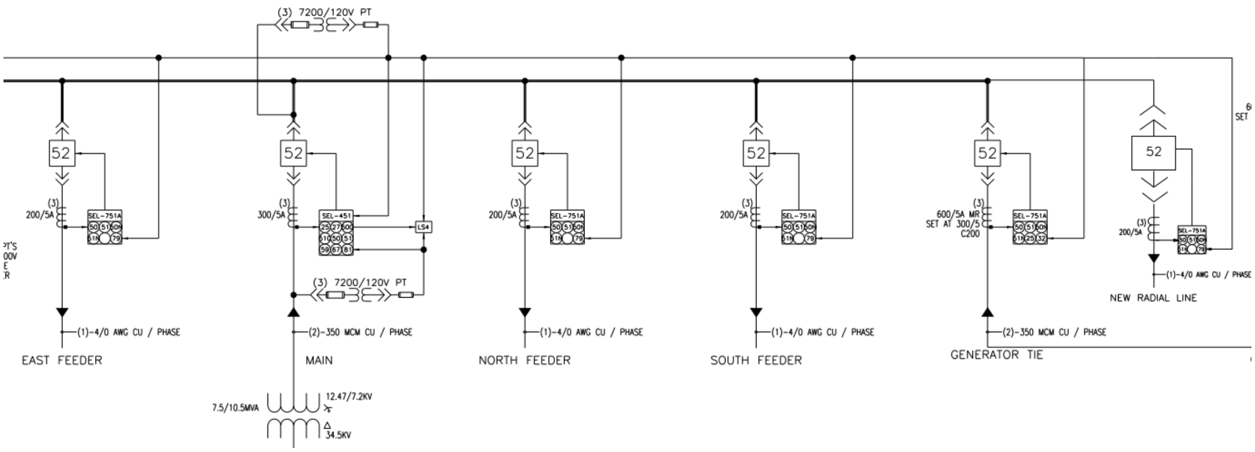


Diagram of design option one:



One-Line Diagram:



Our one-line diagram is applicable for both design options. The diagram shows a breaker and CT being added to the existing equipment. The new equipment is labeled as the "New Radial Line".

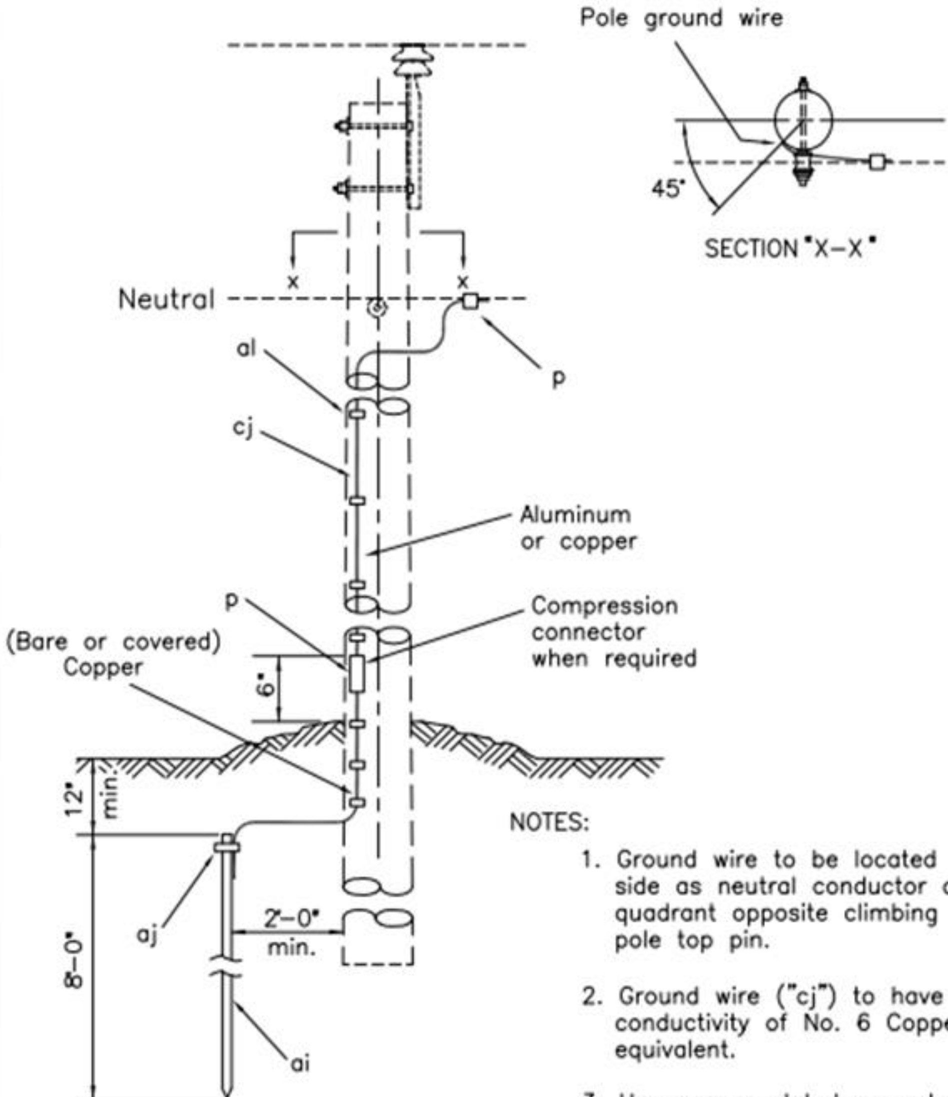
Simulations and Modeling

We used a professional transmission system planning software, OpenDSS, to perform the power flow analysis. This is the same program that many companies use in the industry and we were given access to it through Iowa State's computer labs. By utilizing this program, we were able to prove that our design is successful in supplying the required loads. We also used Microstation, a professional designing software, to create the system one-line diagram.

Standards

The standards used in the Lamoni Municipal Upgrade come from the United States Department of Agriculture Rural Utility Service. These specifications are the standard for all public power utilities and are followed by Lamoni Municipal Utilities. The following standards cover the equipment, structures, and information that will be required for the Underground and Overhead parts of the design. The images have been taken from the specification books that the United States Department of Agriculture Rural Utility Service places on their website. A full list of these spec books can be found on their website at: http://www.rd.usda.gov/publications/regulations-guidelines/bulletins/electric

The Breaker Specifications come from the General Electric DEH41480 Specification and testing book. While we could not include all of the specifications in this section we have added all those that were necessary to the design.



NOTES:

1. Ground wire to be located on same side as neutral conductor and in quadrant opposite climbing space or pole top pin.

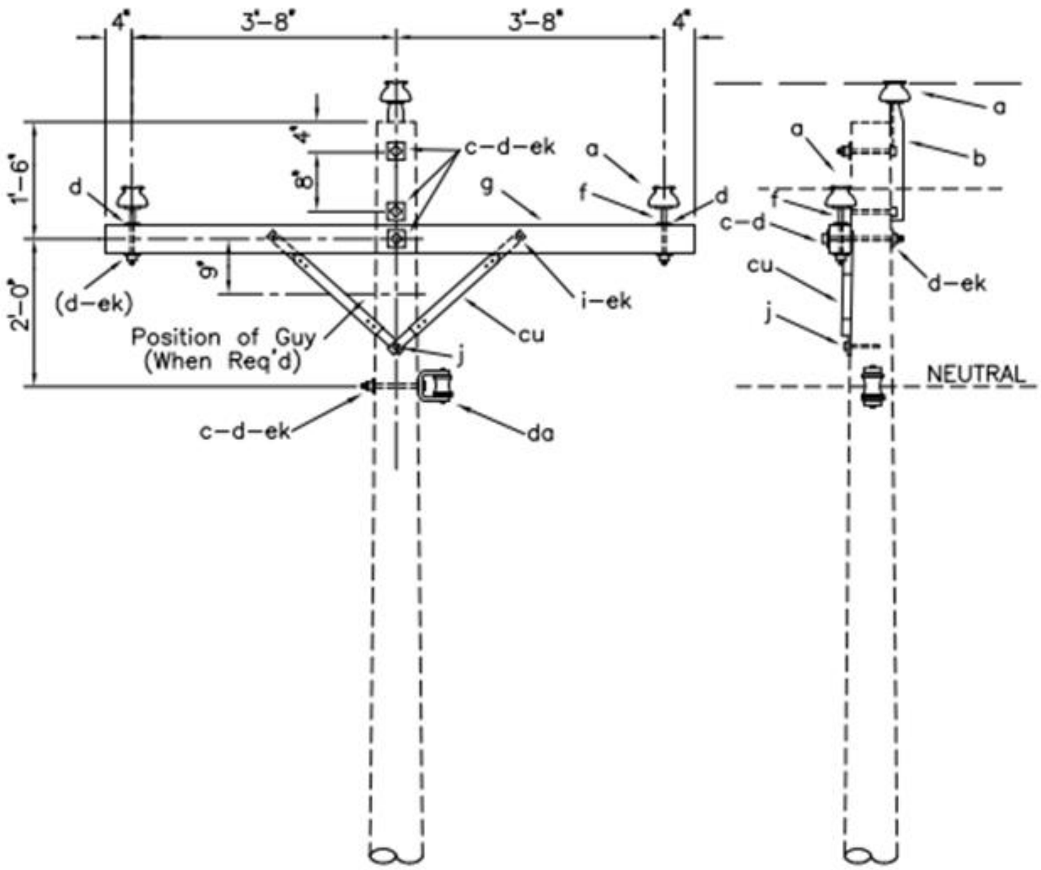
2. Ground wire ("cj") to have minimum conductivity of No. 6 Copper or equivalent.

3. Use <u>copper</u> plated ground rod and copper ground wire and staples, or use galvanized <u>steel ground rod</u>, staples and soft annealed iron, 3–strand, 5/16" ground wire with class C galvanizing.

ITEM	QTY	MATERIAL
p		Connector, compression, as req'd
ai	1	Rod, ground, 5/8" min. diameter
aj	1	Clamp, ground rod
al		Staple, ground wire, as req'd
cj		Wire, pole ground, as req'd

GROUNDING ASSEMBLY – GROUND ROD TYPE

APRIL 2005		H1.1
RUS		(M2–11)



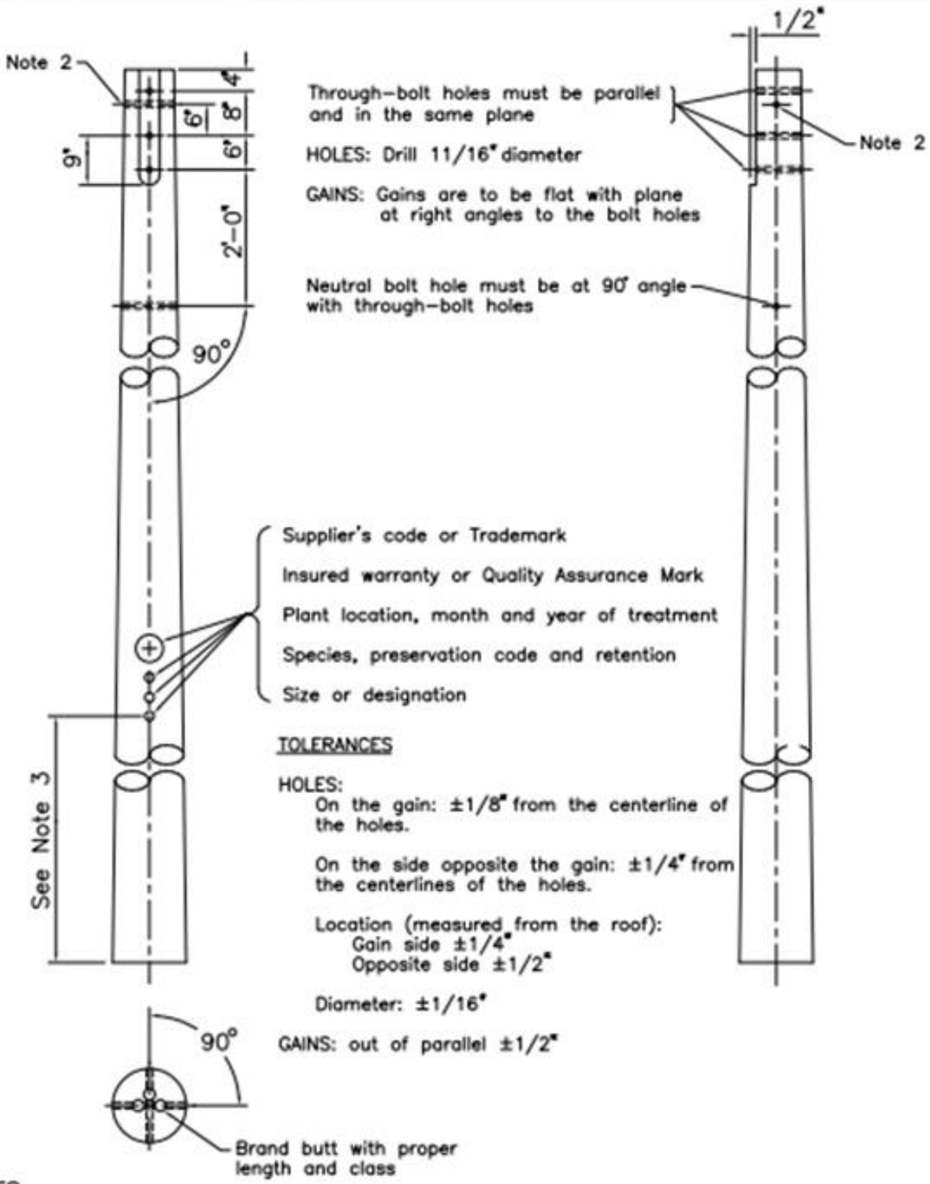
ITEM	QTY	MATERIAL
a	3	Insulator, pin type (12.47/7.2 kV)
b	1	Pin, pole top, 20"
c	4	Bolt, machine, 5/8" x req'd length
d	7	Washer, square, 2 1/4"
f	2	Pin, crossarm, steel, 5/8" x 10 3/4"
g	1	Crossarm, 3 5/8" x 4 5/8" x 8' – 0"
i	2	Bolt, carriage, 3/8" x 4 1/2"
j	1	Screw, lag, 1/2" x 4"
cu	2	Brace, 28"
da	1	Bracket, insulated
ek	6	Locknuts

DESIGN PARAMETERS:

See TABLE I

SINGLE SUPPORT ON CROSSARM

APRIL 2005	3 – PHASE PRIMARY 12.47/7.2 kV	
RUS		C1.13



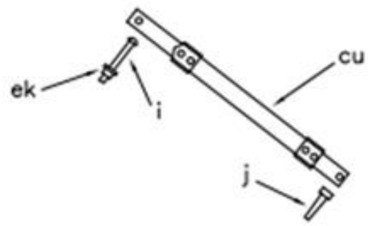
NOTES:

1. All poles shorter than 50 feet must be bored, roofed and gained before treatment, except that Class 7 and smaller poles need not be gained unless requested by purchaser. Roofs may be flat or at a 15° angle at the producer's option.

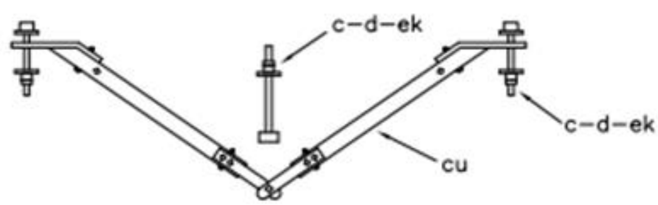
2. Anti-split bolt hole is optional and is to be drilled only when so specified by the purchaser.

3. Bottom of brand or center of metal disk shall be 10' ±2" from the pole butt for poles less than 55' in length; 14' ±2" for poles 55' and longer.

POLE FRAMING GUIDE		
APRIL 2005		W1.1G
RUS		(M20)



W3.1



W3.2

ITEM	MATERIAL	W3.1 QTY	W3.2 QTY
c	Bolt, machine, 1/2" x req'd length		2
c	Bolt, machine, 5/8" x req'd length		1
d	Washer, round, 1 3/8"		2
d	Washer, square, 2 1/4"		1
i	Bolt, carriage, 3/8" x 4 1/2"	1	
j	Screw, lag, 1/2" x 4"	1	
cu	Brace, 28", wood (or fiberglass)	1	
cu	Brace, wood, 60"		1
ek	Locknuts	1	3

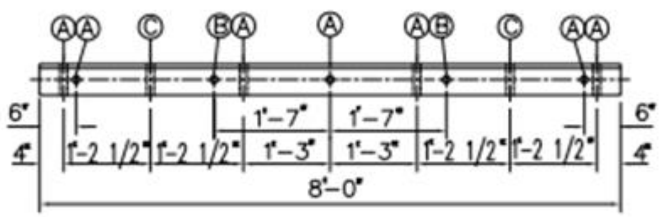
CROSSARM BRACES

APRIL 2005

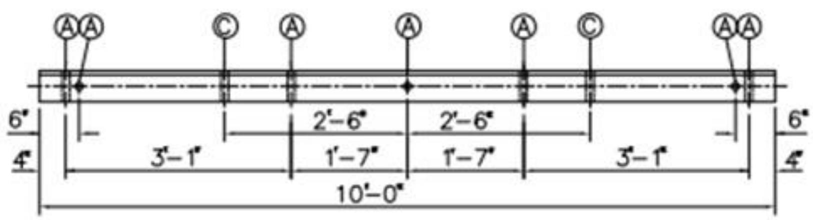
RUS

W3.1,W3.2
(M5-17),(M5-13)

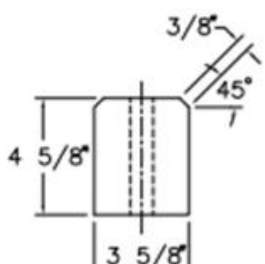
TOLERANCES AND SIZES OF HOLES			
NOMINAL		GO	NO GO
Ⓐ	11/16"	5/8"	3/4"
Ⓑ	7/16"	3/8"	1/2"
Ⓒ	9/16"	1/2"	5/8"



TYPE 04



TYPE 05M

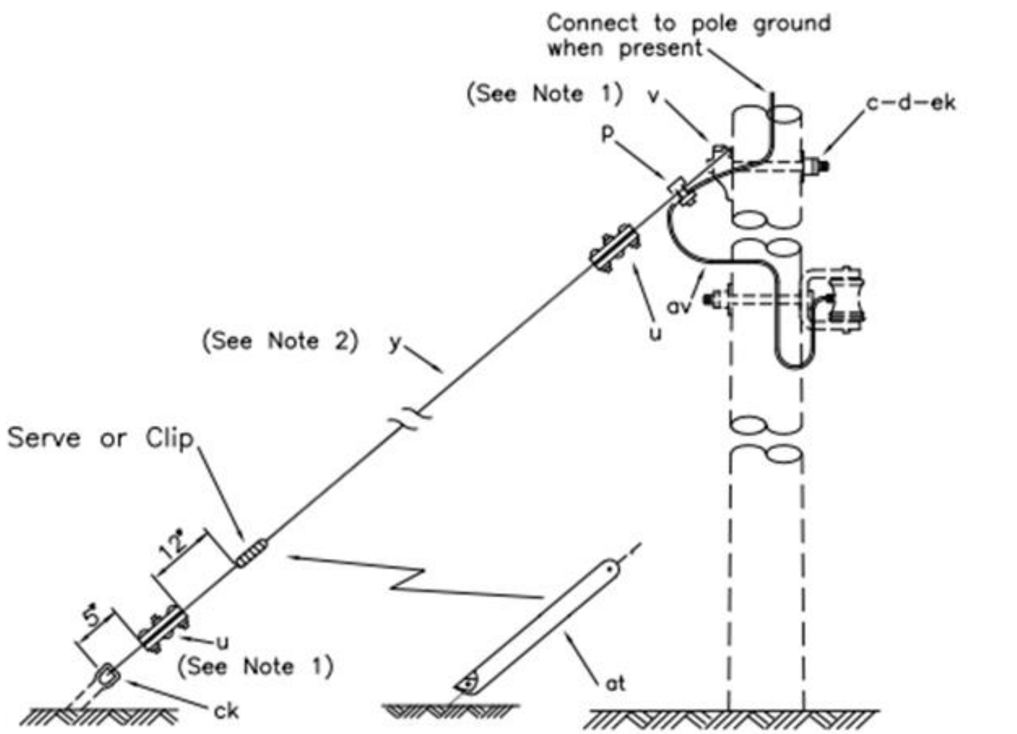


TYPICAL END SECTION

NOTES:

1. Holes are to be located within ±1/8"
2. Length of the crossarm is to be within ±1/4"
3. The tolerance of the cross section is +1/8" and −0" at time of manufacture.
4. All holes are to be drilled on centerlines of crossarm faces.

DISTRIBUTION CROSSARM DRILLING GUIDE		
APRIL 2005		W2.1G
RUS		(M19)



NOTES:

1. Other accepted and equivalent guy deadend (item "u") and attachment (item "v") material may be substituted for the ones shown.
2. Some types of guy attachments use 2 bolts and washer or lag screw (item "j"), change materials accordingly.
3. Specify guy wire size, type and required length.

ITEM	QTY	MATERIAL
c	1	Bolt, machine, 5/8" x req'd length
d	1	Washer, 3" square, curved
p		Connectors, guy bond and as req'd
u	2	Deadend for guy strand (See Note 1)
v	1	Guy attachment (See Note 1)
y		Guy wire, as req'd (See Note 3)
at	1	Guy marker
av		Jumpers, as req'd
ck	1	Clamp, anchor bonding
ek	1	Locknuts

DESIGN PARAMETERS:

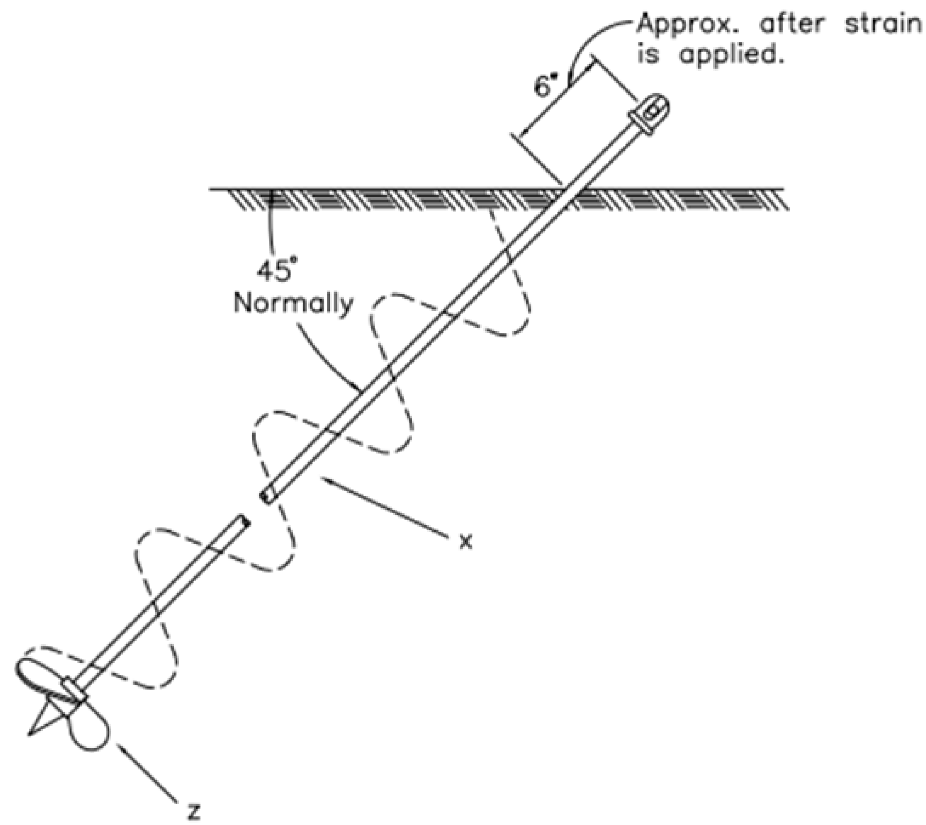
PERMITTED LOAD IS LESSER OF:
6,600 lbs (in any direction)
or 90% of RATED BREAKING
STRENGTH OF GUY WIRE

SINGLE DOWN GUY
(THROUGH BOLT TYPE)

APRIL 2005

RUS

E1.1
(E1-2)



NOTE: Designated maximum holding power rating assumes proper installation in class 5 soil.

	ASSEMBLY: F2	.6	.8	.10	.12
	Minimum Area (sq. in.)	90	100	120	135
ITEM	MATERIAL	QTY	QTY	QTY	QTY
x	Rod, anchor, thimble eye, 5/8" x 7'0"	1	1		
x	Rod, anchor, twin eye, 3/4 X 8'0			1	1
z	Anchor, screw type, power installed	1	1	1	1

ASSEMBLY NUMBERS	
NEW	(OLD)
F2.6	(F1–1S)
F2.8	(F1–2S)
F2.10	(F1–3S)
F2.12	(F1–4S)

DESIGN PARAMETERS:
DESIGNATED MAXIMUM
HOLDING POWER (lbs.)

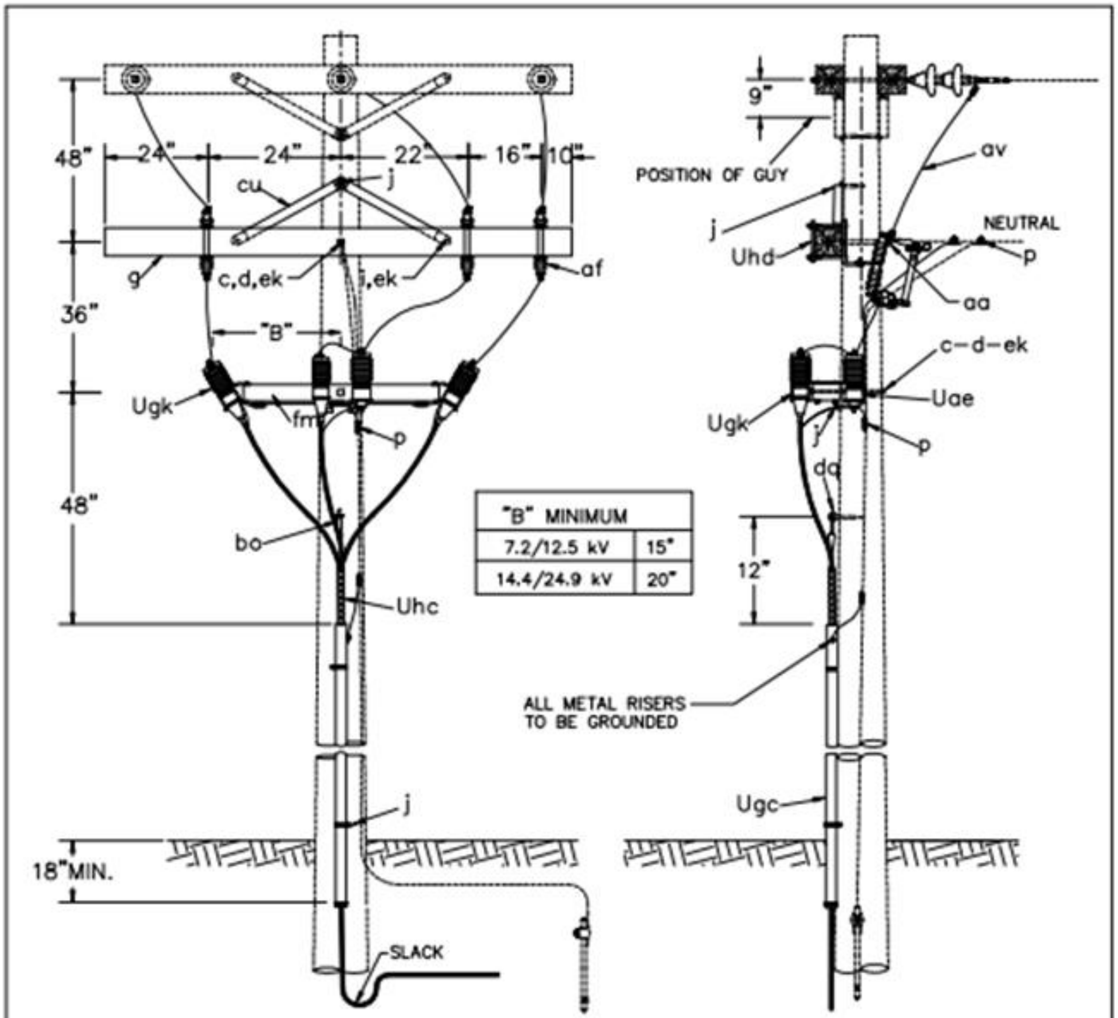
F2.6:	6,000
F2.8:	8,000
F2.10:	10,000
F2.12:	12,000

SCREW ANCHORS, (POWER INSTALLED)

APRIL 2005

RUS

F2.6, F2.8, F2.10, F2.12



"B" MINIMUM	
7.2/12.5 kV	15"
14.4/24.9 kV	20"

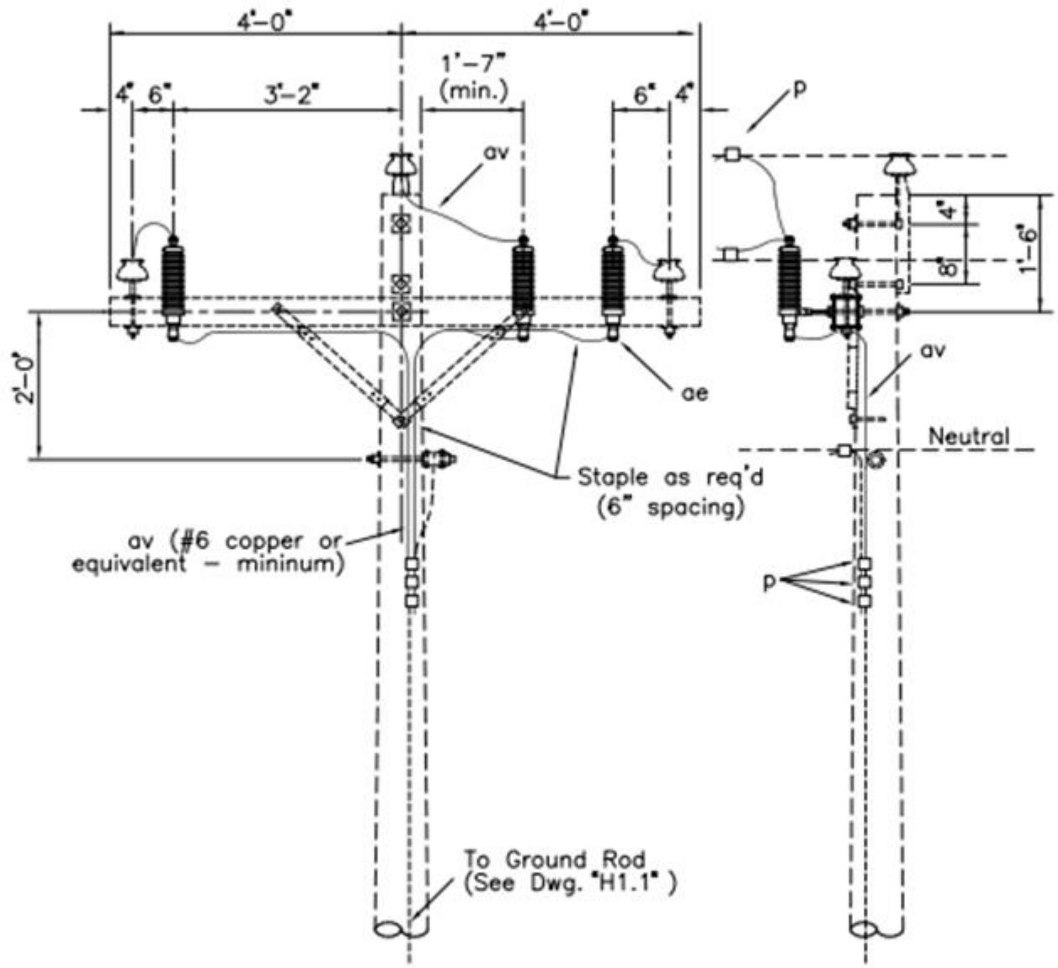
ITEM	QTY.	MATERIAL
c	2	Bolt, machine, 5/8" x required length.
d	2	Washer, square 2 1/4".
g	1	Crossarm, 3 5/8" x 4 5/8" x 8'-0"
i	2	Bolt, carriage, 3/8" x 4 1/2"
j		Screw, lag 1/2" x 4" as required.
p		Connectors, as required.
aa	1	Eyenut, 5/8"
af	3	Cutout
av		Jumpers, as required.
bo	1	Anchor, shackle.
cu	2	Brace, wood, 28"
dq	1	Eye screw, elliptical or drive hook.
ek	4	Locknuts, as required.
fm	1	Mounting bracket.
Uae	3*	Surge arrester
Ugc	1	Cable riser shield. Length as required.
Ugk	3	Cable termination.
Uhc	3	Cable support.

NOTES:

1. TOTAL ARRESTER LEAD LENGTH MUST BE UNDER 3'.
2. NO BENDS PERMITTED WITHIN 6" OF CABLE TERMINAL BASE.
3. ALLOW MINIMUM CABLE SLACK OF 24" AT BOTTOM OF RISER.

THREE PHASE CABLE TERMINAL POLE WITH CUTOUTS AND BRACKET MOUNTING ARRESTERS

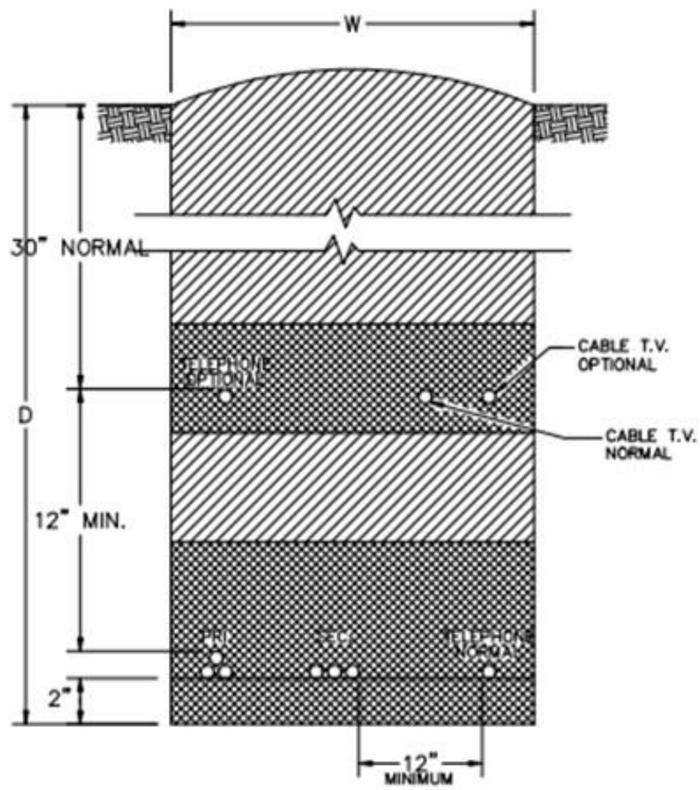
2000 | UC2



ITEM	QTY	MATERIAL
p		Connectors, as req'd
ae	3	Arrester, surge, (9 kV)
av		Jumpers, as req'd

SURGE ARRESTERS – 3 SINGLE PHASE

APRIL 2005	3 – PHASE PRIMARY	
RUS	12.47/7.2 kV	P1.3



LEGEND

- BEDDING SAND OR CLEAN SOIL
- COMPACTED BACKFILL UNLESS OTHERWISE SPECIFIED
- UNDISTURBED EARTH

PRI. = PRIMARY SUPPLY CABLES
SEC. = SECONDARY OR STREETLIGHT WIRES

URT–NT = NORMAL TRENCH 42" – 48" DEPTH
URT–ST = SUPER TRENCH 60" + DEPTH
W = 18" – 24" NORMAL

NOTES:

1. DEPTH (D) AND WIDTH (W) ARE SPECIFIED IN DESCRIPTION OF UNITS.
2. DEPTHS SPECIFIED ARE TO FINISHED GRADE.
3. OVER–EXCAVATE TRENCHES AS NECESSARY TO ALLOW FOR (a) SAND BEDDING OR (b) LOOSE AND SANDY SOILS OR (c) WHERE MORE THAN ONE CABLE WILL BE INSTALLED IN TRENCH AND LAYING OF FIRST CABLE MAY CAUSE TRENCH DAMAGE AND REDUCTION IN DEPTH.
4. SAND BEDDING IS NOT PART OF THESE UNITS AND WILL BE SPECIFIED AS NEEDED.
5. BACKFILLING IS PART OF ALL TRENCHING UNITS INCLUDING JOINT–USE TRENCHES.

	TRENCHES FOR DIRECT BURIAL CABLE		
		2000	UR2–NT UR2–ST

The test cabinet, catalog no. ETC120 (Fig.1) is used to operate an EntelliGuard E™ Drawout low voltage power circuit breaker that has been removed from the metal-enclosed equipment. It provides a convenient means of accessing the electrical close and trip circuits of the breaker during maintenance and inspection procedures. Control voltages must match the rating of charge, close, and trip circuits on the breaker.

This unit is designed to be wall or cabinet mounted. It has a test connector (with green ground wire), a 10-foot wire bundle, switches for opening and closing and charging the breaker, and control power switch, all located on the front of the cabinet.

Separate fuse holders and control power indicating lights are provided for the charge, close, and trip circuits. Lights are also provided for breaker open and close indication. Inside the unit is a terminal block for connecting the control power source(s) to the test cabinet. Four holes are provided on the back of the test cabinet for mounting using 3/8-inch hardware (mounting hardware is not included).

1. Control power input holes
2. Terminal block for control power (inside)
3. Clamp for test connector cable
4. Fuse holders
5. Control power indicating lights
6. Breaker operation switches
7. Close & Trip control power OFF / ON switch
8. Green/Red indicating lights
9. Charging motor control power OFF / ON switch

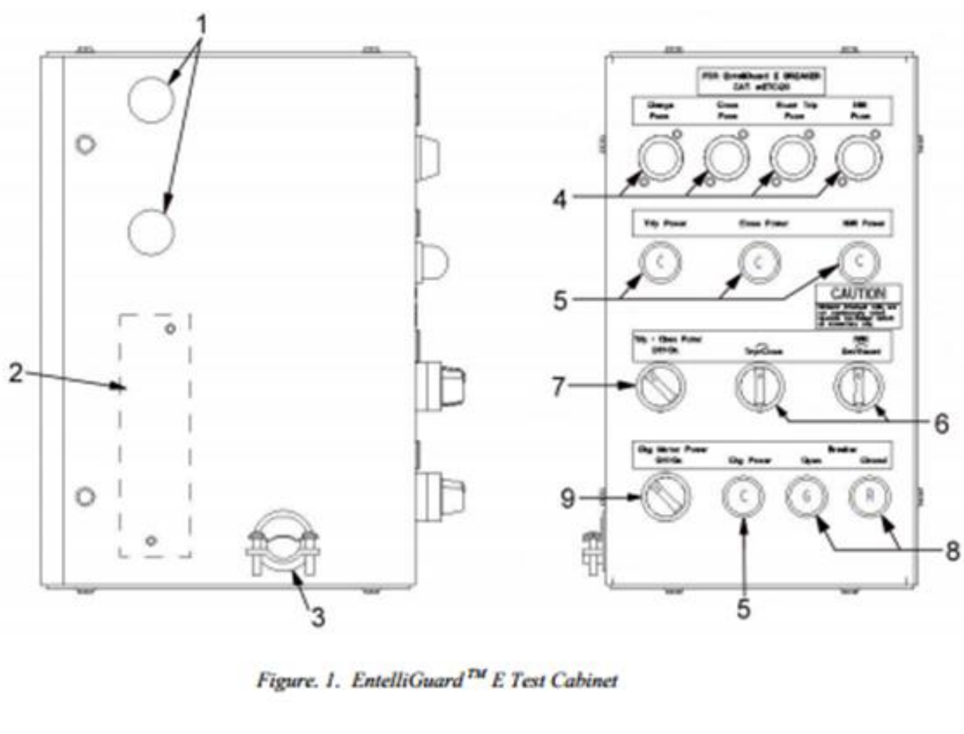


Figure. 1. EntelliGuard™ E Test Cabinet

EntelliGuard G™ Breaker Test Cabinet

Section 3. Description and Principles of Operation

The test cabinet, catalog no. GTC250 (Fig.1) is used to operate an EntelliGuard G™ Drawout low voltage power circuit breaker that has been removed from the metal-enclosed equipment. It provides a convenient means of accessing the electrical close and trip circuits of the breaker during maintenance and inspection procedures. Control voltages must match the rating of charge, close, and trip circuits on the breaker.

This unit is designed to be wall or cabinet mounted. It has a test connector (with green ground wire), a 10-foot wire bundle, switches for opening and closing and charging the breaker, and control power switch, all located on the front of the cabinet.

Separate fuse holders and control power indicating lights are provided for the charge, close, and trip circuits. Lights are also provided for breaker open and close indication. Inside the unit is a terminal block for connecting the control power source(s) to the test cabinet. Four holes are provided on the back of the test cabinet for mounting using 3/8-inch hardware (mounting hardware is not included).

1. Control power input holes
2. Terminal block for control power (inside)
3. Clamp for test connector cable
4. Fuse holders
5. Control power indicating lights
6. CLOSE/OPEN push button switches
7. Close & Trip control power OFF / ON switch
8. Green/Red indicating lights
9. Charging motor control power OFF / ON switch

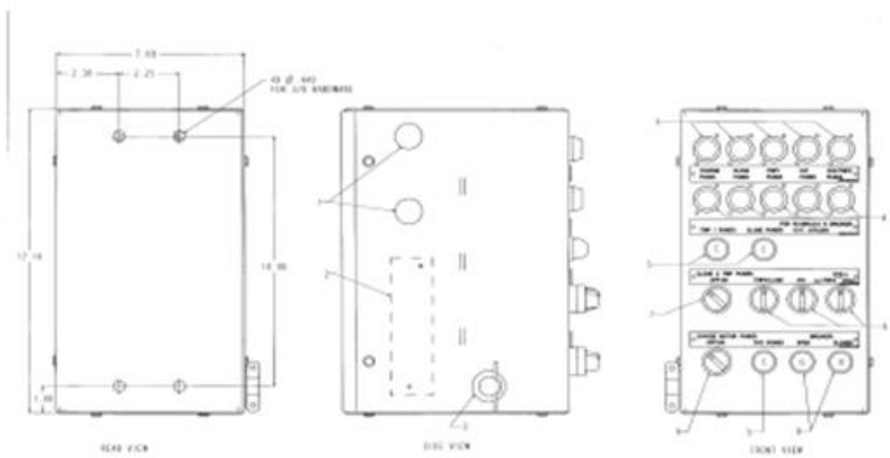


Figure. 1. EntelliGuard G™ Test Cabinet

Do not operate the "MBB" circuit breaker unless the UPS is in BYPASS mode! Failure to follow the operating instructions for this equipment could result in equipment damage, fire, severe injury or death!

8. SYSTEM OPERATION: CONFIGURATION 2 INTERLOCKS

The following User Instructions are for a three circuit breaker MBBC configured to be controlled by a 2-Interlock, 1-Key breaker interlock system:

NORMAL OPERATION

The UPS Input Breaker "UIB" is Closed/On. The Maintenance Bypass Breaker "MBB" is Locked Open/Off with the interlock locking bolt in the extended position and Key A1 held captive. The Maintenance Isolation Breaker "MIB" is Closed/On with the interlock locking bolt in the withdrawn position.

TRANSFER TO MAINTENANCE BYPASS

1. Transfer the UPS to the Bypass mode.
2. Turn Key A1 in the interlock on the "MBB" breaker to unlock.
3. Close/Turn-On the "MBB" breaker. Key A1 is now free.
4. Open/Turn-Off the "MIB" breaker.
5. Insert Key A1 into the interlock on the "MIB" breaker and turn it to lock the "MIB" breaker in the Open/Off position. Key A1 is now held captive.
6. The UPS is now ready for routine maintenance.
7. If further maintenance requires a total shutdown of the UPS and isolation from the input, the "UIB" breaker must be Opened/Turned-Off and the battery supply to the UPS must be disconnected. Refer to your UPS manual for proper shutdown procedures.

RETURN THE UPS AND BYPASS SWITCH TO NORMAL OPERATION

1. If the "UIB" breaker was Opened/Turned-Off for maintenance, then follow the UPS manual for proper startup procedures. To restore input power to the UPS, Close/Turn-On the "UIB" breaker. Make sure the UPS is in Bypass mode before proceeding!
2. Turn Key A1 in the interlock on the "MIB" breaker to unlock.
3. Close/Turn-On "MIB" Breaker. Key A1 is now free.
4. Open/Turn-Off "MBB" Breaker.
5. Insert Key A1 into the interlock on the "MBB" breaker and turn it to lock the "MBB" breaker in the Open/Off position. Key A1 is now held captive.
6. Transfer the UPS from bypass mode to normal mode.

Implementation

For this project the implementation of either solution will be put off for around 20-25 years so that the Municipal can start to raise the funds needed to pay for the project. In general most power projects are designed many years before they are actually put in place.

Testing Process and Testing Results

For testing we used two program OpenDSS and MATLAB. OpenDSS is used in industry for utility distribution analysis. We used OpenDSS for a balanced power flow analysis of our system. OpenDSS is a very dense program and we only learned a little bit of the program, we are not experts at OpenDSS nor can we answer every question about OpenDSS. In order to understand OpenDSS we followed a seminar guide. This seminar guide ran through several different examples for how OpenDSS can be used. This also showed us the general syntax for OpenDSS. MATLAB was used to generate the values for the Zero and Positive sequence impedances. We used equations that we learned in our Distribution Systems Analysis class to first find the values for the Zabc matrix. The Zabc matrix is used for the three phases of a line, however it is not used in industry. The Zabc matrix was used to find the Z0+- matrix which is used in industry to signify the zero, plus, and negative impedances of a line.

The main syntax for OpenDSS to create a power system is to clear your previous session, create a new circuit, create source, create transformer, create lines, and what you want solved. The code and syntax that we created and used is shown in appendix III.

Appendix I: Alternative versions of the design

Over the course of this project 3 designs were considered and discarded for various reasons. These designs were either rejected by the client, or were deemed unfeasible for a variety of reasons. The following section contains a brief overview of each of these designs and the reasons that they were ultimately discarded.

Interconnection Option:

The Interconnection option was to make a new OH line that would run north from the existing primary feeder until it reached the REC Southwest distribution system. This would then connect with a switch to the REC Southwest distribution system. This option would allow back feed into the Lamoni distribution system in case of fault while being cheaper than the final two options.

This option was discarded as the client no longer wished to look into it. The reason the client no longer wished to look into it was that it would require payment to REC southwest whenever the back feed was needed along with providing no other benefit to the Lamoni system when a fault was not occurring.

Primarily Overhead Option:

This option was to run Underground cabling from the substation to Smith Street, then transition to Overhead which would run until the end of the primary feeder.

This option was discarded as the client informed us that Overhead primary would not be acceptable in the industrial section of Lamoni near the interstate.

Tangent switching option:

This option was to use the design for the two primary options, both Underground, and partial Overhead, however having both options end with a tangent riser pole when they reached Spruce Drive, rather than moving south down Spruce Drive to the end of the primary.

This option was discarded when the group went to look at the route after the preliminary design was finished. During the course of the trip it was discovered that the primary extended much further down Spruce Drive than initially thought. This coupled with the fact that the primary also fed at least one factory meant that the line for that section had to be looped to provide redundancy for them.

Appendix II:Other Considerations

Zach

I found this to be an interesting project. I have never dealt with distribution systems outside of class whereas most of my team members have had experience from internships. My background is in generation which is not used in this project at all. In this project I used my knowledge that I learned in EE 303, EE 455, and EE 456. These are the main power classes and have prepared me for my future as a power electrical engineer. In this project I was the Team leader which meant that I did a lot of organization and planning to keep the team on schedule. However, I was not alone in this role I put a lot of trust into my team members which helped get this project done. For this project I was tasked to learn Microstation, OpenDSS, and power flow analysis. Microstation and OpenDSS are two very common programs used in the industry. Microstation is used to create one-line drawings and other forms of drawings, in this project I used Microstation to add a feeder to the existing one-line drawing. OpenDSS is used to simulate systems, in this project we used it to simulate power flow analysis.

Tristan

This project really helped me settle on what I wanted to do as a full time job. I only had experience in working with Transmission Level Networks but coming down to the Distribution Level really helped me decided on becoming a Distribution Engineer. In this project I was set as the Webmaster, this title made me the person to manage our website and to keep all of our documentation online up to date. For this project I had to learn more about Power Flow Analysis. OpenDSS is an extremely dense yet useful program and I am really glad that we had to sit down and learn the program it was an interesting challenge and it is always useful to hone skills like that.

Grant

The project has been a fun exercise in power system design, and has taught me a lot about teamwork and time management. We were given deadlines and tasked with figuring out how to meet them. At the beginning of the senior design project, I was designated as the key concept holder for the team. With the use of google drive documents and presentations, the duty of keeping track of our work was more of a team effort. These tools really helped our group stay organized and allowed us to work from different locations and on our own time. I was very happy with the overall pace of our project. Although it started off slow, we really kicked it into gear and were able to meet all of our deliverables. We actually ended up doing more than we were originally asked because we knew that we were capable of more. This led to some great experience such as learning software like OpenDSS and Microstation. We were also able to gain experience in pricing equipment and creating a payment plan to finance the project. I was happy to see that we used a lot of past knowledge from Iowa State courses to complete many of these tasks. When I was creating the payment plan, I used real financial documents from the city of Lamoni and followed their financial plans for past projects. By using my IE305 textbook, I was able to find the amount of money that Lamoni Municipality would need to set aside each year to fund the project in a given number of years. Overall, the project was a success and very satisfying to see completed.

Yahya

This project was very interesting and it made me learn new stuff as well as brushed up on some of the things I had learnt earlier during my past internships. I have had a little background of distribution and most of the project dealt with this stuff. I learnt to a great extent about how power is distributed in lines from the courses taken so far. I used my knowledge learnt in EE 303 and EE 456. My role as team communication leader included writing the weekly reports and making sure everyone's contribution is recorded. The most interesting part came when me and another team member had to look through the specs book for the quantities needed for the substation, the overhead and underground lines we are planning to implement. It reminded me of my latest internship where I spent a great amount of time going through specs. This project further improved my skill to get stuff needed from the relevant specs book. All the quantities that we obtained from the specs were added to an excel sheet where we priced them and added it to our final cost for both the lines.

Aaron

Over the course of this project I was able to learn about many topics that will help me with my chosen career in distribution. These were the standards in the construction of power, and the setup of economic analysis excel sheets. Standards in power come from spec books and show the proper way to construct power facilities along with the materials that are necessary for them to function. Over the course of this project I learned where to find these books on the Department of Agriculture website, along with how to use them in order to design a new addition to a power system. This is important as I will need to be able to do this for each design I create in the future. The other piece of important information that I learned over the course of this project was how to set up and organize economic analysis sheets for a project. The reason that this is an important skill to learn is that it is necessary for every type of project, even ones who do not have a physical component.

Appendix III: Code

Syntax to create a line system in OpenDss.
To clear a previous session you must have clear above everything in the code.

The syntax to create a new circuit is:

New Circuit.(name of circuit).

The syntax to create a new source is:

Edit Vsource.(name of source) BasekV=(base voltage value) pu=(per unit value for the source) ISC3=(current short circuit value for three phase) ISC1=(current short circuit value for single phase).

The syntax to create a new transformer is:

New Transformer.(name of transformer) Buses=[(name of Source Bus), (name of sending end of transformer)] Conns=[(type of connection delta to wye, delta to delta, wye to wye)] kVs=[(voltage ratings for the transformer)] kVAs=[(power rating for the transformer)] XHL=(impedance of high side of transformer).

The syntax to create a new line is:

New Linecode.(Name of line type) R1=(resistance of line for positive sequence) X1=(impedance of line for positive sequence) R0=(resistance of line for zero sequence) X0=(impedance of line for zero sequence) C1=(capacitance of the line for positive sequence) C0=(capacitance of the line for zero sequence).

The syntax to find the power flow is:

Solve
Show Voltages
Show Currents
Show Powers kVA elements

```
clear
New Circuit.BaseCase

Edit Vsource.Source BaseKV=12.47 pu=1.00 ISC3=1000000 ISC1=1000000

New Transformer.Xfm1 Buses=[SourceBus, FeedOut] conns=[Delta Wye] kVs=[12.47 7.2] kVAs=[10000 10000]  XHL=.747

New Linecode.Penguin R1=.05920 X1=.07694 R0=.10821 X0=.19785 C1=0 C0=0 units=Mi

New Line.Radial Bus1=FeedOut Bus2=LoadBus Linecode=Penguin Length=2.1 units=Mi

New Load.LumpedLoad bus1=LoadBus kV=7.2 kW=6100 PF=1.00

Solve
Show Voltages
Show Currents
Show Powers kVA elements
```

Figure 1 This code generates a power flow analysis for the base case system that Lamoni, Iowa currently has. This code was written in OpenDSS.

```
clear
New Circuit.OHcase

Edit Vsource.Source BaseKV=12.47 pu=1.00 ISC3=1000000 ISC1=1000000

New Transformer.Xfm1 Buses=[SourceBus, FeedOut] conns=[Delta Wye] kVs=[12.47 7.2] kVAs=[10000 10000]  XHL=7.47
New Linecode.Penguin R1=0.05920 X1=0.07694 R0=.10821 X0=.19785 C1=0 C0=0 units=Mi

New Line.Radial Bus1=FeedOut Bus2=LoadBus Linecode=Penguin Length=2.1 units=Mi
New Line.LateralOH Bus1=FeedOut Bus2=LoadBus Linecode=Penguin Length=2.1 units=Mi

New Load.LumpedLoad bus1=LoadBus kV=7.2 kW=6100 PF=0.95

Solve
Show Voltages
Show Currents
Show Powers kVA elements
```

Figure 2 This code generates a power flow analysis for the Overhead case, option 1. This code was written in OpenDSS.

```
clear
New Circuit.UGcase

Edit Vsource.Source BaseKV=12.47 pu=1.00 ISC3=1000000 ISC1=1000000

New Transformer.Xfm1 Buses=[SourceBus, FeedOut] conns=[Delta Wye] kVs=[12.47 7.2] kVAs=[10000 10000]  XHL=7.47

New Linecode.Penguin R1=0.5920 X1=0.7694 R0=1.0821 X0=1.9785 C1=0 C0=0 units=Mi
New Linecode.Emu R1=0.05920 X1=0.04775 R0=.17316 X0=.33482 C1=0 C0=0 units=Mi

New Line.Radial Bus1=FeedOut Bus2=LoadBus Linecode=Penguin Length=2.1 units=Mi
New Line.LateralUG Bus1=FeedOut Bus2=LoadBus Linecode=Emu Length=2.1 units=Mi

New Load.LumpedLoad bus1=LoadBus kV=7.2 kW=6100 PF=0.95

Solve
Show Voltages
Show Currents
Show Powers kVA elements
```

Figure 3 This code generates a power flow analysis for the Underground case, option 2. This code was written in OpenDSS.

```
gmr = .00814; %feet
R=0.592; %ohm per mile
dab=3+8/12;
dbc=3+8/12;
dca=2*(3+8/12);
dan=sqrt((3+8/12)^2+4);
dbn=3.5;
dcn=sqrt((3+8/12)^2+4);

zii = R+0.0953+i*0.12134*(log(1/gmr)+7.93402); %ohm per mile

zab = 0.0953+i*0.12134*(log(1/dab)+7.93402); %ohm per mile
zbc = 0.0953+i*0.12134*(log(1/dbc)+7.93402); %ohm per mile
zca = 0.0953+i*0.12134*(log(1/dca)+7.93402); %ohm per mile

zan = 0.0953+i*0.12134*(log(1/dan)+7.93402); %ohm per mile
zbn = 0.0953+i*0.12134*(log(1/dbn)+7.93402); %ohm per mile
zcn = 0.0953+i*0.12134*(log(1/dcn)+7.93402); %ohm per mile

Z=[zii zab zca zan;zab zii zbc zbn;zca zbc zii zcn;zan zbn zcn zii]
zij=[zii zab zca;zab zii zbc;zca zbc zii];
zin=[zan;zbn;zcn];
znj=[zan zbn zcn];
znn=zii;

zabc=zij-zin*(znn^(-1))*znj

a=(-.5)+i*sqrt(3)/2;
A=[1 1 1;1 a^2 a;1 a a^2];
z012=(A^-1)*zabc*A
```

Figure 4 This is the code that was used to calculate the impedance for the overhead line case, option 1. This code was written in MATLAB.

```
gmrs=((1.21/2)-5/2000)/12; %feet gmr shield
gmrc=.00814 %feet gmr conductor
R=0.592; %ohm per mile
Rs = 5.52655 %resistance of shield
dii=5/12; %distance from conductor to conductor

zii = R+0.0953+i*0.12134*(log(1/gmrc)+7.93402); %ohm per mile
zab = 0.0953+i*0.12134*(log(1/dii)+7.93402); %ohm per mile
zbc = 0.0953+i*0.12134*(log(1/dii)+7.93402); %ohm per mile
zca = 0.0953+i*0.12134*(log(1/dii)+7.93402); %ohm per mile

zss = Rs+0.0953+i*0.12134*(log(1/gmrs)+7.93402); %ohm per mile
zis = 0.0953+i*0.12134*(log(1/gmrs)+7.93402); %ohm per mile

Z=[zii zab zca zis;zab zii zbc zis;zca zbc zii zis;zis zis zis zss]
zij=[zii zab zca;zab zii zbc;zca zbc zii];
zin=[zis;zis;zis];
znj=[zis zis zis];
znn=zss;

zabc=zij-zin*(znn^(-1))*znj

a=(-.5)+i*sqrt(3)/2;
A=[1 1 1;1 a^2 a;1 a a^2];
z012=(A^-1)*zabc*A
```

Figure 5 This is the code that was used to calculate the impedance for the underground line case, option 2. This code was written in MATLAB.