3-Phase Transformers:

Lab 5

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Abstract

As we have learned in the past couple labs, transformers are used to change voltage levels as needed. Specifically three-phase trasnformers three single phase transformers hooked up in either a Wye or Delta configuration. Delta configurations do not require a ground which can be very useful while Wye configurations do. Due to this there are 4 common types of primary to secondary three phase transformers which are delta:delta, wye:wye, wye:delta, and delta:wye.

Wye:delta connection are good for step-down transformers due to the phase voltager of the primary being equal to the supply line voltager divided by sqrt(3).

Delta:wye configurations are good for supplying an increased voltage due to to the secondary side having an increased voltage by a factor of sqrt(3).

Delta:delta configurations voltages remain equal and require more expensive coils, so this is not often used.

Wye:wye configurations are good for when three-phase loads are too small for the installation of a full three-phase transformer, due to the load being able to be carried without exceeding the rating of the transformers is only 58

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1 Introduction

In this lab, we learn more about three-phase transformers and their use in transmission, residential distribution, and voltage regulation. First we will look at and learn how to configure a three-phase transformer. Then we will learn how to configure a residential distribution starting with 208V three-phase source.

Objectives:

Through observation, students:

- learn how to configure three-phase transformer banks
- learn how 120/240 V residential service is distributed from a three-phase line

Analyze and interpret data, and draw conclusions

Develop engineering documentation:

- 3-wire diagrams
- Points lists

2 Circuit Build and Data Gathering

2.1 3-Phase Transformers

We connected a $\Delta - Wye$ 3-phase transformer bank with the following specifications:

- primary-side phase voltage $V_{\phi P} = 208V$
- secondary-side phase voltage $V_{\phi S} = 120V$
- transformer bank $S_{rated} = 250VA$

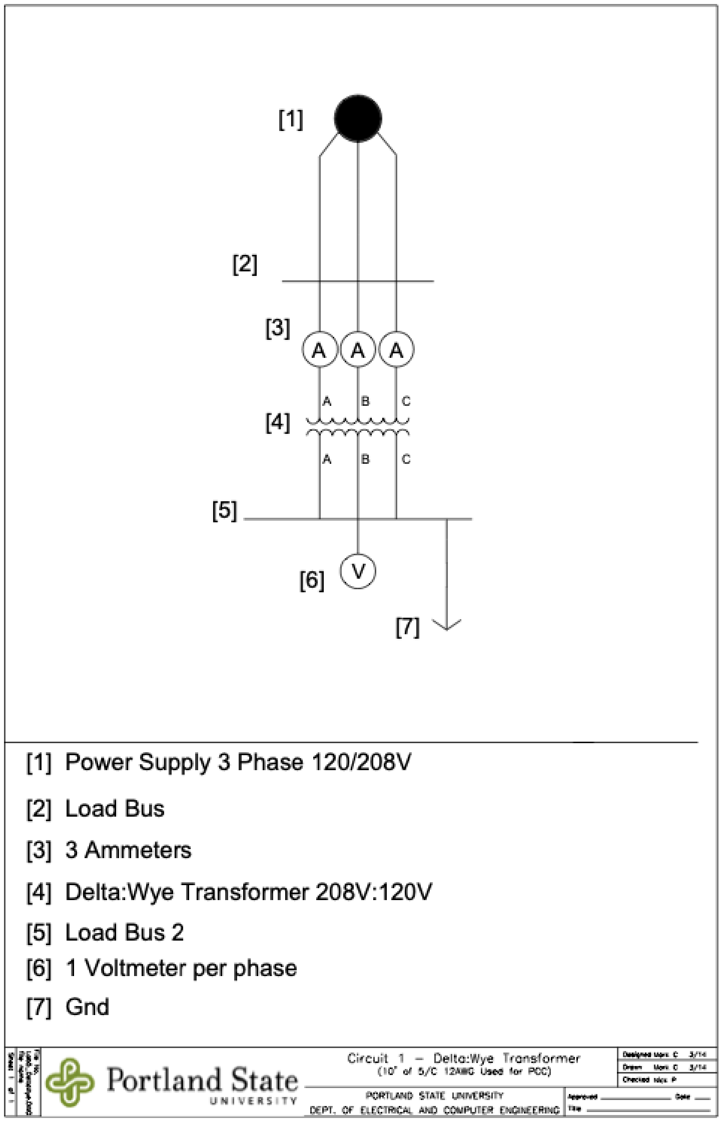

Figure 1: 3-line diagram of a Delta-Wye connected transformer

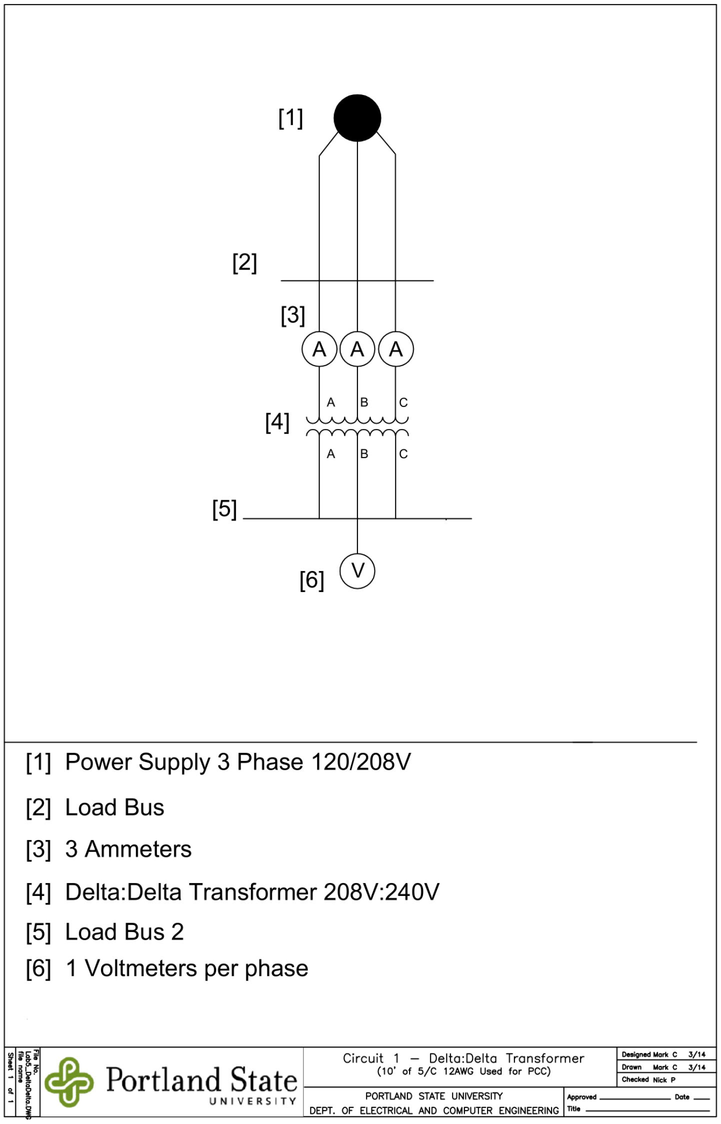

Figure 2: 3-line diagram of a Delta-Delta connected transformer

Δ phase and line formulas

$$V_\phi = V_{Line}$$

$$I_{Line} = \sqrt{3} I_\phi$$

$$I_{\phi P} = \frac{S_{rated}}{V_{\phi P}}$$

Wye phase and line formulas

$$V_{\phi} = \frac{V_{Line}}{\sqrt{3}}$$

$$I_{Line} = I_{\phi}$$

$$I_{\phi P} = \frac{S_{rated}}{V_{\phi P}}$$

The relationship between primary and secondary phase voltages and currents is:

$$V_{\phi P} = aV_{\phi S}$$

$$I_{\phi P} = \frac{I_{\phi S}}{a}$$

Where $a = \frac{V_P}{V_S} = \frac{208V}{120V} = 1.733$

Table 1: Δ-Wye measured voltages and calculated currents

Δ-Wye 208-120V		Calculated	
$V_{\phi P}$	$V_{line,P}$	$I_{\phi P}$	$I_{line,P}$
207.6	207.8	1.204	2.086
$V_{\phi S}$	$V_{line,S}$	$I_{\phi S}$	$I_{line,S}$
119.6	207.5	2.090	2.090

2.2 Residential Distribution System

We connected a single-phase transformer to replicate a residential distribution transformer with the following voltages:

- primary-side voltage $V_P = 208V$
- secondary-side voltages $V_{H1} = V_{H2} = 120V, V_{H1toH2} = 240V$
- $Z_{L120} = 1200 + j240$

- $Z_{L240} = 1200 + j1200$
- Transformer $S_{rated} = 60VA$

Since the voltage rating of the resistor banks are only 120 V, the loads for the 240 V lines have to go through two resistor banks.

Table 2: Residential Open Circuit

$V_{line,P}$	V_{H1}	V_{H2}	$I_{line,P}$	I_{H1}	I_{H2}	I_N
206.4	117.9	117.4	0.089	0.008	0.007	0.007

Table 3: Residential Balanced Load

$V_{line,P}$	V_{H1}	V_{H2}	$I_{line,P}$	I_{H1}	I_{H2}	I_N
205.7	115.3	114.3	0.183	0.091	0.09	0.008

Table 4: Residential Unbalanced Load 1

$V_{line,P}$	V_{H1}	V_{H2}	$I_{line,P}$	I_{H1}	I_{H2}	I_N
206.9	116.5	115.4	0.177	0.092	0.093	0.096

Unbalanced load 1: $Z_{L,H2} = 240 + j1200$

Table 5: Residential Unbalanced Load 2

$V_{line,P}$	V_{H1}	V_{H2}	$I_{line,P}$	I_{H1}	I_{H2}	I_N
206.4	112.5	114.5	0.277	0.255	0.081	0.179

Unbalanced load 2: $Z_{L,H1} = 300 + j300$**,** $Z_{L,H2} = 1200 + j600$

3 Data Analysis and Interpretation, Drawing Conclusions

3.1 3-Phase Transformers

Table 6: Δ-Wye measured voltages and calculated currents

Δ-Wye 208-120V		Calculated	
$V_{\phi P}$	$V_{line,P}$	$I_{\phi P}$	$I_{line,P}$
207.6	207.8	1.204	2.086
$V_{\phi S}$	$V_{line,S}$	$I_{\phi S}$	$I_{line,S}$
119.6	207.5	2.090	2.090

Calculated measurements for different 3-phase transformer configurations:

Table 7: Calculated Δ-Wye

Δ-Wye 208-120V			
$V_{\phi P}$	$V_{line,P}$	$I_{\phi P}$	$I_{line,P}$
208	208	1.20	2.08
$V_{\phi S}$	$V_{line,S}$	$I_{\phi S}$	$I_{line,S}$
120.0	207.8	2.08	2.08

Table 8: Calculated $\Delta - \Delta$

$\Delta - \Delta$ 208-120V			
$V_{\phi P}$	$V_{line,P}$	$I_{\phi P}$	$I_{line,P}$
208	208	1.20	2.08
$V_{\phi S}$	$V_{line,S}$	$I_{\phi S}$	$I_{line,S}$
120	120	2.08	3.61

Table 9: Calculated Wye - Wye

Wye-Wye 208-120V			
$V_{\phi P}$	$V_{line,P}$	$I_{\phi P}$	$I_{line,P}$
120.1	208	2.08	2.08
$V_{\phi S}$	$V_{line,S}$	$I_{\phi S}$	$I_{line,S}$
69.3	120.0	3.61	3.61

Table 10: Calculated Wye-Δ

Wye-Δ 208-120V			
$V_{\phi P}$	$V_{line,P}$	$I_{\phi P}$	$I_{line,P}$
120.1	208.0	2.08	2.08
$V_{\phi S}$	$V_{line,S}$	$I_{\phi S}$	$I_{line,S}$
69.3	120.1	3.61	6.25

In all the above cases, $S = V_\phi I_\phi = S_{rated} = 250VA$

3.2 Residential Distribution System

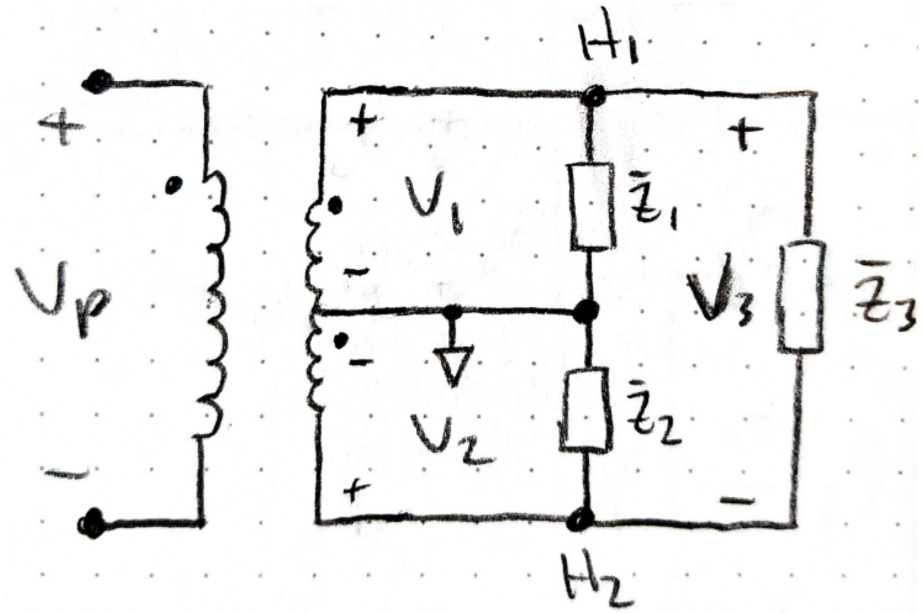

Figure 3: Circuit model of a Residential distribution transformer

The measured values used a balanced load of $Z_{1b} = Z_{2b} = 1200 + j240\Omega$ and $Z_{3b} = 1200 + j1200\Omega$. The measured values used an unbalanced load of $Z_{1u} = 300 + j300\Omega$, $Z_{2u} = 1200 + j600\Omega$ and $Z_{3u} = Z_3$.

Table 11: Residential Open Circuit

$V_{line,P}$	V_{H1}	V_{H2}	$I_{line,P}$	I_{H1}	I_{H2}	I_N
206.4	117.9	117.4	0.089	0.008	0.007	0.007

$S_{rated} = 60VA$, $V_P = 208V$, $V_{240} = 240V$, $V_{120} = 120V$. The turns ratio is $a = \frac{208}{240} = 0.867$

$$I_P = \frac{V_P}{a^2 Z_{eq}} - I_{line,P,OC}$$

Where Z_{eq} is the equivalent impedance as seen from H1 and H2, and $I_{line,P,OC}$ is the primary side line current in the open circuit test. With balanced loads, $I_P = 0.19A$ and with unbalanced loads, $I_P = 0.26A$.

$$I_{H1} = \frac{V_{120}}{Z_1} \quad \text{and} \quad I_{H2} = \frac{V_{120}}{Z_2} \quad \text{and} \quad I_N = |I_{H1} - I_{H2}|$$

$$S_{H1} = V_{120} I_{H1}$$

With balanced loads, $I_{H1} = I_{H2} = 0.098A$, $I_N = 0$ and $S_{H1} = S_{H2} = 11.8VA$. With unbalanced loads, $I_{H1} = 0.283A$, $I_{H2} = 0.0894A$, $I_N = 0.194A$, $S_{H1} = 34VA$, and $S_{H2} = 10.7VA$.

These values compare closely with the measured values from part 1:

Table 12: Residential Balanced Load

$V_{line,P}$	V_{H1}	V_{H2}	$I_{line,P}$	I_{H1}	I_{H2}	I_N
205.7	115.3	114.3	0.183	0.091	0.09	0.008

Table 13: Residential Unbalanced Load 2

$V_{line,P}$	V_{H1}	V_{H2}	$I_{line,P}$	I_{H1}	I_{H2}	I_N
206.4	112.5	114.5	0.277	0.255	0.081	0.179

Unbalanced load 2: $Z_{L,H1} = 300 + j300$, $Z_{L,H2} = 1200 + j600$

3.3 Summary of relevant NEC codes

NEC 210.70A: Requirements for lighting and switches; At least one wall switch-controlled lighting outlet shall be installed in every habitable room and bathroom. Along with at least one wall switch-controlled lighting outlet shall be installed in hallways, stairways, attached garages, and detached garages with electric power. This section is important because engineers need to design a power system that can handle a pretty specific amount of power in each area without breaking the bank; this helps aid their estimates.

NEC 210.52A: Requirements for receptacles; This section talks about requirements for receptacles and the three main being small-appliance branch circuits, laundry branch circuits, and bathroom branch circuits all three of which are important to know the power requirements for since each drain a pretty specific amount of power on average.

NEC 240.4: Overcurrent protective devices for small conductors, residential; This section talks about conductors and other flexible cords that need to be protected related to 310.14. They talk about different conductors including small conductors 18-10AWG, tap conductors, transformer secondary conductors, and overcurrent protection specific to conductor applications; This includes ACs, capacitor circuit conductors, electric welder circuit, fire alarm, motor appliances, phase converter supplies conductors, and more. These are all super important in a power engineer's job of building a power system for neighborhoods especially since these items can draw large amounts of current.

NEC 210.19A: Wire sizing for typical branch circuits; We actually looked at this for a bunch of HW assignments, these tables allow for proper sized conductors for specific circumstances. Allowing for specific current, and weather conditions for the conductors to be able to handle.

NEC 310.15B: Sizing of residential service entrances; This section talks about single-phase dwelling services and feeders which is important for the engineer to understand what current/voltages are needed for specific homes, or facilities. Services and feeders are rated for 100 - 400Amps, which in no case shall a feeder for an individual dwelling unit be required to have an ampacity greater than specified, so this gives the engineer a cap to how much rated current the system needs.

4 Conclusion

After completing this lab, we now know how to use the LabVolt 8348 to hookup a three-phase transformer that is a Delta:Wye configuration and use LVDDAC in order to monitor the currents and voltages of each phase. Using this data we were able to calculate the rated S, Vbank, Ibank, Vphase, Iphase. We also did this for a residential distribution system. Then proceeded to do it for the rest of the configurations as well. For the residential system we learned how to calculate the expected S, Vp, Ip, V240, V120, IH1, IH2, IN, S120, and compare these values with measured. We also learned how to make a 3-line diagram and create a proper points list, along summarizing specific NEC codes.

A Three-Phase Transformers Point List

A.1 Point List : Power Supply

LabVolt Power Supply, 8821		Point Type						
Point Description	Origin Address	DO	DI	AO	AI	Pwr	Destination Address	Destination Description
AC Variable 0-120/208 V Phase A	4	0	0	0	1	1	1	Primary 1, Three-Phase Xfrmr Bank, 8348-43
AC Variable 0-120/208 V Phase B	5	0	0	1	0	1	6	Primary 2, Three-Phase Xfrmr Bank, 8348-43
AC Variable 0-120/208 V Phase C	6	0	0	0	1	1	11	Primary 3, Three-Phase Xfrmr Bank, 8348-43
AC Variable 0-120/208 V Neutral	N	0	0	1	0	1	10	Secondary 2, Three-Phase Xfrmr Bank, 8348-43
24VAC, 0.4A Power Input	Power Input	0	0	0	0	1	Power Input	24VAC, 0.4A Power supply, DAC 9063
Total		0	0	2	2	5		

A.2 Data Acquisition and Control Interface

LabVolt DAC Interface, 9063		Point Type						
Point Description	Origin Address	DO	DI	AO	AI	Pwr	Destination Address	Destination Description
Voltage 500V	E1	0	0	0	1	1	1	Primary 1, Three-Phase Xfrmr Bank, 8348-43
Voltage 500V	E2	0	0	0	1	1	1	Primary 1, Three-Phase Xfrmr Bank, 8348-43
Voltage 500V	E3	0	0	0	1	1	4	Secondary 1, Three-Phase Xfrmr Bank, 8348-43
Voltage 500V	E4	0	0	0	1	1	4	Secondary 1, Three-Phase Xfrmr Bank, 8348-43
Voltage COM	E1	0	0	1	0	1	2	Primary 1, Three-Phase Xfrmr Bank, 8348-43
Voltage COM	E2	0	0	1	0	1	6	Primary 2, Three-Phase Xfrmr Bank, 8348-43
Voltage COM	E3	0	0	1	0	1	5	Secondary 1, Three-Phase Xfrmr Bank, 8348-43
Voltage COM	E4	0	0	1	0	1	9	Secondary 2, Three-Phase Xfrmr Bank, 8348-43
Computer USB Port	Computer I/O	0	1	1	1	1	Computer I/O	Computer USB Port
24VAC, 0.4A Power Input	Power Input	0	0	1	1	1	Power Input	24VAC, 0.4A Power Input, 8821
Total		0	0	4	4	10		

A.3 Point List : LabVolt Three-Phase Transformer Bank

3-Phase Transformer, 8348-43		Point Type						
Point Description	Origin Address	DO	DI	AO	AI	Pwr	Destination Address	Destination Description
Primary 1 208 V	1	0	0	1	1	1	12 + E1 + E2 + 4	Primary 3, Three-Phase Xfrmr Bank, 8348-43 +500V,DAC, 9063 + Pwr Phase A, 8821
Primary 1 208 V	2	0	0	0	1	1	6 + E1	Primary 2, Three-Phase Xfrmr Bank, 8348-43 + COM, DAC, 9063
Secondary 1 208/120 V	4	0	0	1	0	1	E3 + E4	500V, DAC, 9063
Secondary 1 208/120 V	5	0	0	0	1	1	10 + E3	Secondary 2, Three-Phase Xfrmr Bank, 8348-43 + 500V, DAC, 9063
Primary 2 208 V	6	0	0	0	1	1	E2 + 6	COM, DAC, 9063 + Pwr Phase B, 8821
Primary 2 208 V	7	0	0	0	1	1	11	Primary 3, Three-Phase Xfrmr Bank, 8348-43
Secondary 2 208/120 V	9	0	0	0	1	1	E9	COM, DAC, 9063
Secondary 2 208/120 V	10	0	0	0	1	1	N + E1	Pwr Neutral, 8821
Primary 3 208 V	11	0	0	1	0	1	6	Pwr Phase C, 8821
Total		0	0	3	7	9		

B Residential Distribution System Point List

B.1 Point List : Power Supply

LabVolt Power Supply, 8821		Point Type						
Point Description	Origin Address	DO	DI	AO	AI	Pwr	Destination Address	Destination Description
AC Variable 0-120/208 V Phase A	4	0	0	0	1	1	I1	Currents terminal 4A, DAC 9063
AC Variable 0-120/208 V Phase B	5	0	0	1	0	1	4	Coil 2 208 V, Single Phase Xfrmr, 8341
AC Variable 0-120/208 V Neutral	N	0	0	1	0	1	5	Coil 3 120 V, Single Phase Xfrmr, 8341
24VAC, 0.4A Power Input	N	0	0	0	0	1	Power Input	24VAC, 0.4A Power supply, DAC 9063
Total		0	0	2	1	4		

B.2 Data Acquisition and Control Interface

LabVolt DAC Interface, 9063		Point Type						
Point Description	Origin Address	DO	DI	AO	AI	Pwr	Destination Address	Destination Description
Currents terminal 4A	I1	0	0	0	1	1	4	Pwr Phase A, 8821
Currents terminal 4A	I2	0	0	0	1	1	Red Bottom	Resistive load Phase A Bottom, Resistive Load, 8311
Currents terminal 4A	I3	0	0	0	1	1	Black Bottom	Resitive load Phase B Bottom, Resistive load, 8311
Currents terminal 4A	I4	0	0	0	1	1	Red Bottom	Inductive load Phase A Bottom, Inductive load, 8321
Currents COM	I1	0	0	1	0	1	3	Coil 2 208 V, Single Phase Xfrmr, 8341
Currents COM	I2	0	0	1	0	1	4	Coil 2 208 V, Single Phase Xfrmr, 8341
Currents COM	I3	0	0	1	0	1	Black Top	Inductive load Phase B Top, Inductive load, 8321
Currents COM	I4	0	0	1	0	1	2	Coil 1 120 V, Single Phase Xfrmr, 8341
Voltage 500V	E1	0	0	0	1	1	3	Coil 2 208 V, Single Phase Xfrmr, 8341
Voltage 500V	E2	0	0	0	1	1	1	Coil 1 120 V, Single Phase Xfrmr, 8341
Voltage 500V	E3	0	0	0	1	1	6	Coil 3 120 V, Single Phase Xfrmr, 8341
Voltage COM	E1	0	0	1	0	1	Red Top	Inductive load Phase A Top, Inductive load, 8321
Voltage COM	E2	0	0	1	0	1	2	Coil 1 120 V, Single Phase Xfrmr, 8341
Voltage COM	E3	0	0	1	0	1	5	Coil 3 120 V, Single Phase Xfrmr, 8341
Computer USB Port	Computer I/O	0	1	1	1	1	Computer I/O	Computer USB Port
24VAC, 0.4A Power Input	Power Input	0	0	1	1	1	Power Input	24VAC, 0.4A Power Input, 8821
Total		0	0	7	7	16		

B.3 Point List : Single Phase Transformer

Sgl. Ph. Transformer, 8341		Point Type						
Point Description	Origin Address	DO	DI	AO	AI	Pwr	Destination Address	Destination Description
Coil 1 120 V	1	0	0	0	1	1	Blue Bottom	Resistive load Phase C Bottom, Resistive load, 8311
Coil 1 120 V	2	0	0	0	1	1	5	Coil 3 120 V, Single Phase Xfrmr, 8341
Coil 2 208 V	3	0	0	0	1	1	I1	Currents COM, DAC, 9063
Coil 2 208 V	4	0	0	1	1	1	5 + E2	Pwr Phase B, 8821 + Currents COM, DAC, 9063
Coil 3 120 V	5	0	0	1	1	1	2 + N	Coil 1 120 V, Single Phase Xfrmr, 8341 + Pwr Neutral, 8821
Coil 3 120 V	6	0	0	1	0	1	Blue Bottom + Black Top	Inductive load Phase C Bottom, Inductive Load, 8321 + Resistive load Phase B Top, Resistive load, 8311
Total		0	0	3	5	6		

B.4 Point List : Inductive Load

Inductive Load, 8321		Point Type						
Point Description	Origin Address	DO	DI	AO	AI	Pwr	Destination Address	Destination Description
Inductive load Phase A Top	Red top	0	0	0	1	1	E1	COM, DAC, 9063
Inductive load Phase A Bottom	Red bottom	0	0	1	1	1	I4 + Black Bottom	Current Terminal 4A, DAC, 9063 + Inductive load Phase B Bottom, Inductive Load, 8321
Inductive load Phase B Top	Black top	0	0	1	0	1	I3	Current Terminal 4A, DAC, 9063
Inductive load Phase B Bottom	Black bottom	0	0	1	0	1	Red Bottom	Inductive load Phase A Bottom, Inductive Load, 8321
Inductive load Phase C Top	Blue top	0	0	1	0	1	Blue Bottom	Resistive load Phase C Bottom, Resistive Load, 8311
Inductive load Phase C Top	Blue top	0	0	0	1	1	Blue Bottom	Resistive load Phase C Bottom, Resistive Load, 8311
Inductive load Phase C Bottom	Blue bottom	0	0	0	1	1	Blue Top	Resistive load Phase C Top, Resistive Load, 8311
Inductive load Phase C Bottom	Blue bottom	0	0	0	1	1	6	Coil 3 120 V, Single Phase Xfrmr, 8341
Total		0	0	4	5	8		

B.5 Point List : Resistive Load

Inductive Load, 8321		Point Type						
Point Description	Origin Address	DO	DI	AO	AI	Pwr	Destination Address	Destination Description
Resistive load Phase A Top	Red top	0	0	1	0	1	1	Coil 1 120 V, Single Phase Xfrmr, 8341
Resistive load Phase A Bottom	Red bottom	0	0	1	0	1	I2	Current Terminal 4A, DAC, 9063
Resistive load Phase B Top	Black top	0	0	0	1	1	6	Current COM, DAC, 9063
Resistive load Phase B Bottom	Black bottom	0	0	0	1	1	I3	Current Terminal 4A, DAC, 9063
Resistive load Phase C Top	Blue top	0	0	0	1	1	1	Coil 1 120 V, Single Phase Xfrmr, 8341
Resistive load Phase C Top	Blue top	0	0	1	0	1	Blue Bottom	Inductive load Phase C Bottom, Resistive Load, 8311
Resistive load Phase C Bottom	Blue bottom	0	0	1	0	1	Blue Top	Inductive load Phase C Top, Resistive Load, 8311
Resistive load Phase C Bottom	Blue bottom	0	0	0	1	1	Blue Top	Inductive load Phase C Top, Resistive Load, 8311
Total		0	0	4	4	8		

References

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YES

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