Lab 4:

Single-Phase Transformers

PORTLAND STATE UNIVERSITY
MASEEH COLLEGE OF ENGINEERING & COMPUTER SCIENCE
DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

Authors:
KAI BOLDT
RYAN NAND
LIHONG ZHAO
June 18, 2021

Maseeh College of Engineering and Computer Science
PORTLAND STATE UNIVERSITY

ECE 347L
POWER SYSTEMS I LABORATORY

Contents

List of Figures

List of Tables

1 Introduction

The primary focus of this lab is to introduce single-phase power transformers, that includes autotransformers. The first portion of the lab involves testing and acquiring data from a single-phase 120-60/60V transformer for both an open and closed-circuit configuration. From the primary and secondary voltages and currents, and real power acquired from the open and short-circuit tests, then we'll use the data to calculate the circuit parameters of a primary-side cantilever circuit model. Once the circuit parameters are calculated, we will use these values to determine the Voltage Regulation (VR) and Efficiency (η) of the 120-60/60V single-phase transformer. The second portion of the lab involves designing a MATLAB algorithm to calculate the load-regulate Voltage Regulation and Efficiency given a complex load. The function must include a flagging function for over currents and under/over voltages.

A **Transformer** is a passive electric component that utilizes Faraday's Law of Induction by converting one value into another. This is done with a process called mutual induction by a coil inducing a voltage into another coil. This allows transformers to either increase/decrease voltage or current levels without altering the operating frequency presented within the system. There's a "primary winding" coil and a "secondary winding" coil, typically the primary side coil is of a higher voltage that is stepped down to for residential or commercial use. A transformer behaves like a linear device and the **Turns Ratio** (TR) is important to the operation of stepping up or down the voltages. The Turns Ratio is the ratio of turns from the primary winding to the secondary winding. For example, if a transformer has a 4:1 ratio then the secondary side will have approximately a fourth of the voltage that is applied to the primary side.

Practical transformers will experience some form of loss when in operation. However, it is possible to construct an equivalent circuit model that accounts for all the losses in a real transformer. An adequate model can be accomplished by performing an open-circuit test and a short-circuit test. In the open-circuit test, the transformer's secondary winding is open circuited causing the primary winding to experience the full-load line voltage. This test is used to determine the parallel elements of R_C and X_M. In the short-circuit test, the secondary winding is shorted causing the primary winding to experience low voltage on the primary winding. This test is used to determine the series elements of $R_{eq,p}$ and $X_{eq,p}$. It's imperative to not exceed the I_{rated} current to keep the short circuit voltage much smaller than V_{rated}. Once these parameters are found, then the Voltage Regulation (VR) and the Efficiency (η) of the transformer can be determined. For real transformers, they have series impedances associated within them (observed through the short-circuit test) causing the output voltage will vary regardless if the load remain constant. Therefore, Voltage Regulation is a good way to visualize the potential variance between the no load and full load. Lastly, the efficiency of the transformer is ratio of output power to input power. This is used to observe how significant the losses present in the operation of the transformer.

The Losses Present in a Transformer

1) Copper (I^2R) Losses - The resistive heating losses in the primary and secondary windings of the transformer.

2) Hysteresis Loasses - Is the loss due to the arrangement of the magnetic field in the core during every half cycle.

3) Eddy Current Losses - Are the resistive heating losses observed in the core of the transformer.

2 Calculations, Analysis Discussion

Equations Used

Open Circuit

$$V_{OC} = V_P \tag{1}$$

$$I_{OC} = I_P \tag{2}$$

$$P_{OC} = P_P \tag{3}$$

$$PF_{OC} = cos(\theta_{OC}) = \frac{P_{OC}}{I_{OC}V_{OC}} \tag{4}$$

$$\theta_{OC} = arctan(PF_{OC}) \tag{5}$$

$$\bar{Y}_{OC} = \frac{I_{OC}}{V_{OC}}\angle - \theta_{OC} \tag{6}$$

$$R_C = \frac{1}{Re(\bar{Y}_{OC})} \tag{7}$$

$$X_m = \frac{1}{Im(\bar{Y}_{OC})} \tag{8}$$

Short Circuit

$$V_{SC} = V_P \tag{9}$$

$$I_{SC} = I_P \tag{10}$$

$$I_{rated} = \frac{S_{rated}}{V_{rated}} \tag{11}$$

$$P_{SC} = P_P \tag{12}$$

$$Z_{SC} = \frac{V_{SC}}{I_{SC}} \tag{13}$$

$$R_{eq,p} = \frac{P_{SC}}{{I_{SC}}^2} \tag{14}$$

$$X_{eq,p} = \sqrt{{Z_{SC}}^2 - {R_{SC}}^2} \tag{15}$$

Voltage Regulation

$$\bar{V}_{nl} = V_{rated} + I_{rated} * (R_{eq} + jX_{eq}) \tag{16}$$

$$\bar{V}_{fl} = V_{rated} \tag{17}$$

$$VR = \frac{|\bar{V}_{P,nl|} - |\bar{V}_{P,fl}|}{|\bar{V}_{P,fl}|} * 100\% \tag{18}$$

Efficiency

$$P_{out} = V_{rated} I_{rated} cos(\theta) \tag{19}$$

$$P_{Cu} = (I_{rated})^2 * R_{eq,p} \tag{20}$$

$$P_C = \frac{(V_{rated})^2}{R_C} \tag{21}$$

$$Efficiency(\eta) = \frac{P_{out}}{P_{out} + P_{Cu} + P_C} * 100\% \tag{22}$$

Observations

Status	V$_P(V)$	I$_P(A)$	V$_S(V)$	I$_S(A)$	P$_P(W)$
Open Circuit	121.4	0.026	121.0	None	2.157
Short Circuit	14.77	0.500	0.181	0.495	4.301

Table 1: LVDAC Measurements of Primary and Secondary Winding

Calculation

PF$_{OC}$	θ_{OC}	$\bar{Y}_{OC}(S)$	Z$_{SC}(\Omega)$
0.68	47.16	0.000214 $\angle$-47.08	29.54

R$_C(\Omega)$	X$_m(\Omega)$	R$_{eq,p}(\Omega)$	X$_{eq,p}(\Omega)$	VR
6849.32	-6369.43	17.20	24.02	12.41%

Table 2: Calculations for Series and Parallel Elements in Cantilever Circuit

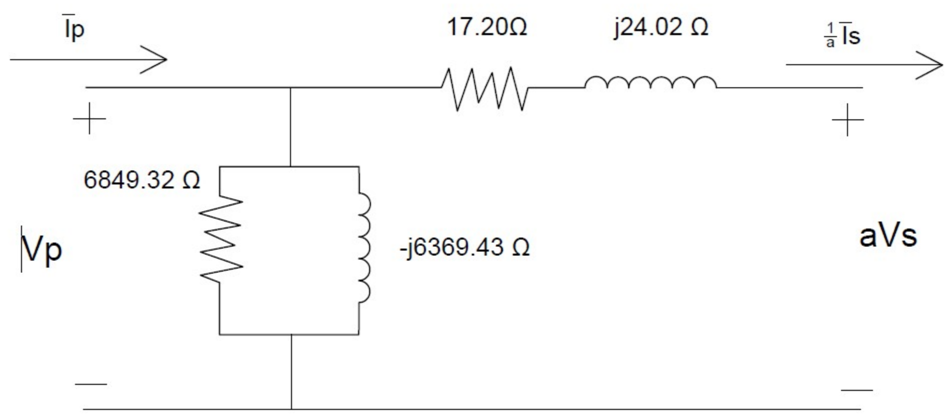


Figure 1: Primary Side Cantilever Equivalent Circuit

Efficiency:

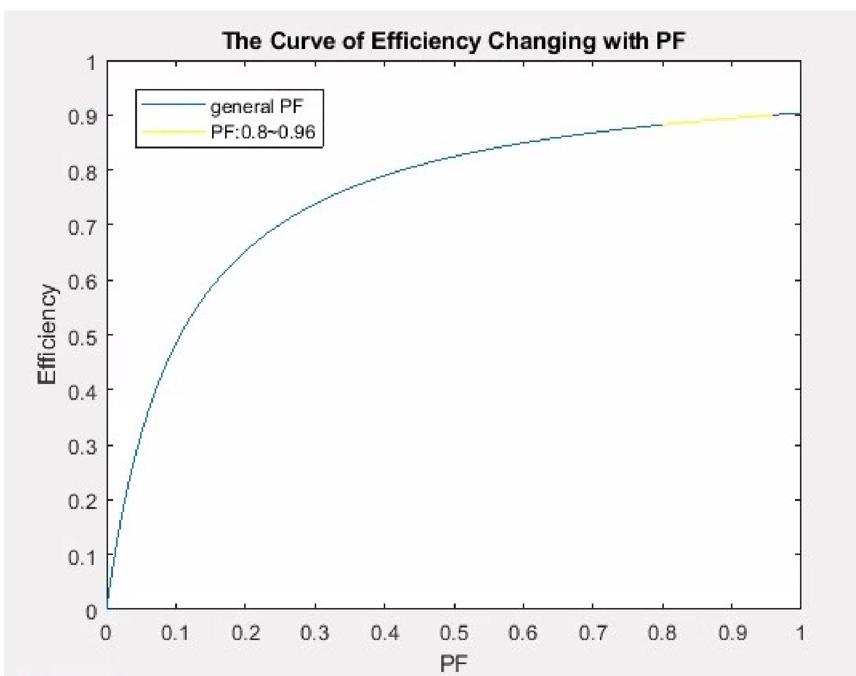


Figure 2: Efficiency of a 120-60/60V Transformer Based on Power Factor

The efficiency of a transformer is proportional to the output of real power within the system. However, the output of real power is dependent on the power factor (PF). From Figure 2, it can be observed that the efficiency in the transformer due to the power factor initially behaves in a exponential behavior, but progressively becomes linear till it reaches an asymptotic Efficiency of 0.9038 (90.38%). To achieve the maximum efficiency with this transformer the Copper losses must be equal to the Core losses. Ideally we want the losses to be equal to zero, but however some sort of loss in the coil or the core is inevitable once a load is attached to the transformer. It's important to notice that the more capacitive or inductive the transformer behaves, the total output power is lower causing a dramatic decrease in efficiency. Most transformer operate at a full load efficiency approximately 95-98.5%. Our transformer from the plot displays that we quite reaching this threshold of efficiency, but it's a good visual representation of how the transformer's efficiency is affected by the power factor. Conclusively, the efficiency of a transformer varies with the power factor (PF). When the real power of output is much bigger than the sum of Core loss and Iron loss, the efficiency is close to a constant.

Analysis

In this lab, we measured the voltage and current in the primary side and secondary side. Comparing the theory we talked about in lecture, we can calculate the circuit parameters for a primary-side cantilever equivalent circuit model by an open circuit and short circuit test. For example, Rc and Xm can be calculated by the data from open circuit. As formulas (5) and (6) shows, we can get the PF of open circuit firstly so that the value of θ is known. Then, we have the total admittance of open circuit through formula (7). Finally, we get R_C and X_m by formula (8) and (9).

Furthermore, the equivalent resistance and reactance for the primary side are easier to have by short circuit test. To begin with, we must know how to calculate the total impedance of the short circuit as formula (14) shown. What's more, the equivalent resistance for the primary side can be calculated by formula (15). So, we have the total impedance of the short circuit and the equivalent resistance for the primary side. Indeed, the reactance for the primary side can be gotten through formula (16).

Now, we got all of the circuit parameters for a primary-side cantilever equivalent circuit model as shown in figure 1. Next, we need to calculate voltage regulation. For the calculation of voltage regulation, we need to know V_{fl} and V_{nl}. As we know, V_{fl} is equal to the rated voltage and V_{nl} can be calculated by formula (17) (Note that the rated current is equal to the current in short circuit.) The remainder of V_{nl} minus V_{fl} is easy to be calculated. Therefore, the voltage regulation is the remainder of V_{nl} minus V_{fl} divides V_{fl} as shown in formula (19).

At last, the efficiency of the transformer is calculated by formula (23). In this lab, the efficiency is not a constant because there is no rated load connecting to the transformer. Hence, we have to assuming a load with a PF lagging between 0.8 and 0.96 (The reason is explained above). It is generally known that core loss can be defined by open circuit test and the copper loss can be determined by short circuit test. Finally, we can get the curve of Efficiency changing with PF. As a result, efficiency changes very minimally if the range of PF is 0.8 0.96. It conforms to the theory we learned in class. In addition, when calculating P_{Cu} and P_C, we found that the values of them are close to the real power in the short circuit and open circuit. It accords to the theory that P_C is approximately equal to P_{OC} and P_{Cu} is approximately equal to P_{SC}. In conclusion, to reduce the loss in total output real power you need to minimize the copper and core losses. This is achieved by having a more ideal power factor (as close to unity as you can get).

3 Engineering Design

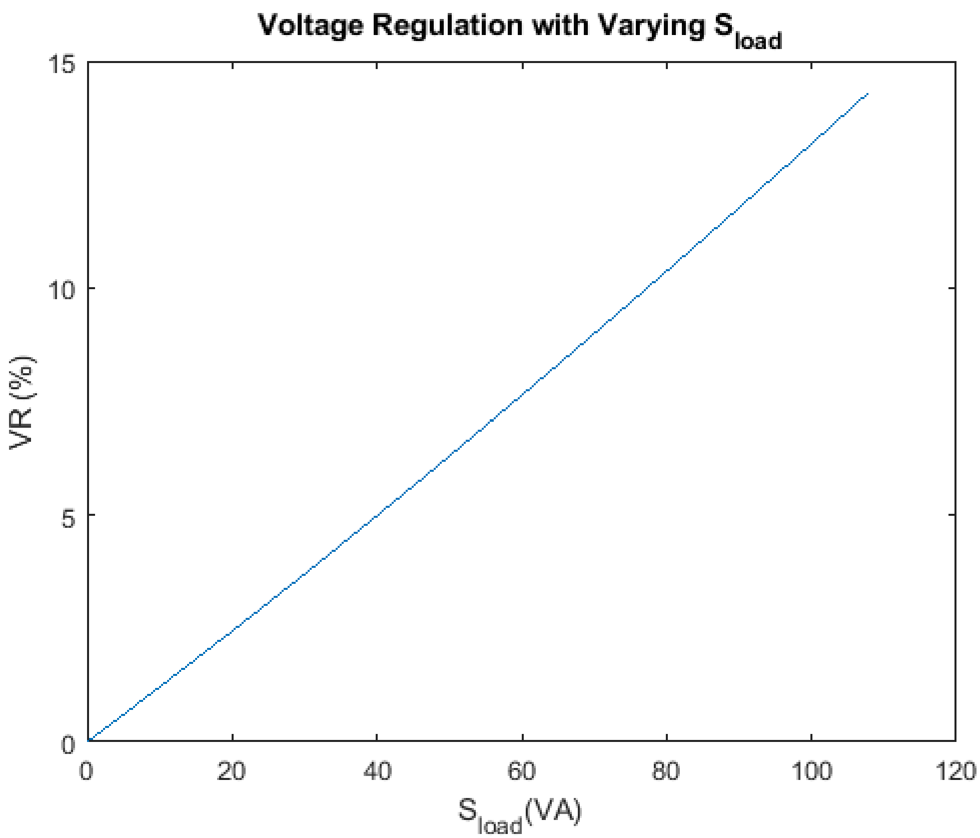
Test Code

Testing the functions will be done with both varying magnitudes and phases along with using constant magnitudes and phases. The results will be plotted to show confirmation of theory. Some assumptions are that each of these functions are independent from each other and is specifically designed for the 8341 LabVolt 120-60/60 V transformer.

```
%These are the testing variables
a = linspace(0, 1.8*60, 20);      % Equally spaced voltage points
b = linspace(-90, 90, 20);        % Equally spaced phase points
c = 120;                          % Constant voltage
d = 0;                            % Constant phase
e = 1.25;                         % Overcurrent factor
f = [.95 1.05];                   % Under/Over voltage factor
```

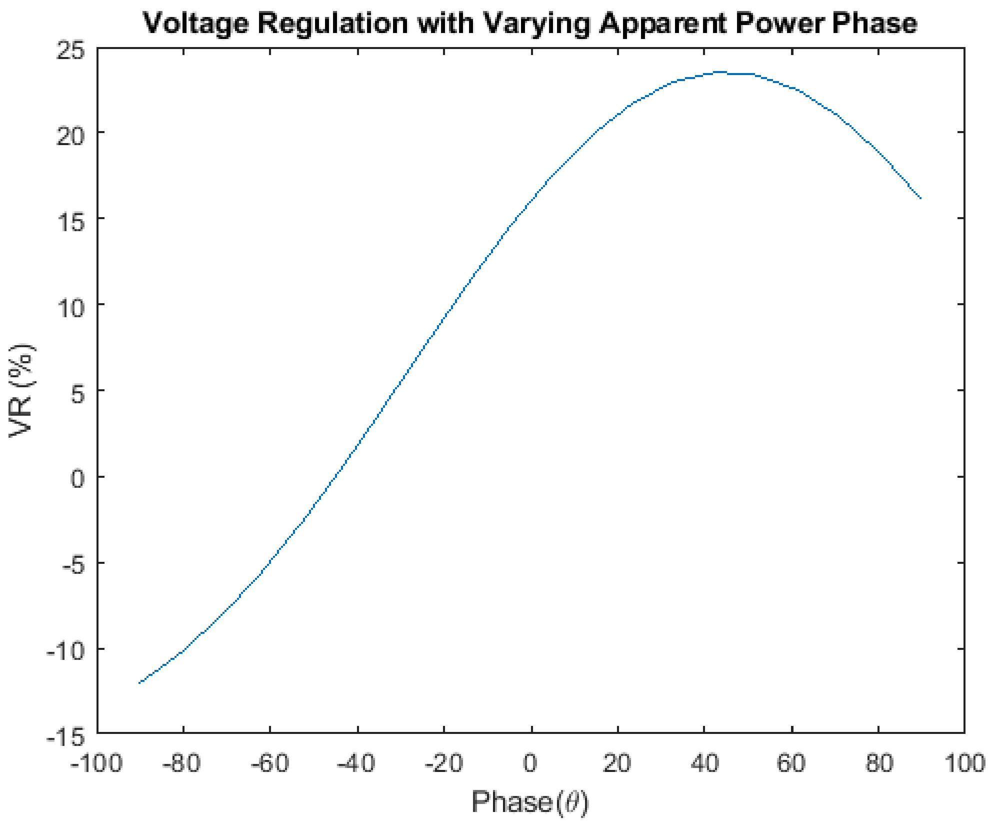
VR with Varying Apparent Power Magnitude

```
VR = volt_reg(a, d);      % Voltage regulation function
figure(1)                 % Create figure
plot(a, VR)               % Plot
% Plot details
title('Voltage Regulation with Varying S_{load}')
xlabel('S_{load}(VA)')
ylabel('VR (%)')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% The following plot has a constant phase at 0 degrees where the
% magnitude ranges from 0 to 108 V. This plot shows what seems to be
% a linear relationship between voltage regulation and apparent power
% magnitude.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```



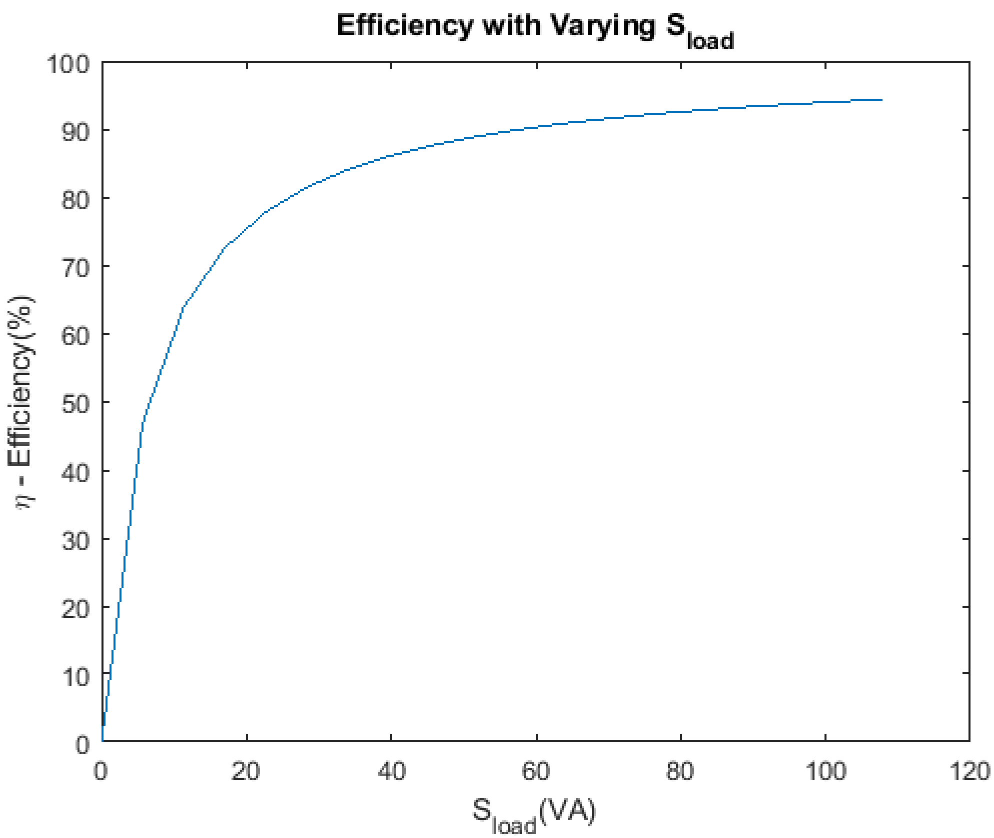
VR with Varying Apparent Power Phase

```
VR = volt_reg(c, b);      % Voltage regulation function
figure(2)                 % Create figure
plot(b, VR)               % Plot
% Plot details
title('Voltage Regulation with Varying Apparent Power Phase')
xlabel('Phase(\theta)')
ylabel('VR (%)')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% The following plot shows the expected relationship between phase
% and voltage regulation. It shows a sinusoidal relationship. The
% apparent power magnitude was held to a constant of 120.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```



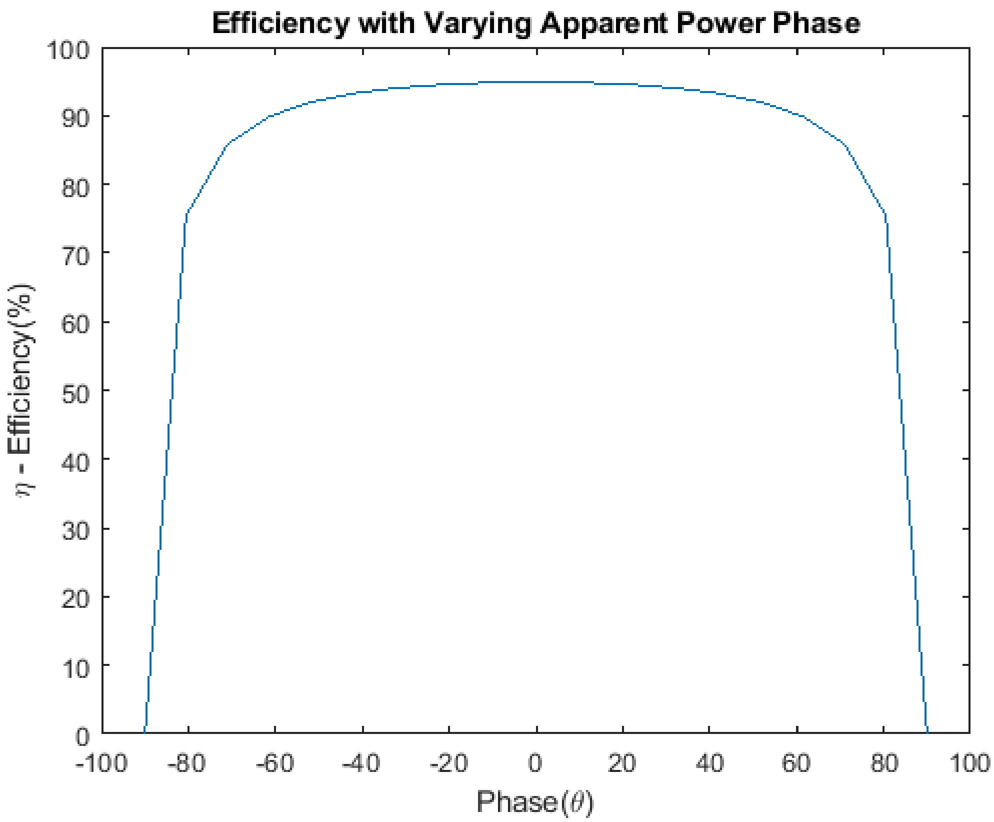
Efficiency with Varying Apparent Power Magnitude

```
n = eff(a, d);  % Efficiency function
figure(3)       % Create figure
plot(a, n)      % Plot
% Plot details
title('Efficiency with Varying S_{load}')
xlabel('S_{load}(VA)')
ylabel('\eta - Efficiency(%)')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% The following plot shows the expected relationship between varying
% apparent power magnitude and efficiency. One can expect that the
% efficiency will not reach 100% in realistic situations. We can see
% that increasing the magnitude increases effiency to a degree. The
% phase was held constant at 0 degrees.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```



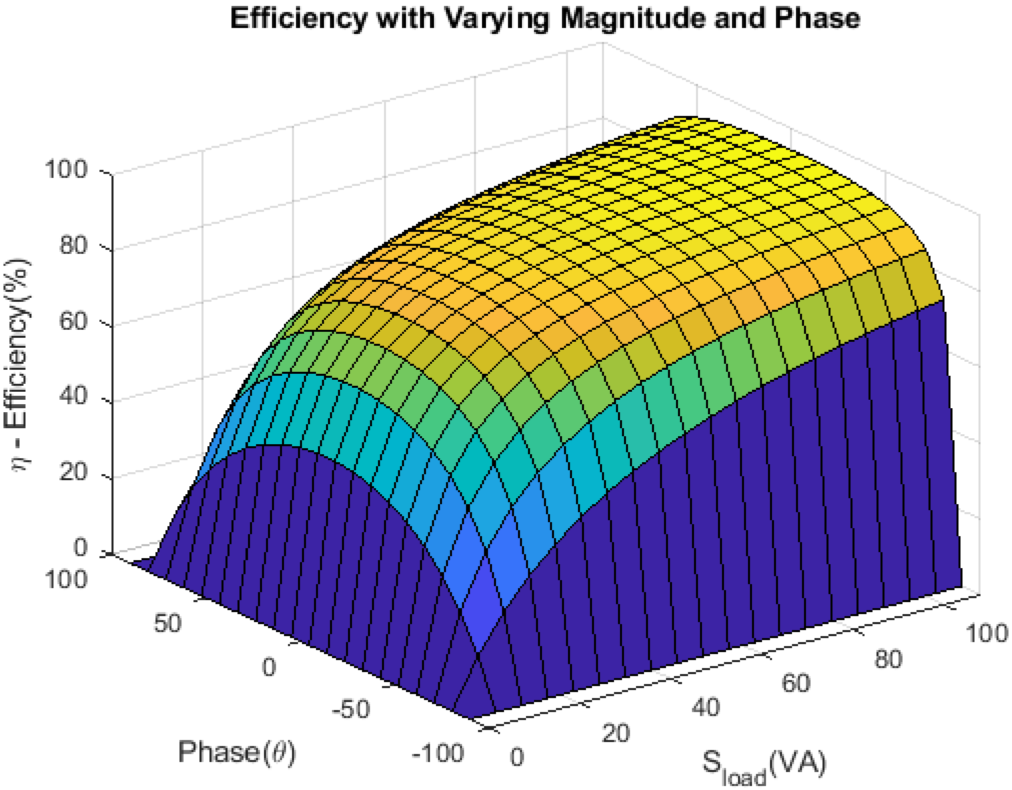
Efficiency with Varying Apparent Power Phase

```
n = eff(c, b);  % Efficency function
figure(4)       % Create figure
plot(b, n)      % Plot
% Plot details
title('Efficiency with Varying Apparent Power Phase')
xlabel('Phase(\theta)')
ylabel('\eta - Efficiency(%)')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% In the following plot apparent power magnitude was held at 120.
% With phase ranging from -90 to 90 we can expect a parabolic
% relationship that leads to a sinusoidal result, since it is phase
% angles. We can also see that peak does not reach 100% efficiency
% which is to be expected.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```



Efficiency with Varying Magnitude and Phase

```
[x,y] = meshgrid(a,b); % Creat grid of points
n = eff(x, y);         % Use grid of points to get efficiency
figure(5)
surf(a,b,n)            % Plot using surface plot
% Plot details
title('Efficiency with Varying Magnitude and Phase')
xlabel('S_{load}(VA)')
ylabel('Phase(\theta)')
zlabel('\eta - Efficiency(%)')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% This additional plot is just to show that other plot configurations
% will work these functions as well. The plot shows the combination
% of the previous two efficiency plots. Creating a 3D plot with two
% variables, apparent power magnitude and phase.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```



Overcurrent with Varying Line Current

```
for i = 1:6
    g = i*.2;       % Stepping line currents for testing of function
    I_flag = OC(g, e);  % Overcurrent function
    if I_flag == true   % If flag was set output proper statement
        fprintf('A current of %.2f is over the rated current
 tolerance!\n', g)
    else                % If flag not set output proper statement
        fprintf('A current of %.2f is within the rated current
 tolerance.\n', g)
    end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Here the output result is shown underneath the function down below.
% This was programmed in a way to show linear relation and a
% expectation that the current increases to the point of overcurrent.
% The printed statements can show this.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Under/Over Voltage with Varying Voltage Magnitudes

```
for i = 1:6
```

```
    h = 40*i;         % Step voltage magnitudes for test of function
    V_flag = UV_OV(h, f); % Under/Over voltage function
    if V_flag == true % If flag set to under output proper statement
        fprintf('A voltage of %.2f is under the rated voltage
 tolerance!\n', h)
    elseif V_flag == 2 % If flag set to over output proper statement
        fprintf('A voltage of %.2f is over the rated voltage
 tolerance!\n', h)
    else                % If flag not set output proper statement
        fprintf('A voltage of %.2f is within the rated current
 tolerance.\n', h)
    end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Here the output result is shown underneath the respective function
% down below. We can see that the printed statements can show a
% parabolic relationship. In the middle we have acceptible voltage
% levels with bounds.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Voltage Regulation Function

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% The following is a function to calculate the voltage regulation
% given apparent power as a magnitude for the first parameter and a
% phase for the second parameter. They both can be arrays for their
% respective values as well. The function will return voltage
% regulation as a percentage or an array of percentages depending on
% the type of arguments.
% Input restrictions:
% Apparent power magnitude: 0 <= |S| <= 108
% Phase: -90 <= theta <= 90
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function VR = volt_reg(S_load, theta)
    theta = theta*pi/180;          % Conversion to radians
    % Secondary current in transformer
    Is = S_load./120.*cos(theta)+S_load./120.*sin(theta);
    Vp = 120 + (17.2+24.02i).*Is;   % Primary voltage in transformer
    Vpmag = sqrt(real(Vp).^2 + imag(Vp).^2); % Magnitude of Vp
    VR = (Vpmag-120)./120.*100;     % Voltage Regulation percentage
end
```

Efficiency Function

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% The following function is used to find the efficiency given
% apparent power magnitude and a phase for the first and second
% arguments respectively. Both arguments can be an array of values.
% The function will return effiency as a percentage or an array of
% percentages.
% Input restrictions:
% Apparent power magnitude: 0 <= |S| <= 108
% Phase: -90 <= theta <= 90
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function n = eff(S_load, theta)
    theta = theta*pi/180;       % Conversion to radians
    P_out = S_load.*cos(theta); % Power delivered to load
    P_cu = 2.157;               % Power dissipated in windings
    P_core = 4.301;             % Power dissipated in core
    n = P_out./(P_out + P_cu + P_core).*100;  % Efficiency
end
```

Overcurrent Function

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% The following function is used as an interrupt when the line
% current is over the rated current. The input arguments are line
% current magnitude and per-unit overcurrent factor. Both arguments
% have to be constants. If  the current is over the rated current
% tolerance than the function will set the return value.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function I_flag = OC(I_line, C_I)
    length = size(I_line);             % Get length of input array
    I_flag = zeros([1 length]);   % Preallocate flag array with zeros
    I_rated = .5;                      % Rated current of transformer
    for i = 1:length(2)                % Check each index of array
        if I_line(i) >= C_I*I_rated    % If >= current tolerance
            I_flag(i) = 1;             % Set flag
        else                           % Else continue checking
            I_flag(i) = 0;
        end
    end
end                                    % Return array of flags
```

```
A current of 0.20 is within the rated current tolerance.
A current of 0.40 is within the rated current tolerance.
A current of 0.60 is within the rated current tolerance.
A current of 0.80 is over the rated current tolerance!
A current of 1.00 is over the rated current tolerance!
A current of 1.20 is over the rated current tolerance!
```

Under/Over Voltage Function

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% The following function is used as an interrupt when primary or
% secondary voltage is over/under the rated voltage tolerances. The
% inputs are the magnitude of the primary/secondary voltage for the
% first argument and the under and over voltage factors for the
% second argument as an array only (first index of the array is the
% under-voltage factor the second index is the over-voltage factor).
% If the given voltage is out of bounds of the tolerance than the
% return value will be set to (1) if under and (2) if over voltage.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function V_flag = UV_OV(V, C_v)
    length = size(V);           % Get length of input array
    V_flag = zeros([1 length]); % Preallocate flag array with zeros
```

```
    V_rated  = 120;             % Rated voltage of transformer
    for i = 1:length(2)    % Loop to check each index of input array
        if V(i) <= C_v(1)*V_rated   % If voltage <= input tolerance
            V_flag(i) = 1;          % Set flag
        elseif V(i) >= C_v(2)*V_rated % If volt >= input tolerance
            V_flag(i) = 2;          % Set flag
        else                        % Else continue checking
            V_flag(i) = 0;
        end
    end
end                                 % Return array of flags
```

```
A voltage of 40.00 is under the rated voltage tolerance!
A voltage of 80.00 is under the rated voltage tolerance!
A voltage of 120.00 is within the rated current tolerance.
A voltage of 160.00 is over the rated voltage tolerance!
A voltage of 200.00 is over the rated voltage tolerance!
A voltage of 240.00 is over the rated voltage tolerance!
```

Published with MATLAB® R2019b

Design Analysis

To summarize these results we can see a trend that most transformers should follow from these plots. However, these particular functions were established having a particular transformer in mind. So even though there is a trend among these results that other transformer are expected to follow, having a more precise model is what's important here. The main purpose for these functions were to model more accurate numbers for a better design (by visualization and understanding of these numbers). For example, we can now determine a range of values for the magnitude of apparent power that will draw about ninety percent efficiency and for what phases that becomes nullified. That is very important if one wants a good design. Therefore, simulation models and being able to create these models is a very important design tool.

4 Conclusion

The primary focus of this lab is to introduce single-phase power transformers, that includes autotransformers. The first portion of the lab involves testing and acquiring data from a single-phase 120-60/60V transformer for both an open and closed-circuit configuration. From the primary and secondary voltages and currents, and real power acquired from the open and short-circuit tests, then we'll use the data to calculate the circuit parameters of a primary-side cantilever circuit model. Once the circuit parameters are calculated, we will use these values to determine the Voltage Regulation (VR) and Efficiency (η) of the 120-60/60V single-phase transformer. The second portion of the lab involves designing a MATLAB algorithm to calculate the load-regulate Voltage Regulation and Efficiency given a complex load. The function must include a flagging function for over currents and under/over voltages.

Through this experiment, we applied the theory of open and short circuit test for transformer learned in lecture and verified the data. We found that most of the data matches both the theory and the calculations presented. Through this experiment, we have a better understanding of the calculation of circuit parameters for a primary-side cantilever equivalent circuit model, especially regarding the voltage regulation and the efficiency of a transformer. How power factor proportionally affects the efficiency of a transformer is good parameter to understand when it comes to designing a power system. We want to achieve as much real power output as possible without wasting it through unnecessary reactance in the system. By conducting this single-phase experiment we observed that the relationship isn't linear throughout, therefore getting a specific power factor is vital to gaining maximum desired efficiency.

From the theories learned above we were able to establish and design a model utilizing MATLAB software. This model was specifically designed for the 8341 LabVolt 120-60/60 V transformer. The same transformer used to analyze theoretical data along with field data in part one. This was done using the data-sheet for the product as well as utilizing transformer characteristics found in the first part of the lab. Therefore, we were able to compare and contrast the models between the two.

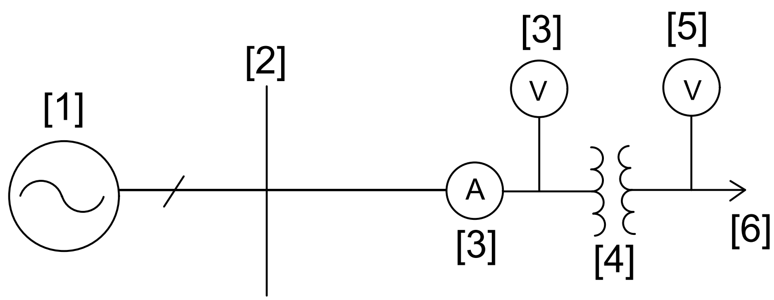
Our findings further established a connection between the control of efficiency and voltage regulation. Two very important factors when utilizing transformers in design. We looked into what parameters were involved in creating a better design, such as apparent power and line current. Being able to understand these concepts and being able to create a model using software (such as MATLAB) will only help design a better system.

Overall, this lab displayed some very key design factors that need to be present when designing a transformer in a power system. The lab requirements and analysis were straight forward to complete. However, we gained a better insight on how the power factor directly affects both voltage regulation and efficiency. While we're limited in the number of turns we can make within our transformer, but we can control the power factor to achieve a better optimal operating efficiency by reducing the losses observed in the transformer. If we were going to redo the experiment in the future we now have a better foundation on how to achieve a better design that we could implement.

A Appendix: Engineering Documents

	Item	Vendor	Part Number	Quantity	List Price	Net Price
1	Transformer Module, Sgl. Phase	Lab-Volt	8341-20	1	$370.00	$370.00
2	Power Supply, Var. 3ph, 24Vac	Lab-Volt	8821-20	1	$2,870.00	$2,870.00
3	Inter Data Acq Ctr, for model 9069-1	Lab-Volt	9063-B0	1	$3,499.00	$3,499.00
4	Black -36.0" (914.40mm) Banana Plug Stackable Patch Cord 14AWG (5kV) ,	Pomona Electronics	B-36-0	2	$6.09	$12.18
5	Red -36.0" (914.40mm) Banana Plug, Stackable Patch Cord 14AWG (5kV)	Pomona Electronics	B-36-2	6	$6.09	$36.54
6	White -36.0" (914.40mm) Banana Plug, Stackable Patch Cord 14AWG (5kV)	Pomona Electronics	B-36-9	1	$6.09	$6.09
7	Safety Lockout Hasp	Grainger	1U177	1	$6.15	$6.15
8	1-9/16 in. Aluminum Keyed Padlock	Master Lock	141DLFHC	1	$7.98	$7.98
					Total	$6807.94

Table 3: Bill of Materials



Open Circuit One-Line Diagram

Notes

[1] Power Supply Single-Phase, 8821-20

[2] Banana cables (B-36) used to connect between transformer/equipments

[3] Data Acquisition and Control, 9063-B0
A - Ammeter (I1)
V - Voltmeter (E1)

[4] 120-60/60V transformer, 8341-20
Rating:
60VA 120/208/120V
0.5/0.3/0.5A 60Hz

[5] Data Acquisition and Control, 9063-B0
Secondary Winding:
V - Voltmeter (E2)

[6] Single-Phase Load:
Open-Circuit
no other connections after Voltmeter (E2)

EE347L lab #4 – Single–Phase Transformers
One–line Diagram

Designed	Team 3	05/20
Drawn	Boldt	05/20
Checked		

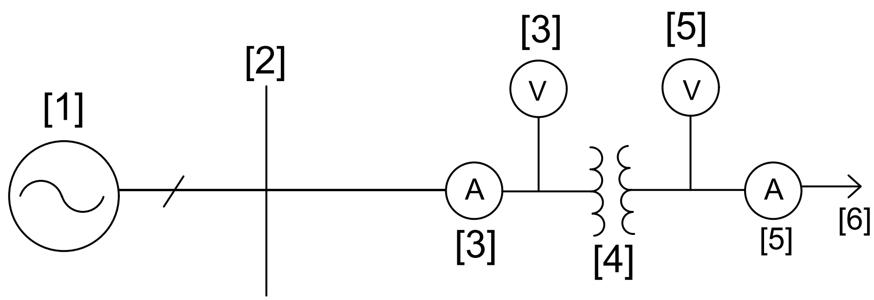
Portland State UNIVERSITY

PORTLAND STATE UNIVERSITY
DEPT. OF ELECTRICAL AND COMPUTER ENGINEERING

Approved ____ Date ____
Title ____

File No. *.DWG file name
Sheet 1 of 1

PRODUCED BY AN AUTODESK STUDENT VERSION
PRODUCED BY AN AUTODESK STUDENT VERSION
PRODUCED BY AN AUTODESK STUDENT VERSION



Short Circuit One-Line Diagram

Notes

[1] Power Supply Single-Phase, 8821-20

[2] Banana cables (B-36) used to connect between transformer/equipments

[3] Data Acquisition and Control, 9063-B0
A - Ammeter (I1)
V - Voltmeter (E1)

[4] 120-60/60V transformer, 8341-20
Rating:
60VA 120/208/120V
0.5/0.3/0.5A 60Hz

[5] Data Acquisition and Control, 9063-B0
Secondary Winding:
V - Voltmeter (E2)
A - Ammeter (I2)

[6] Single-Phase Load:
Short-Circuit
no other connections after Ammeter (I2)

Designed Team 3	05/20
Drawn Boldt	05/20
Checked	

EE347L lab #4 – Single–Phase Transformers
One–line Diagram

Portland State UNIVERSITY

PORTLAND STATE UNIVERSITY
DEPT. OF ELECTRICAL AND COMPUTER ENGINEERING

Approved ______ Date ____
Title ______

File No.
*.DWG
file name
Sheet 1 of 1

POINT ASSIGNMENT INDEX

PAGE NO.	NO. OF S	DESCRIPTION
1	1	This index
2	1	Lab-Volt Power Supply, 8821-20 (Single Phase)
3	1	Lab-Volt Transformer Module, Sgl. Phase 8341-20
4	1	Lab-Volt Inter Data Acq Ctr for model 9069-1

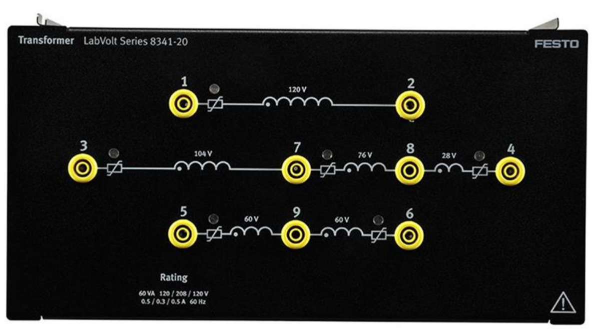
REV	DATE	DESCRIPTION	Created By	Checked by
1	05/22/20	LabVolt Power Supply connection to LabVolt Tranformer Module Sgl. Phase and DAC for Open and Short Circuit Tests	KB	RB, RN, LZ
2	05/25/20	Revisions made for Transformer Module and DAC Connections	KB	RN, LZ
3				
4				
5				

Open Circuit										
LabVolt Power Supply, 8821		POINT TYPE								
		Hardware Point					Virtual Point			
Point Description	Origin Address	DO	DI	AO	AI	Pwr		Destination Address	Destination Description	Notes
AC Variable 120/208V Phase A	4	0	0	0	0	1	0	I1 Red	Current Terminal (DAC)	
0-120/208V 5A Neutral	N	0	0	0	0	1	0	6	120V Transformer Single Phase	
24VAC, 0.4A Power Input	Power Input	0	0	0	0	1	0	Power Input	24VAC, 0.4A Power supply, DAC 9063	24 VAC power supply
	Total Points	0	0	0	0	3	0			

Short Circuit										
LabVolt Power Supply, 8821		POINT TYPE								
		Hardware Point					Virtual Point			
Point Description	Origin Address	DO	DI	AO	AI	Pwr		Destination Address	Destination Description	Notes
AC Variable 120/208V Phase A	4	0	0	0	0	1	0	I1 Red	Current Terminal (DAC)	
0-120/208V 5A Neutral	N	0	0	0	0	1	0	6	120V Transformer Single Phase	
24VAC, 0.4A Power Input	Power Input	0	0	0	0	1	0	Power Input	24VAC, 0.4A Power supply, DAC 9063	24 VAC power supply
	Total Points	0	0	0	0	3	0			

Open Circuit										
LabVolt Transformer Module (Single Phase) 8341-20		POINT TYPE								
		Hardware Point								
Point Description	Origin Address	DO	DI	AO	AI	Pwr	Virtual Point	Destination Address	Destination Description	Notes
120V Transformer Single Phase	5	0	0	0	0	1	0	I1 Black	Current Terminal, DAC, 9063	Primary Winding
120V Transformer Single Phase	6	0	0	0	0	1	0	N	0-120/208V 5A Neutral, 8821-20	
120V Transformer Single Phase	5	0	0	0	0	1	0	E1 Red	Voltage 500V, DAC, 9063	Primary Winding
120V Transformer Single Phase	6	0	0	0	0	1	0	E1 Black	Voltage 500V, DAC, 9063	
120V Transformer Single Phase	1	0	0	0	0	1	0	E2 Red	Voltage 500V, DAC, 9063	Secondary Winding
120V Transformer Single Phase	2	0	0	0	0	1	0	E2 Black	Voltage 500V, DAC, 9063	
	Total Points	0	0	0	0	6	0			

Short Circuit										
LabVolt Transformer Module (Single Phase) 8341-20		POINT TYPE								
		Hardware Point								
Point Description	Origin Address	DO	DI	AO	AI	Pwr	Virtual Point	Destination Address	Destination Description	Notes
120V Transformer Single Phase	5	0	0	0	0	1	0	I1 Black	Current Terminal, DAC, 9063	Primary Winding
120V Transformer Single Phase	6	0	0	0	0	1	0	N	0-120/208V 5A Neutral, 8821-20	
120V Transformer Single Phase	5	0	0	0	0	1	0	E1 Red	Voltage 500V, DAC, 9063	Primary Winding
120V Transformer Single Phase	6	0	0	0	0	1	0	E1 Black	Voltage 500V, DAC, 9063	
120V Transformer Single Phase	1	0	0	0	0	1	0	E2 Red	Voltage 500V, DAC, 9063	Secondary Winding
120V Transformer Single Phase	2	0	0	0	0	1	0	E2 Black	Voltage 500V, DAC, 9063	
120V Transformer Single Phase	1	0	0	0	0	1	0	I2 Red	Current Terminal 4A, DAC, 9063	Secondary Winding
120V Transformer Single Phase	2	0	0	0	0	1	0	I2 Black	Current Terminal 4A, DAC, 9063	
	Total Points	0	0	0	0	8	0			



Open Circuit

Data Acquisition and Control Interface, 9063		POINT TYPE								
		Hardware Point					Virtual Point			
Point Description	Origin Address	DO	DI	AO	AI	Pwr		Destination Address	Destination Description	Notes
Current Terminal (DAC)	I1 Red	0	0	0	0	1	0	4	AC Variable 120/208V Phase A, 8821-20	
Current Terminal (DAC)	I1 Black	0	0	0	0	1	0	5	120 V Transformer Single Phase, 8341-20	Ammeter Primary Winding
Voltage 500V (DAC)	E1 Red	0	0	0	0	1	0	5	120V Transformer Single Phase, 8341-20	Voltmeter Primary Winding
Voltage 500V (DAC)	E1 Black	0	0	0	0	1	0	6	120V Transformer Single Phase, 8341-20	
Voltage 500V (DAC)	E2 Red	0	0	0	0	1	0	1	120V Transformer Single Phase, 8341-20	Voltmeter Secondary Winding
Voltage 500V (DAC)	E2 Black	0	0	0	0	1	0	2	120V Transformer Single Phase, 8341-20	
Computer USB Port	Computer I/O	0	0	0	0	1	0	Computer I/O	Computer USB Port	
24VAC, 0.4A Power Input	Power Input	0	0	0	0	1	0	Power Input	24VAC, 0.4A Power Input, 8821	
	Total Points	0	0	0	0	8	0			

Short Circuit

Data Acquisition and Control Interface, 9063		POINT TYPE								
		Hardware Point					Virtual Point			
Point Description	Origin Address	DO	DI	AO	AI	Pwr		Destination Address	Destination Description	Notes
Current Terminal (DAC)	I1 Red	0	0	0	0	1	0	4	AC Variable 120/208V Phase A, 8821-20	
Current Terminal (DAC)	I1 Black	0	0	0	0	1	0	5	120 V Transformer Single Phase, 8341-20	Ammeter Primary Winding
Current Terminal (DAC)	I2 Red	0	0	0	0	1	0	1	120 V Transformer Single Phase, 8341-20	Ammeter Secondary Winding
Current Terminal (DAC)	I2 Black	0	0	0	0	1	0	2	120 V Transformer Single Phase, 8341-20	
Voltage 500V (DAC)	E1 Red	0	0	0	0	1	0	5	120V Transformer Single Phase, 8341-20	Voltmeter Primary Winding
Voltage 500V (DAC)	E1 Black	0	0	0	0	1	0	6	120V Transformer Single Phase, 8341-20	
Voltage 500V (DAC)	E2 Red	0	0	0	0	1	0	1	120V Transformer Single Phase, 8341-20	Voltmeter Secondary Winding
Voltage 500V (DAC)	E2 Black	0	0	0	0	1	0	2	120V Transformer Single Phase, 8341-20	
Computer USB Port	Computer I/O	0	0	0	0	1	0	Computer I/O	Computer USB Port	
24VAC, 0.4A Power Input	Power Input	0	0	0	0	1	0	Power Input	24VAC, 0.4A Power Input, 8821	
	Total Points	0	0	0	0	10	0			

```
x = 0:0.01:1;
cos = x;
V_OC = 121.4;
V_rated = V_OC;
I_SC = 0.500;
I_rated = I_SC;
P_out = V_rated * I_rated * cos;
P_sc = 2.157;
P_Cu = P_sc;
P_oc = 4.301;
P_C = P_oc;
y = P_out./(P_out + P_Cu + P_C);
z = y(81:97);
plot(x,y)
title('The Curve of Efficiency Changing with PF')
hold on
plot(x(81:97),z,'Color','y')
xlabel('PF');ylabel('Efficiency')
hold off
legend('general PF','PF:0.8~0.96')
```

Figure 3: The Code of Figure 1

[1] S. Chapman, "Electric Machinery and Power System Fundamentals," New York: McGraw-Hill, 2002 pp.82-125
[2] Portland State University Power Lab, *347 Lab3: Power Harmonic Analysis* Accessed on: May 5, 2020. [Video File] Available: https://www.youtube.com/watch?v=LqZ3IQhxlrMfeature=youtu.be
[3] "Transformer Basic and Transformer Principles", [Online]. Available: https://www.electronics-tutorials.ws/transformer/transformer-basics.html?utm$_r eferrer = https$%3A%2F%2F $www.google.com$%2F
$[Accessed : May 29, 2020]$

Authors

Ryan Nand, is a BS candidate in the Electrical & Computer Engineering department at Portland State University. A PhD in Physics and an Olympic gold medalist. His research and studies have only just begun.

Kai Boldt, is a BS candidate in the Electrical & Computer Engineering department at Portland State University. World Renown Genius, Billonaire, Playboy, Philathropist. His research and studies have only just begun, but researches designing digital filters in his free time.

Lihong Zhao, is a BS candidate in the Electrical & Computer Engineering department at Portland State University. Passionate Power Student.

Acknowledgements

I would like to thank my Olympic coach Dr. Joe who stood up for me in my darkest of times. My non-existent cat whom I would be petting right now as I type this acknowledgement if the cat were to exist.

Disclaimer

The contents of this report reflect the views of the authors, who are solely responsible for the facts and the accuracy of the material and information presented herein. This document is disseminated in the interest of information exchange.