Single-Phase Transformers:

Lab 4

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Abstract

A single-phase transformer can be used to increase or decrease voltage from primary to secondary windings. Transformers always have an efficiency and losses which is ideally between 94-96 percent.

The two main purposes of transformers are step up transformers and step down transformers. Which just mean the primary to secondary either steps up the voltage so like 120 to 240V or step down which is from primary to secondary is like 240/120V.

Some types of transformers include power transformers, distribution transformers, and instrument transformers. Power transformers typically are used to transmit electricity and have a high rating. Distribution transformers have a comparatively lower rating than a power transformers and is used to distribute electricity. Instrument transformers are further sub-categorized into current and potential transformers which are used to relay and protect instruments simultaneously.

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1 Introduction

In this lab, we are looking at a single-phase power transformer, which includes autotransformers. We will design an experiment to determine the circuit models of transformers, which are then modeled using a MATLAB script. We also determine the transformers efficiency as well as maximum power configurations for autotransformers.

Objectives Students learn how to:

- configure a test bench for performing open circuit and short circuit transformer testing
- perform the procedures for these two tests
- exercise precautions during testing, particularly during the short circuit test

Analyze and interpret data, and draw conclusions
Develop engineering documentation:

- Bill of materials
- Points list
- One-line diagram

2 Circuit Build and Data Gathering

Tests Performed/ Conditions:

For the open circuit test, we measured the voltage, current, and power with the data acquisition and control interface paired with LVDAC across the primary transformer.

- Ammeter in series with primary transformer
- Voltmeter across secondary transformer as well as primary.
- Adjust power-supply voltage to max and take measurements

For the short circuit test, we measured the voltage, current, and power with the data acquisition and control interface paired with LVDAC across the primary transformer/secondary transformer.

- Ammeter in series with primary transformer and shorting on secondary transformer
- Voltmeter across secondary transformer as well as primary.
- We adjust current very slowly to rated current on both windings, and take measurements

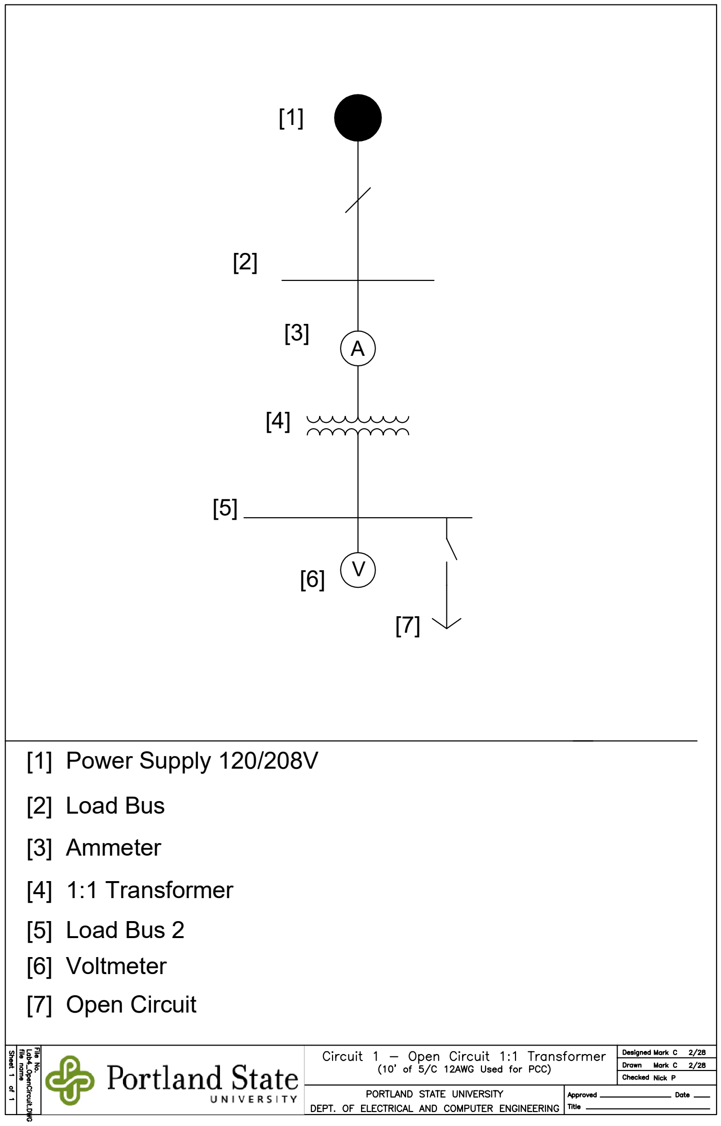

Figure 1: One-line diagram of Circuit 1- Open Circuit

The one line diagram for the single phase transformer open circuit

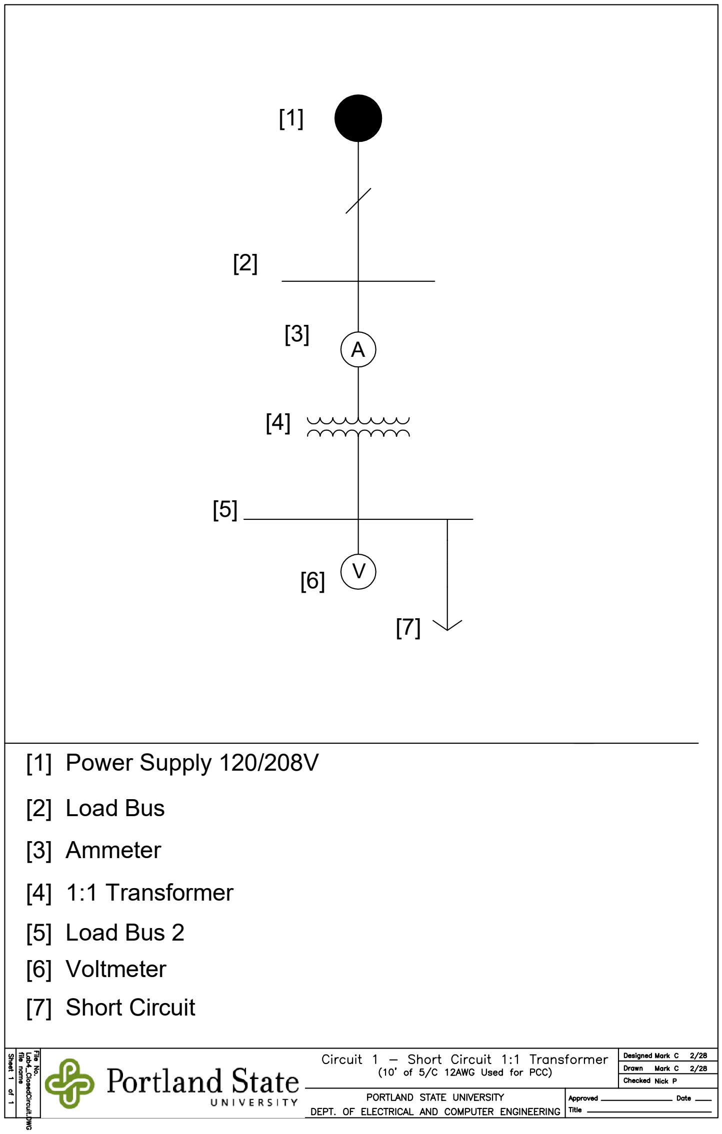

Figure 2: One-line diagram of Circuit 2- Short Circuit

The one line diagram for the single phase transformer short circuit

2.1 Test Results

Table 1: Open circuit LabVolt readings

Open Circuit Test			
E1	I1	P1	E2
120.4	0.026	2.165	120.2

Table 2: Short circuit LabVolt readings

Short Circuit Test				
E1	I1	P1	E2	I2
14.81	0.505	4.393	0.182	0.500

These measurements can be renamed to use in our formulas for finding the parallel and series components of the transformer equivalent circuit.

Table 3: Open circuit and short circuit test variables

Voc = Vrated	Ioc (A)	Poc (W)	Vsc (V)	Isc (A)	Psc (W)
120.4	0.026	2.165	14.81	0.505	4.393

2.2 Calculations

The open-circuit test allows us to calculate the values for the parallel components of an equivalent cantilever model for the tested transformer.

We are trying to find $\bar{Y}_{OC} = Y_{OC}\angle - \theta_{OC}$:

$$Y_{OC} = \frac{I_{OC}}{V_{OC}} = \frac{26mA}{120.4V} = 216\mu S$$

$$\theta_{OC} = cos^{-1}\left(\frac{P_{OC}}{I_{OC}V_{OC}}\right) = 46.24°$$

$$\bar{Y}_{OC} = 217\mu S\angle - 46° = 151 - j156\mu S$$

$$R_{core} = \frac{1}{G} = 6667\Omega \quad \text{and} \quad X_m = \frac{1}{B} = 6452\Omega$$

The short-circuit test lets us calculate the values for the series components:

$$\bar{Z}_{SC} = \bar{Z}_{eq,P} = R_{eq,P} + jX_{eq,P} = Z_{SC}\angle\theta_{SC}$$

$$Z_{SC} = \frac{V_{SC}}{I_{SC}} = 29.33\Omega$$

$$\theta_{SC} = cos^{-1}\left(\frac{P_{SC}}{V_{SC}I_{SC}}\right) = 54^{\circ}$$

$$\bar{Z}_{eq,P} = 17.24 + j23.73\Omega$$

$$R_{eq,P} = 17.24\Omega \quad \text{and} \quad X_{eq,P} = 23.73\Omega$$

The series components are a couple orders of magnitude smaller than the parallel components, which is what we would expect.

Efficiency is found using only the resistance values:

$$P_{core} = \frac{V_p^2}{R_{core}} \quad \text{and} \quad P_{cu} = \left(\frac{I_{line}}{a}\right)^2 R_{eq,P}$$

a for this model is 1, since the primary and secondary voltages are both 120 V.

3 Data Analysis and Interpretation, Drawing Conclusions

3.1 Program instructions

This section details a program written in MATLAB which simulates the transformer tested in this lab. It takes a complex a complex load, a choice of under/over-voltage factors, and a choice of overcurrent factor as arguments. It returns the efficiency and voltage regulation of the transformer under that load, both in percentages.

To use the function, it can be called in the command prompt as:

```
VR(sLoad_mag,sLoad_phi,C_v,C_I)
```

Where `sLoad_mag` is the magnitude of the load (in VA), `sLoad_phi` is the phase angle of the load (in degrees), `C_v` is a two element array starting with the under-voltage coefficient and ending with with the over-voltage coefficient, and `C_I` is the over-current coefficient. Each of these coefficients works by being multiplied by the rated primary voltage or rated load current to set a threshold for warning flags.

Here is an example of using the program:

```
>> VR(60,60,C_v,C_I)
iLine:
0.2500 - 0.4330i
ans = Efficiency: 81.69 %
ans = Voltage regulation: 6.1 %
```

3.2 Code testing

Here are some examples of inputs that result in flags. Associated variables were also printed for checking.

```
>> VR(100,78,C_v,C_I)
S_load_conj:
 20.791 - 97.815i
```

```
iLine:
 0.1733 - 0.8151i
I_line:
0.8333
Over Current Flag
Vp_fl:
140.37
PF:
0.2079
ans = Efficiency: 45.52 %
ans = Voltage regulation: 17.0 %
```

```
>> VR(109,78,C_v,C_I)
sLoad too high
```

```
>> VR(60,60,C_v,C_I)
S_load_conj:
30.000 - 51.962i
iLine:
0.25000 - 0.43301i
I_line:
0.50000
Vp_fl:
127.33
PF:
0.50000
ans = Efficiency: 81.69 %
ans = Voltage regulation: 6.1 %
```

Another test we made for the program was to loop through S load magnitudes from 0 to 100 in increments of 10 and plot both the voltage regulation and line current.

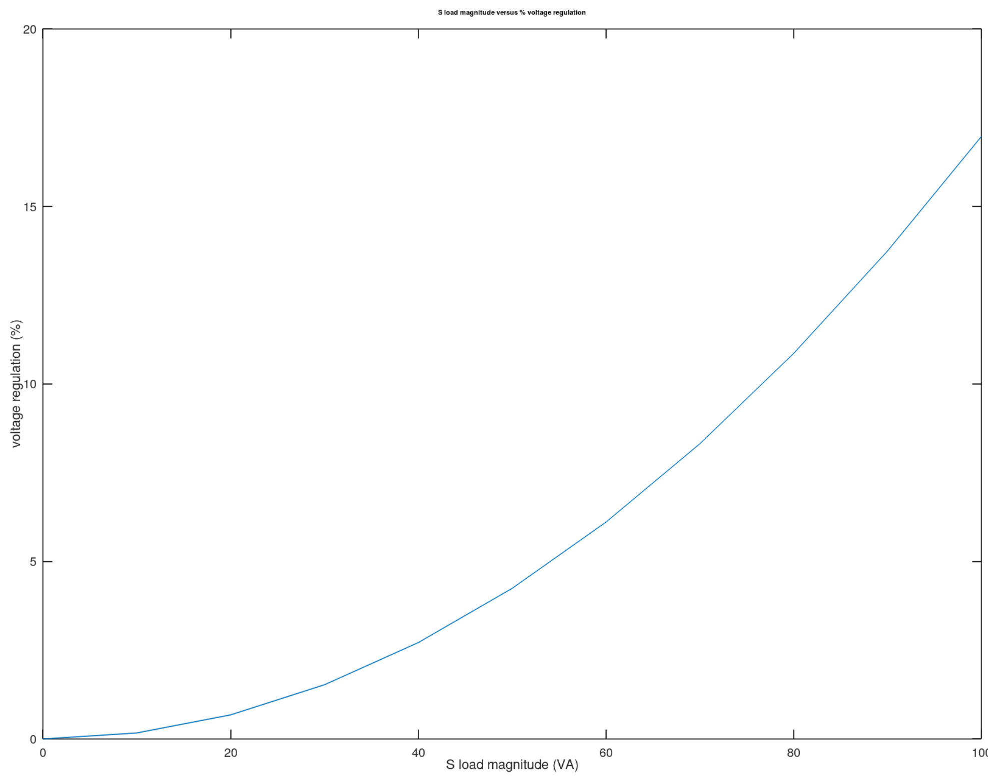

Figure 3: S load magnitude versus voltage regulation

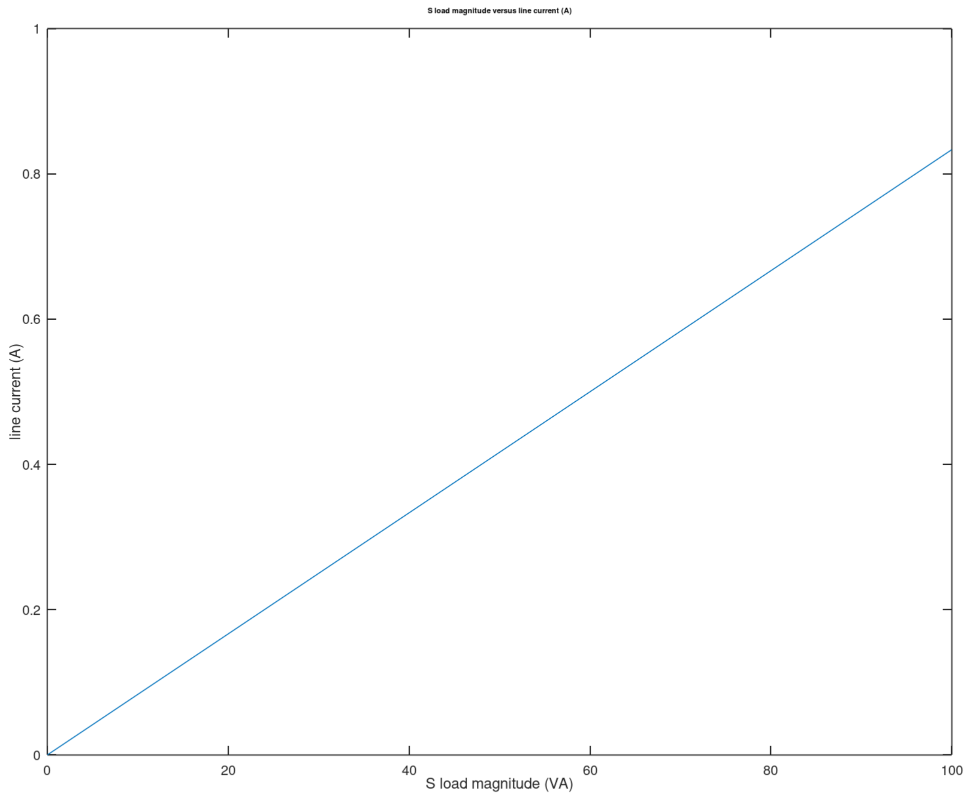

Figure 4: S load magnitude versus Line current

3.3 Full MATLAB code

```
% program takes sLoad_mag, sLoad_phi (degrees), C_v, C_I
% C_v is a 2 element array of under and over voltage coefficients
% such that C_v(1)*V_p is the threshold of undervoltage
% returns voltage regulation as a percent

% These are default values:
% Overcurrent coeff
C_I = 1.1;
% under/over voltage coeffs
C_v = [0.95, 1.2];
```

```
% Function For Checking Overcurrent
function OverCurrentCheck = OverCurrentCheck(I_line, C_I, I_rated)
   if I_line > C_I * I_rated
       disp ('Over Current Flag')
   end
end

% Function For Checking Under-Overvoltage
function UnderOverVoltageCheck = UnderOverVoltageCheck(V_p,C_v)
   if V_p <= C_v(1)*V_p
       disp('Under Voltage Flag');
   end
   if V_p >= C_v(2)*V_p
       disp ('Over Voltage Flag');
   end
end

% Function to find efficiency
function Efficiency = Efficiency(S_rated, sLoad_phi, iLine, Vp_fl)
   # resistance values found from lab testing
   Reqp = 17.24;
   Rcore = 6667;

   % find the power loss
   P_core = Vp_fl^2 / Rcore;
   P_cu = iLine^2*Reqp;
   PF = cos(deg2rad(sLoad_phi));
   disp("PF:")
   disp(PF)
   P_out = S_rated * PF;
   % calculate efficiency
```

```
   eff = P_out / (P_out + P_core + P_cu) * 100;
   sprintf('Efficiency: %.2f %%', eff)
end

% Function to return voltage regulation
% also checks for overcurrent and over/under voltage
% also reports power transfer efficiency
function VR = VR(sLoad_mag, sLoad_phi, C_v, C_I)
   S_rated = 60;
   I_rated = 0.5;
   V_s = 120;
   Reqp = 17.24;
   Xeqp = 23.73;

   % check if input sLoad_mag is within range
   if sLoad_mag > 1.8 * S_rated
       disp('sLoad too high');
   % check if input sLoad_phi is within range
   elseif sLoad_mag < 0
       disp('sLoad too low');
   elseif sLoad_phi < -90 || sLoad_phi > 90
       disp('sLoad angle out of bounds')
   % If the above are true, then perform calculations
   else
       % generate single complex S_load variable
       [sL_re,sL_im] = pol2cart(deg2rad(sLoad_phi),sLoad_mag);
       sL_conj = complex(sL_re,-sL_im);
       disp("S_load_conj:")
       disp(sL_conj)
       % find line current
       iLine = sL_conj / V_s;
```

```
        disp("iLine:")
        disp(iLine)

        % check that the line current isn't over specified threshold
        iLine_mag = abs(iLine);
        disp("I_line:")
        disp(iLine_mag)
        OverCurrentCheck(iLine_mag, C_I, I_rated)

        % find full load primary voltage
        Vp_fl = abs(iLine^2 * complex(Reqp,Xeqp)) + V_s;
        disp("Vp_fl:")
        disp(Vp_fl)

        % check that the primary voltage isn't under or over threshold
        UnderOverVoltageCheck(Vp_fl, C_v)

        % find the efficiency of power transform
        Efficiency(S_rated, sLoad_phi, iLine_mag, Vp_fl);

        % find the voltage regulation
        V_reg = abs(Vp_fl - V_s) / V_s * 100;
        sprintf('Voltage regulation: %.1f %%', V_reg)
    end

end
```

4 Conclusion

After completing this lab, we now know the basics of a single-phase transformer and how to measure the voltages and currents in both the primary and secondary side of a 1:1 transformer in both an open circuit and short circuit test. We also know how to use a MATLAB script to calculate load-regulated voltage given a complex load.

A Appendix:

A.1 Bill Of Materials

No.	Item	Vendor	Part Number	Qt.	List Price	Net Price
1	Safety Lockout Hasp	Gralnger	1U177	1	$7.98	$7.98
2	Power Supply	Labvolt	8821-20	1	$2,870.00	$2,870.00
3	Data Acquisition and Control Interface	Labvolt	9063-B0	1	$3,499.00	$3,499.00
4	EE 347 Lab Kit	EPL Portland State Uni.	N/A	1	$7.50	$7.50
5	Transformer Module, Sgl. Ph.	LabVolt	8341-00	1	$370.00	$370.00
6	Banana Plug Patch Cord (Black)	Allied Electronics	B-36-0	8	$6.59	$52.72
7	Banana Plug Patch Cord (Red)	Allied Electronics	B-36-2	10	$6.59	$65.90
8	Banana Plug Patch Cord (White)	Allied Electronics	B-36-9	6	$6.59	$39.54
Total Price						$6,912.64

A.2 Point List : 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	AC Variable 0-120/208 V Phase A
Currents terminal 4A	I2	0	0	0	1	1	1	Secondary Coil 1 120 V-AC
Currents COM	I1	0	0	1	0	1	5	Primary Coil 3 120 V-AC
Currents COM	I2	0	0	1	0	1	2	Secondary Coil 1 120 V-AC
Voltage 500V	E1	0	0	0	1	1	5	Primary Coil 3 120 V-AC
Voltage 500V	E2	0	0	0	1	1	1	Secondary Coil 1 120 V-AC
Voltage COM	E1	0	0	1	0	1	6	Primary Coil 3 120 V-AC
Voltage COM	E2	0	0	1	0	1	2	Secondary Coil 1 120 V-AC
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		

Note: For the Short Circuit Test banana plug patch cords were used from current I2 terminal 4A and current I2 COM to the Secondary Coil 1 120 V-AC.

A.3 Point List : Single Phase Transformer

LabVolt Transformer ,8341	Point Type							
Point Description	Origin Address	DO	DI	AO	AI	Pwr	Destination Address	Destination Description
Secondary 1 120 V- AC	1	0	0	1	0	1	I2 + E2	Currents terminal 4A + Voltage 500V,DAC 9063
Secondary 1 120 V- AC	2	0	0	0	1	1	I2 + E2	Currents COM + Voltage COM,DAC, 9063
Primary Coil 3 120 V- AC	5	0	0	1	1	1	E1 + I1	Output Voltage 500V + Input Currents COM,DAC 9063
Primary Coil 3 120 V- AC	6	0	0	1	1	1	N + E1	AC Variable 0-120/208V, 8821 + Voltage COM,DAC 9063
Total		0	0	3	3	4		

Note: For the Short Circuit Test banana plug patch cords were used from Secondary Coil 1 120 V-AC (origin point 1 and 2) as stated in the note from section A.2 Point List : Data Acquisition and Control Interface

A.4 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	1	0	1	I1	4A current terminal, DAC 9063
AC Variable 0-120/208 V Neutral	N	0	0	0	1	1	6	Primary Coil 3 120 V- AC, 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	2	5		

References

Authors

Nick Porter, is a BS candidate in the Electrical & Computer Engineering department at Portland State University. He has started a focus on signal processing, but maintains an interest in power transmission, especially with the growing use of automation for smart grids

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YES

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