

Efficiency of step down transformer biology essay



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This extended essay deals with the efficiency of step down transformers in relation the current drawn in the secondary coil. Transformers are one of the most widely used components in electronic devices. Due to its ability to effectively convert voltages to a desired EMF (electro motive force), I thought that analyzing the efficiency of such a device could provide valuable insights for in order to cut power losses; an issue that is becoming a growing concern with the depletion of fossil fuels.

My initial hypothesis was that a greater current drawn in the secondary coil would result in a greater efficiency. This was based on a mathematical proof. My experimentation with the step down transformer gave me results that supported my initial hypothesis, thus suggesting that the efficiency increased with an increase in current drawn. This was plotted on a graph, and a linear relationship was obtained. The data was not as precise as preferred, as there were reasonable errors with efficiency. However, this was due to the equipment used. The data that I collected was highly accurate as the R2 value of the graph obtained was 0.985.

The strong evidence in favour of the relation has led me to believe that an optimum output current can be identified for each device to minimise power loss in the device as a whole. Considering the number of electronic devices that use transformers today, it will assist in ameliorating the energy crisis. However, further research as well as inclusion of step - up transformers will provide more conclusive evidence.

Word Count: 254

Contents

Introduction:

Power Transmission

The electricity that is generated at the power stations has to be brought to our households and industries to be of any use. The power could be brought to us in two ways :

By using a low voltage and high current

By using a high voltage and low current

This is true because of the relation $P = VI$, where P is power, V is voltage and I is Current; so in order to keep the power constant as the voltage increases the current must decrease and vice versa.

If option 1 - high current and low voltage - is used, then there will be a tremendous loss in energy. As the current passes through the wires connecting the power stations and our homes, there is a heating loss which is equal to I^2R . So, greater the current, greater the loss in energy. Hence it would instead be more viable to use extremely high voltages and miniscule currents in order to transport the electricity. However, in order to avoid the heating loss, the electricity is transported at a voltage which is of the order of 106 Volts, while household appliances run on current with a voltage of about 10 -20 Volts. Thus a device is needed which can alter the voltage of the current. This is where a transformer comes in.

Transformer

Figure

Source: http://www.constructionknowledge.net/electrical/images_electrical/transformer.jpg, February 6th, 2010

A transformer consists of a soft iron core with coils of wire on either end. It works on the basic principle of electromagnetic induction. Thus when a current is passed through the primary coil, a second current is induced in the secondary coil. However, in order for there to be any induced current in the secondary coil, the voltage in the primary coil has to be continuously altering (which will result in a change in magnetic flux associated with the secondary coil). Hence, an AC current has to be used. Depending on the ratio of turns of the primary coil to the secondary coil, the transformer can be step up or step down. If the primary coil has more number of turns it is a step down transformer while if the secondary coil has more number of turns it is a step up transformer.

As with any other device, transformers are not 100% efficient. Transformers lose energy in four main ways -

Heating loss in the wires

Formation of eddy currents

Hysteresis loss in the transformer core

Back emf induced by the secondary coil

In this essay, I shall focus on efficiency of step down transformers, and how it is related to the current obtained.

Efficiency

In any device efficiency is defined as power output divided by power input. When specifically related to transformers, efficiency refers to the ratio between the power in the secondary coil and the power in the primary coil. As said before, power is measured through the formula $P = VI$, and due the losses of energy stated, the efficiency is never 100%.

Hypothesis

If the power in the Primary coil is P_p with a voltage V_p and current I_p , and the power in the secondary coil is P_s , with voltage V_s and current I_s , the efficiency, η . Since my focus is limited to the relationship of current in the secondary coil, I shall attempt to keep the power in the secondary coil constant. Thus, the by varying the current and voltage in the primary coil, I will be able to vary the the current in the secondary coil. If for different I values, the input power changes, then the efficiency too will change indicating a relationship.

My hypothesis is that the efficiency will be related to the current in the secondary coil. This is because three main modes of losses in energy in transformers are related to current. Hysteresis is proportion to the square of the current, heating losses are calculated by the formula I^2R and back emf too depends on the current in the secondary coil. Thus, variations in current will affect power loss, and hence energy. However, a linear relationship is not expected. Firstly, there are three different quantities that are being affected,

and second, each of those quantities themselves are not linearly related to current in the secondary coil.

This experiment could help in assessing the optimum current that should be drawn in order to ensure optimum efficiency. This would have major ramifications in devices which use transformers; for example, electric arc welders use extremely high currents at extremely low voltages. This results in heat loss through I^2R which would melt the metal. Hence, step-down transformers are essential components of electric arc welders. Thus, if the efficiency were to depend on the current drawn, (as I hypothesize), it would have to be taken into consideration by producers and consumers alike.

Mathematical Proof of Hypothesis

However, the problem may not be as simple as it looks. Since the current affects energy loss in three different ways, a change in it may cause the energy losses to change in different ways. Thus if one mode of loss of energy increases with increase in current, while the other two are inversely proportional, this experiment may not be able to accurately explain the separate components individually, but should be able to identify the optimum current as it takes into account the net effect of the change in current.

Interestingly, keeping the power output constant will allow me to keep the numerator of efficiency constant. If I take \hat{I}^2 to be the energy lost, then the equation becomes:

The initial ratio should be equal to 1 as the total power induced in the secondary coil plus the energy lost should be equal to the energy in the

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primary coil; this is derived from the principle of conservation of energy.

Taking this to be a $y = mx + c$ graph, one would assume that \hat{I}_\pm is the c .

However, since in this experiment, power output is kept constant, becomes the c . Hence, for the equation to be of the form $y = mx + c$, it should be modified to:

However, in order to derive a relationship between the energy loss and the input current alone (as a first step to later deriving the function between efficiency and output current), I will have to have only two variables in the equation. Since V_p is a function of current, i. e. $V_p = I_p R$ and let as it is a constant, the equation can be further simplified to:

Since, I am looking to minimize energy loss or, differentiating the equation should give a rough indication as to the trend to be expected.

Differentiating with respect to I_p

Minimizing means that should be as low as possible, ideally 0. Thus when becomes 0, becomes 0. Hence, lower the value of I_p , lesser the energy loss. What this implies is that the opposite would be true in the secondary coil - a low primary current means a high secondary current. Thus, the heat loss should be the least when the current in the secondary coil is high. However, this might be a special case, as here the power in the secondary coil is constant.

While the math does give me a basis on which to form a hypothesis, and could help explain the results if they support the hypothesis, it cannot be used directly in my data processing. The main reason for this is that the

resistance of the circuit is unknown in my experiment. Though I am influencing some portion of it through the resistance box, there is no way that I can determine the resistance of the entire circuit. Hence, I will not be able to use the equation directly in my processing. Instead, I will use a slightly approximate method that will help me identify the trend, though it would not help me quantify the resistance. I will use a graph of efficiency versus output current. Thus, based on the trend that I get, I could verify if the initial hypothesis was correct - if efficiency increases with output current, the hypothesis would be proven correct.

Design of the experiment

The biggest difficulty in the design of the experiment is maintaining the output power constant. Now, the only way that this can be achieved is through trial and error. Also, varying the input voltage to current ratio, will vary the output voltage to current ratio in the opposite way (assuming no variation due to energy losses). Thus the varying of the input V-I ratio will also assist in developing the \hat{I} versus I_s graph later on. One of the major drawbacks of this design and line of reasoning is that it is not taking eddy currents into consideration at all. Therefore I will use industrially manufactured transformers which have heavily laminated cores. This will ensure that eddy currents are reduced as much as possible. Using industrially manufactured transformers however has its own set of problems. The transformers that can be used for this experiment (as in small size, of operation specifications such as 220V-12V or 6V-220V) can hold only small currents (a maximum of 2-3 A). Hence, the range of readings I will be able to obtain will be limited to some extent. Even the industrially manufactured

transformers hardly ever have efficiencies in excess of 50%. What remains to be seen though, is how this ratio changes with a change in the current drawn.

The Circuit

The circuit has to be properly equipped to keep the power output constant. The power supply will be a dimmer stat as this will allow me to place a variety of voltages across the circuit. I will also use a load/rheostat in the secondary coil so that I can keep the power constant even with changes in efficiency - for example, if the efficiency increases with increasing current, an increase in voltage in the primary coil will result in a greater increase in power in the secondary coil than before. The resistor will help me neutralize these variations. This set up will then be connected to an ammeter, and then the primary coil of the transformer. The secondary coil will have an ammeter connected in series and a voltmeter connected in parallel.

Data Collection and Processing

The first step in the data collection is to identify the raw data table. Since the variables that I am measuring are the currents and voltages in the primary and secondary circuit, these values will be part of my raw data table. Also, integral to the design are the chosen power output and the resistance that is being applied on the secondary coil to ensure this. Hence, these two will also be an important part of the raw data table.

Thus the data table will look something like this:

I have included one example to elucidate my data collection and method of processing

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Output Power

Output Current

Output Voltage

Input Current

Input Voltage

1. 3936

8. 71

0. 160

2. 61

1. 610

The data however needs to be processed further in order to be interpreted.

I first need to calculate the input and output powers. Both are calculated the formula $P = VI$. Since, I am trying to keep the output power constant, the output power is predetermined at 1. 39 W. The input power is hence $2. 61 \times 1. 610 = 4. 2021\text{W}$. The efficiency is hence, $\eta = \frac{1. 39}{4. 2021} = 0. 3316$

This same process is repeated for every reading that I took, and hence I got my processed data table. The processed data table will consist of the output current and the efficiency with their respective uncertainties. The error propagation is described below, while the graph follows after.

Processed Data Table

Output Current in mA (I)

Uncertainty in mA $\pm \hat{I}$ I

Efficiency (\hat{I})

Uncertainty $\pm \hat{I}$ \hat{I}

7.81

0.05

0.3065

0.01720

8.71

0.05

0.3316

0.01965

4.82

0.05

0.2071

0.00962

5.09

0.05

0.1928

0.00896

4.92

0.05

0.1859

0.00854

4.90

0.05

0.1852

0.00849

7.41

0.05

0.2816

0.01529

6.23

0.05

0. 2417

0. 01220

5. 83

0. 05

0. 2224

0. 01086

8. 22

0. 05

0. 3165

0. 01825

4. 12

0. 05

0. 1714

0. 00757

3. 24

0. 05

0. 1292

0. 00555

3. 69

0. 05

0. 1562

0. 00674

4. 39

0. 05

0. 1791

0. 00803

3. 88

0. 05

0. 1422

0. 00614

Error Propagation:

Errors are a very important part of any experiment, as no process is perfect.

Since readings are not perfectly precise, the upper and lower limits of uncertainties in the values have to be defined.

I will start with the uncertainties in raw data.

Uncertainty for current output: $\pm 0.05\text{mA}$ - This is determined due to the random error involved. The systematic error was only 0.01mA (the least count of the digital multimeter), and as the random error was greater, it was discarded. The random error was quite big since there were fluctuations in readings. I took multiple repetitions for a couple of currents, and hence determined the random error. So for output current the repetitions are shown below:

Reading 1

Reading 2

Reading 3

Uncertainty

4.86

4.94

4.90

± 0.04

8.65

8.77

8.71

± 0.06

Hence average uncertainty is $(0.04 + 0.06)/2 = 0.05$

Thus the absolute uncertainty for output current was determined to be ± 0.05 mA.

The same process of taking multiple readings for each of output voltage, input current and input voltage. Interestingly, uncertainty in input current was the same as that of output current which is ± 0.05 mA, while the uncertainties in both input and output voltage were ± 0.005 V. Though it would have been more precise to take multiple readings every single time, this proved to be very difficult due to the limitations of the dimmer stat. Hence, I took multiple readings only for 2 values in each of them.

Quantity

Reading

Uncertainty

Input Current

3.120

± 0.05 mA

Output Current

4.900

± 0.05 mA

Input Voltage

2. 417

$\pm 0.003V$

Output Voltage

0. 285

$\pm 0.003V$

These errors have to be taken forward to the respective powers as well.

Since $P = VI$,

Power Input = $V_i \cdot I_i = 3.12 \cdot 2.417 = 7.5410mW$

= $\pm 0.13645mW$

Similarly,

Finally since ,

Hence and

This method of error processing is done for every reading. I have shown only one example her, but the rest are in the appendices.

Now that the processed data as well as the errors have been defined, a graph can be obtained. The graph is basically the efficiency versus the output current. This will help identify the trend and hence the implications.

Graphical Analysis

The graph is a straight line graph showing a direct relationship between efficiency and output current. Since the variables are directly proportional, the greater the output current, the greater the efficiency. The current has been taken on the x-axis as it is the independent variable while the efficiency is on the y-axis as it is the dependent variable. The error bars have been included. However there are two anomalous points - (3.88, 0.1422) and (4.82, 0.2071). A line of best fit has been incorporated with an R^2 value of 0.985 which indicates very accurate data.

Thus the data that I have collected supports the initial hypothesis that I made. While I have mathematically supported the hypothesis earlier, the physics-explanation is still left.

In order to answer this, I will look at each of the three current related sources of energy loss separately.

I will start by analysing the heating loss in the wires of the transformers. This is determined by the formula I^2R ; since the resistance can be rewritten as , the heating loss can be rewritten as . Thus, since the heating loss is directly proportional to the length of the wire, the longer the wire the greater the loss in power. As the current output is large, it implies that the current input is low, which means that the transformer is a step down transformer. Since in a step down transformer, N_s Next, we come to hysteresis loss. Hysteresis loss, according to an article by the eccentric scientist Nikola Tesla, is proportional to the square of the input current. Thus, it can be inferred that the efficiency

increases with increasing current in the secondary current as the hysteresis loss follows the opposing trend.

Last but not the least, we come to back emf. Interestingly, this source of power loss also fits the hypothesis. Back emf refers to the emf that is re-induced by the secondary coil in the primary coil. This emf, thus opposes the initial emf that is present, and in overcoming this, there is some loss of power. Thus, the greater the change in emf in the secondary coil, the greater the power loss due to back emf. As current increases in the secondary coil, the emf reduces, and hence so will the change in emf due to the alternating magnetic flux. Thus, a greater secondary current will reduce power loss due to back emf as well.

Thus we have seen the physical explanations for the data that I had collected. As I said earlier, one major problem is the complete negligence of eddy currents. That however cannot be helped given the limitations of my design.

Application of findings to real life:

The above findings have great implications on any device that uses transformers. Due to the relation that has arisen, a higher efficiency is an inherent property of any step down transformers, while consequently, step up transformers tend to have lower efficiencies. Thus producers and consumers of devices which use these transformers need to take this into consideration. Take the electric arc welder for example. This is device that works at extremely low voltages with extremely high currents. Thus, the normal 220V that is available on the mains has to be stepped down, and

hence it uses a step down transformer. Thus, the efficiency of the device would tend to be reasonably high.

Extending the same ideas to power transmission systems, the opposite effect is noticed. Due to the Joule heating effect, power is normally transmitted at high voltages and low currents. Hence when it reaches the households, the power has to be stepped down. Here though, the relative change in voltage is comparatively far lesser than in the electric arc welder. Thus the efficiency here will be a lot lesser than in the electric arc welder. Thus, this power loss has to be taken into consideration when planning out the power transmission systems. The optimum voltage to current should be determined so that the total power loss between the transformer, as well as the wire should be as less as possible. Thus, using the relation from this data as well as the Joule-heating effect, the power loss has to be minimized for the whole system and not just the loss during transmission in the wires.

Conclusion and Evaluation

Source of Error

Like any other experiment, there are errors are present here.. These were:

First, eddy currents were not taken into consideration. In order to overcome this, I used laminated cores. The problem with eddy currents is that they cannot be quantified using the data I could collect, and hence I could not calculate them. Also, it is next to impossible to nullify them completely.

However, as this was present through all readings, it becomes a part of the systematic error. As this is negligible (the x-intercept of the graph is very

close to 0), it can be concluded that eddy currents did not affect the readings by much.

The second major source of error was my crude method of keeping power output constant. Starting with the insensitive dimmer stat, I could not control the power output to more than 3 significant figures. Thus there were variations in the power output which were of the order of 10^{-3} . This too would have added to the error caused. This though would have been part of the random error, as it varied from reading to reading. However, due to the fact that multiple readings were taken, the error would have been minimized.

Another source of error is the resistance in both circuits. The resistance in both circuits was unknown. Though I did determine some portion of the resistance through the resistance box, the wires were not ideal, i. e. they too had a resistance of their own. The power loss from these wires is thus not accounted for. To be more accurate, this too should be calculated and subtracted from the total power loss to get the power lost only in the transformer.

Improvements in design:

First of all, a more sensitive dimmer stat must be used. This basically means that the least count of the dimmer stat should be 1mV so that fine tuning can be done.

Second, wires of known resistivity and length should be used. This will help make the readings more accurate as then power lost in the external circuit can be removed.

Also, I used only 1 transformer throughout my experiment. Though multiple readings were taken, random error could have been further minimised by using multiple transformers.

Scope for further research

My experiment was limited to just step down transformers. Though a relation was identified, it remains to be seen whether the relation will hold or become the opposite with step up transformers. The reason behind this is that the turns ratios of step up transformers follow an opposite trend to that of step down transformers, i. e. in step down transformers N_s Reflections

For me, this extended essay was much more than just a requirement to be fulfilled in order to complete the IB Diploma. Throughout this process I have gained valuable hands-on experience which I am sure will help me in my further studies. Apart from pushing the boundaries of my knowledge, I have also developed my research skills. Not only have I figured out how to go about a basic research project, but I have also learnt not to be disappointed in the face of setbacks. This essay was my third one, as problems arose in the first and second ones. Although I was initially disheartened, now I regard them as being equally important experiences, as I have realized that failure is part of any scientific process. In fact, it was the first couple of failures that helped me understand the subject better than I could have hoped. Personally this was a deeply enriching experience that I know will assist me for a long time to come.

Bibliography

Feynman, R. P. (2005). The Feynman Lectures on Physics, The Definitive Edition Volume 2. Addison Wesley.

Halliday, R. a. (2004). Fundamentals of Physics. Wiley.

Heathcote, M. J. (2007). The J & P Transformer Book: A Practical Technology of the Power Transformer. Newnes.

Tsokos, K. A. (2008). Physics for the IB Diploma. Cambridge: Cambridge University Press.

[http://en.wikisource.](http://en.wikisource.org/wiki/The_Losses_Due_to_Hysteresis_in_Transformers)

[org/wiki/The_Losses_Due_to_Hysteresis_in_Transformers](http://en.wikisource.org/wiki/The_Losses_Due_to_Hysteresis_in_Transformers)

<http://www.citycollegiate.com/transformers2.htm>

[http://www.constructionknowledge.](http://www.constructionknowledge.net/electrical/images_electrical/transformer.jpg)

[net/electrical/images_electrical/transformer.jpg](http://www.constructionknowledge.net/electrical/images_electrical/transformer.jpg)

http://www.copper.org/applications/electrical/energy/trans_losses.html

http://www.elkor.net/pdfs/AN0305-Current_Transformers.pdf

http://www.allaboutcircuits.com/vol_2/chpt_9/2.html

http://www.conformity.com/artman/publish/printer_47.shtml

http://www.losgatosmanufacturing.com/classes/handouts/arc_welding_unit.pdf

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Appendices

Appendix 1

My raw data is presented below

Output Current in mA (I_s)

Output Voltage in V (V_s)

Input Current in mA (I_p)

Input Voltage in V (V_p)

7.81

0.179

2.65

1.721

8.71

0.160

2.61

1.610

4.82

0.290

3.01

2. 242

5. 09

0. 273

3. 09

2. 333

4. 92

0. 283

3. 12

2. 401

4. 90

0. 285

3. 12

2. 417

7. 41

0. 188

2. 75

1. 799

6. 23

0. 223

2. 85

2. 017

5. 83

0. 239

2. 94

2. 131

8. 22

0. 169

2. 63

1. 669

4. 12

0. 338

3. 28

2. 477

3. 24

0.430

3.51

3.073

3.69

0.376

3.49

2.545

4.39

0.317

3.21

2.420

3.88

0.360

3.41

2.880

Appendix 2

The processed data without the errors is represented below:

Output power in mW (Ps)

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Input Power in mW (Pp)

Efficiency ($\hat{\cdot}$)

1. 3980

4. 5607

0. 3065

1. 3936

4. 2021

0. 3316

1. 3978

6. 7484

0. 2071

1. 3896

7. 2090

0. 1928

1. 3924

7. 4911

0. 1859

1. 3965

7. 5410

0. 1852

1. 3931

4. 9473

0. 2816

1. 3893

5. 7485

0. 2417

1. 3934

6. 2651

0. 2224

1. 3892

4. 3895

0. 3165

1. 3926

8. 1246

0. 1714

1. 3932

10. 7862

0. 1292

1. 3874

8. 8821

0. 1562

1. 3916

7. 7682

0. 1791

1. 3968

9. 8208

0. 1422

Appendix 3

This is the data with the uncertainties included.

Output Current in mA (I_s)

Uncertainty in mA ($\hat{I}'' I_s$)

Output Voltage in V (V_s)

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Uncertainty in V (\hat{V} Vs)

Output power in mW (Ps)

Uncertainty in mW (\hat{P} Ps)

7.81

0.05

0.179

0.005

1.3980

0.0480

8.71

0.05

0.160

0.005

1.3936

0.0516

4.82

0.05

0.290

0.005

1.3978

0.0386

5.09

0.05

0.273

0.005

1.3896

0.0391

4.92

0.05

0.283

0.005

1.3924

0.0388

4.90

0.05

0.285

0.005

1.3965

0.0388

7.41

0.05

0.188

0.005

1.3931

0.0465

6.23

0.05

0.223

0.005

1.3893

0.0423

5. 83

0. 05

0. 239

0. 005

1. 3934

0. 0411

8. 22

0. 05

0. 169

0. 005

1. 3892

0. 0496

4. 12

0. 05

0. 338

0. 005

1. 3926

0.0375

3.24

0.05

0.430

0.005

1.3932

0.0377

3.69

0.05

0.376

0.005

1.3874

0.0373

4.39

0.05

0.317

0.005

1. 3916

0. 0378

3. 88

0. 05

0. 360

0. 005

1. 3968

0. 0374

Input Current in mA (I_s)

Uncertainty in mA (\hat{I} I_s)

Input Voltage in V (V_s)

Uncertainty in V (\hat{I} V_s)

Input Power in mW (P_s)

Uncertainty in mW (\hat{I} P_s)

2. 65

0. 05

1. 721

0.005

4.5607

0.09930

2.61

0.05

1.610

0.005

4.2021

0.09355

3.01

0.05

2.242

0.005

6.7484

0.12715

3.09

0.05

2. 333

0. 005

7. 2090

0. 13210

3. 12

0. 05

2. 401

0. 005

7. 4911

0. 13565

3. 12

0. 05

2. 417

0. 005

7. 5410

0. 13645

2. 75

0.05

1.799

0.005

4.9473

0.10370

2.85

0.05

2.017

0.005

5.7485

0.11510

2.94

0.05

2.131

0.005

6.2651

0.12125

2. 63

0. 05

1. 669

0. 005

4. 3895

0. 09660

3. 28

0. 05

2. 477

0. 005

8. 1246

0. 14025

3. 51

0. 05

3. 073

0. 005

10. 7862

0. 17120

3. 49

0. 05

2. 545

0. 005

8. 8821

0. 14470

3. 21

0. 05

2. 420

0. 005

7