Revisiting the Rectifier: A More Efficient Approach to Modern Electricity Supply

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Background

Rectification is the process in which electricity is converted from alternating current (AC) to direct current (DC). Electricity is supplied as AC to minimise power losses incurred in transmission. These losses can be modelled using **Joule's Law**:

$$P = I^2 * R$$

This equation states that the power loss is equivalent to the square of the current times the resistance. Thus, minimising the current therefore results in less power losses. Using AC power results in a large voltage across transmission lines, but allows for minimal current.

The rectification process is vital in powering household electronics, as these appliances require a steady supply of power achieved through DC.

Introduction to Rectification

All electronic components contain rectification circuits which allow for this steady supply of power. These circuits contain diodes, capacitors and resistors which allow for the conversion of AC to DC. This usually takes the form of a **bridge rectifier** which can be seen in the image below:

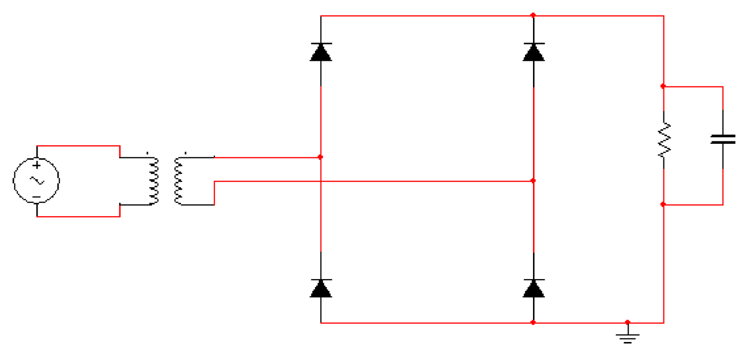

Fig. 1: Bridge Rectifier

The use of diodes allows for the electricity to flow in **one direction**. Thus the two pairs of diodes allows for the handling of the positive and negative cycles of the electrical power.

Research Statement

My research was concerned with designing a more efficient rectifier. Currently, only **81.2%** of the supplied AC is converted to DC. This wasted power is mostly lost in the form of the voltage having to overcome diode threshold voltages, of which the value is typically 0.6V [1]. This loss in power unfortunately means that households are paying for wasted energy.

Methodology

In order to investigate if a higher efficiency could be obtained, multiple design iterations were performed. These were originally designed on paper and were then implemented in simulation software such as Multisim to validate the design. Components were tested in the lab to simulate real-world operation. A total of **12 designs were iterated through** until a more efficient rectifier was yielded.

In conducting research, I was able to utilise MOSFETs in the rectification circuit. Ordinarily, these devices are active, meaning they require an external power source to use. Moreover, MOSFETs are rarely utilised in AC circuits as they mostly function as amplifiers or switches under DC. However, I was able to bias the circuit in order to use these devices **without the need for an external source**. MOSFETs are preferable due to being **voltage controlled** and that they possess a lower threshold voltage than a diode on average - meaning that there are less losses associated with threshold voltage.

Circuit Description

A significant discovery was the use of the substrate terminal. This terminal is composed of a different material to the other terminals, thereby possessing different properties to the drain and source gates of a MOSFET, which are conventionally used for conduction. Hence, the *threshold voltage is significantly lower* which hence influences how the power is conducted. **This threshold voltage has been discovered to be slightly below 0.29V**.

As the circuit conducts AC power, two MOSFETs are utilised to account for the negative phase of the power. The two MOSFET body terminal outputs are then connected to create a common signal, which is ultimately converted to a DC signal via the RC circuit.

The voltage is reduced through the utilisation of a step-down transformer to allow for the safe operation of the MOSFETs, as too high a voltage would cause these devices to malfunction, and was transformed in such a way as to ensure the maximum amount of power at the output. This transformer is *centre-tapped* to ensure that the waves are shifted by 180 degrees to account for both positive and negative half cycles.

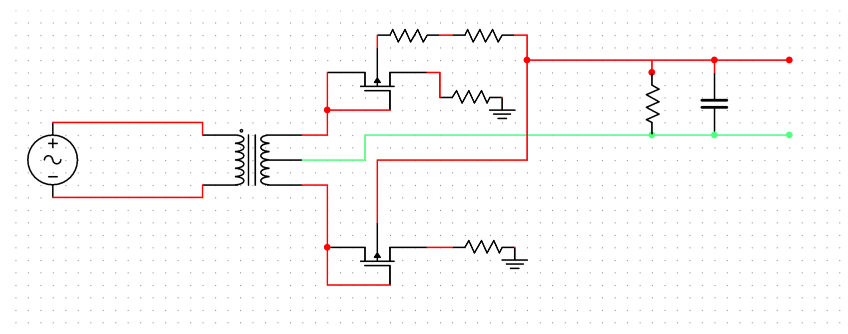

Fig. 2: Implementation of MOSFET Controlled Rectifier

Results

Conducting analysis using Multisim, **the maximum efficiency of my circuit can theoretically reach a value of 93%** - a significant increase over the current best efficiency of 81.2%. This value is obtained by comparing the output power (available at the load resistor) to the input power. My implementation of this rectifier is also **much less power hungry compared to the bridge rectifier, showing a 63%** decrease in input power. The image below demonstrates the reduction in power consumption:

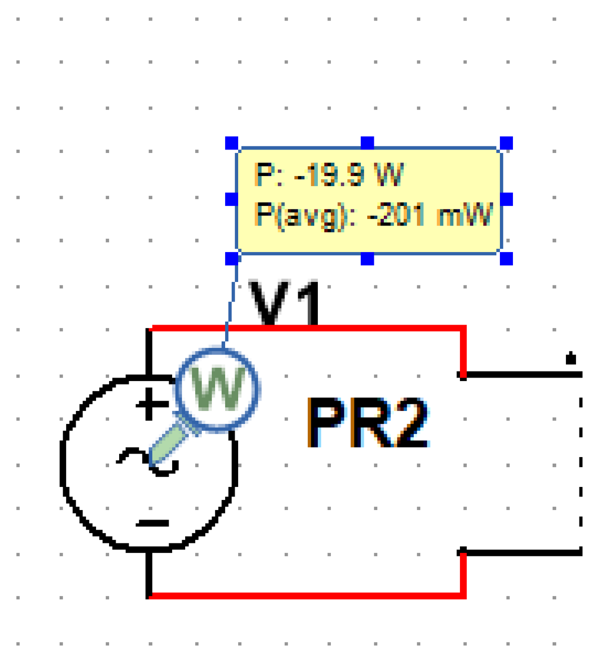

Fig. 3: Bridge rectifier power draw

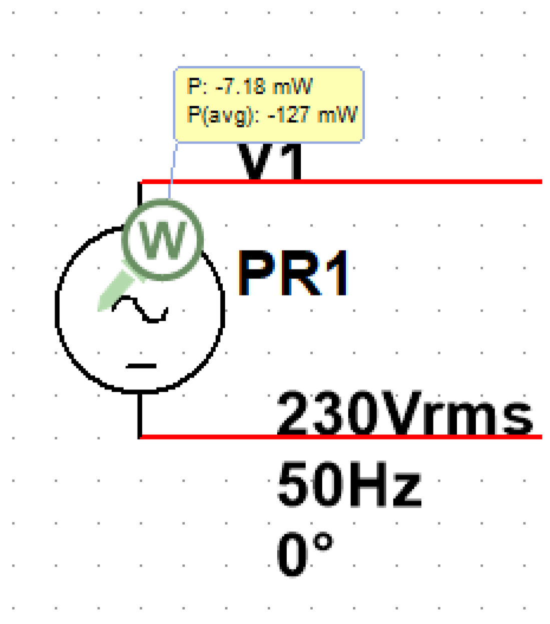

Fig. 4: MOSFET controlled rectifier power draw

The heightened efficiency translates to large financial saving. An increase of just 1% allows the area of North Dublin to save a collective sum of **€998,701 - €1,557,629 per annum** [3] (dependent on electricity supplier).

References

[1] Bharathwaj Muthuswamy. "Diodes: Experiment Guide". In: *EECS 100 Spring 2004, Berkeley* (2004).

[2] Mitu Raj. "MOSFET symbol - direction of source terminal". In: *electronics.stackexchange.com* (2021).

[3] Switcher.ie. "What is the Average Gas and Electricity Bill in Ireland". In: (2022).

Additional Findings

In carrying out tests, it was found that the MOSFET can be biased in such a way to conduct two identical signals in opposite phases while conducting AC power. This was the initial approach to create a more efficient rectifier as it would mean that a rectification circuit could be constructed with only one MOSFET. However, this proved to be extremely inefficient, as an efficiency was yielded of around 20% due to the drain terminal being used.

This discovery could prove to be useful in the driving of two separate circuits with one device. The circuit can be seen below:

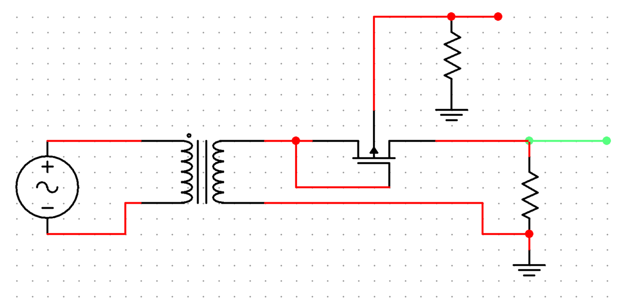

Fig. 5: MOSFET dual-circuit biasing

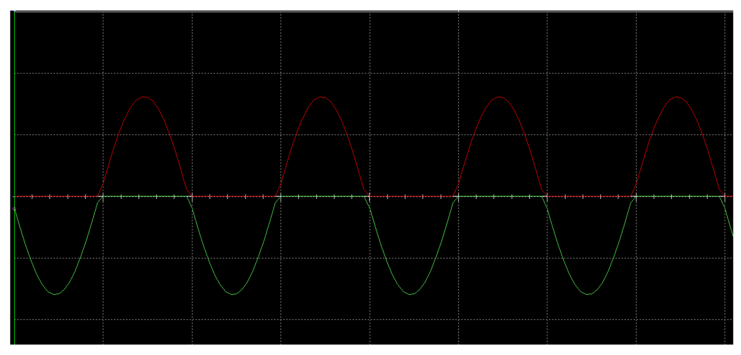

Fig. 6: Generated waveform of dual-biased MOSFET

Remarks

The advent of a more efficient rectifier will positively impact all households, especially with the **growing energy costs**.

The implementation of this more efficient rectifier is largely theoretical. This is mainly due to difficulties associated with finding a MOSFET with 4 terminals, as convention has the substrate terminal connected to the most negative / positive terminal, as shown below:

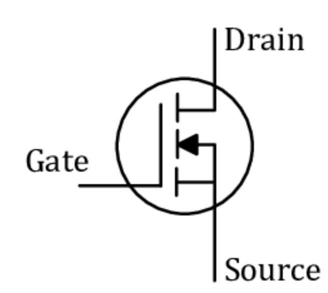

Fig. 7: Illustration of a conventional MOSFET. [2]

Preliminary testing was carried out in the lab to test if the substrate terminal can conduct AC power which is possible.

Acknowledgements

I would like to thank the Electrical and Electronic Department, specficially my supervisor, Dr. Declan O'Loughlin for his supervision and giving me direction in the project, Dr. Justin King for his guidance and expertise, Eugene O'Rourke for his help with equipment, and the Laidlaw Foundation for giving me the opportunity to conduct this research.