Generation of Ripple Voltage by a Capacitance Filter in a Full Wave Bridge Rectifier

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Abstract: ***Efficiency stands as a key factor in the development of all systems across the world. In such a scenario, ripple voltage as a component of the RC or rectification circuit is often not taken into consideration, causing a gap in our understanding of the efficiency of such circuits. By analysing the effects of different values of capacitance on the ripple voltage, the optimally modelled relation between the two can be generated, allowing for the creation of much more efficient circuits and electric components.***

Keywords: Efficiency, Ripple Voltage, Rectification

1. Introduction

Full Wave bridge rectification stands as a means of converting AC output to DC output effectively to allow for sustainable and convenient powering of electrical equipment that are used daily such as phones, laptops etc. In this age of technology, delivering efficient and quick sources of electricity has become a key area of research. This paper aims to explore this efficiency and explores how AC output can be converted to DC output with the least loss of energy and evaluate the loss of energy that takes place. To do so, the aim of the research is to investigate the ripple voltage produced by a capacitance filter in a full wave bridge rectification circuit. A capacitance filter has been chosen since it is the most widely used filter due its mass availability and affordability. To e

2. Theory/ Literature Survey

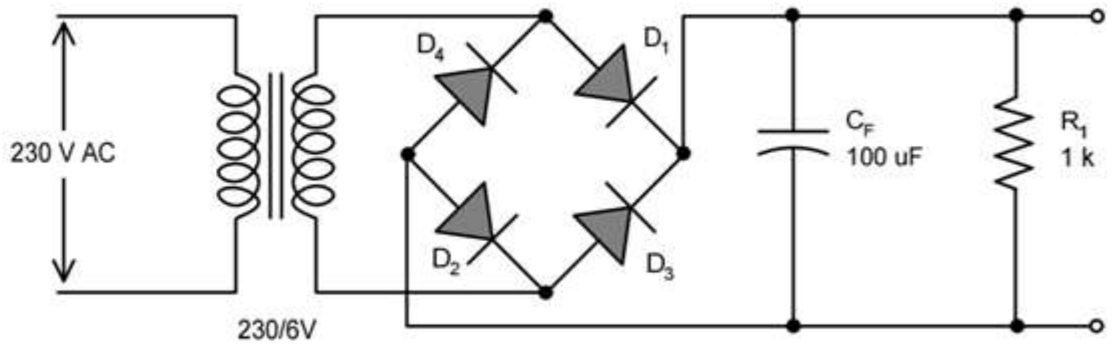

Figure 1

As stated by JF Scoville in the *Study of Capacitors for static inverters and converters, 1964* the diode rectifier is an electrical instrument which is used to convert alternating current into direct current, which is constant and uni-directional. Traditional full wave diode bridge rectifiers comprise of four diodes arranged in a square arrangement such that current flowing in any direction would go through the load in the internal circuit in a constant direction. Nonetheless, the DC voltage produced would see a periodic change in its value due to the periodic change in the AC input, visually observed as that of a sin curve. Consequently, it is essential to utilise a capacitance input filter along with the diode bridge rectifier circuit to stabilise the output voltage. The charging of the capacitor and the discharge of the capacitor across the load in the increasing voltage phase and decreasing voltage phase respectively would result in the difference in the maximum and minimum output voltage to become minimal, thus effectively stabilising the output to pure dc voltage and increasing the efficiency of the circuit and AC to DC conversion. This phenomenon is also known as the "smoothening of an alternating voltage input".

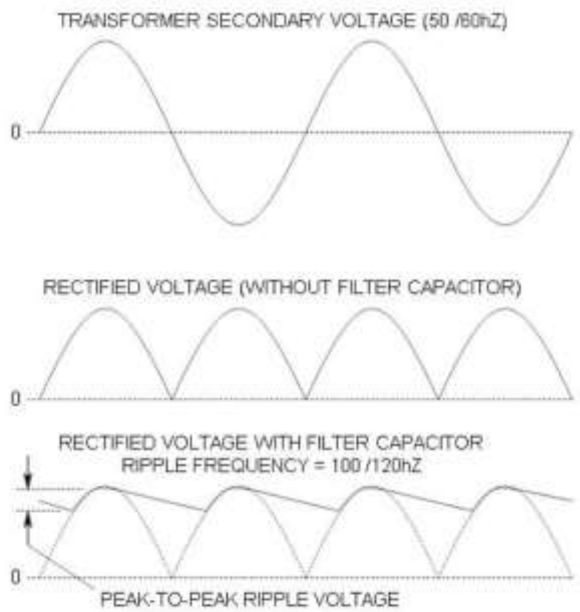

Figure 2

As derived by A Berizzi, A Silvestri et al in the *Short Circuit Current calculations for DC systems 1996*, to approximately calculate the difference between minimum and maximum output voltage or the peak-to-peak ripple voltage the following formula is used:

$$V_p = \frac{I}{fC} \quad (1)$$

$$Assuming\ \frac{I}{f} \ll RC$$

The Derivation of the formula is as follows:

$$V_{\max} = V_{peak} - V_{diode}$$

$$V_{min} = V_{max} \times e^{\frac{-T}{RC}}$$

$$V_{ripple} = V_{Max} - V_{min}$$

$$V_{ripple} = V_{Max} - (V_{max} \times e^{\frac{-T}{RC}})$$

Wherein:

Table 1

V_p	Peak to Peak Ripple Voltage
I	DC Load Current
C	Peak to Peak Ripple Frequency
f	Capacitance
T	Peak to Peak Ripple Time Period
R	Load Resistance

To further understand the working of a full wave bridge rectifier with a capacitance filter, there can be a reference made to the work of MA Andrade, F Burgio et al who came up with two distinct images for the same in their paper *Partial discharge behaviour under single phase half and full bridge rectifiers*. The circuit diagram is the typical square shaped diode bridge with a capacitance filter. The curve below shows the difference created using a capacitance filter. The filter allows for the smoothening of the ripple, thus maintaining a stable DC output.

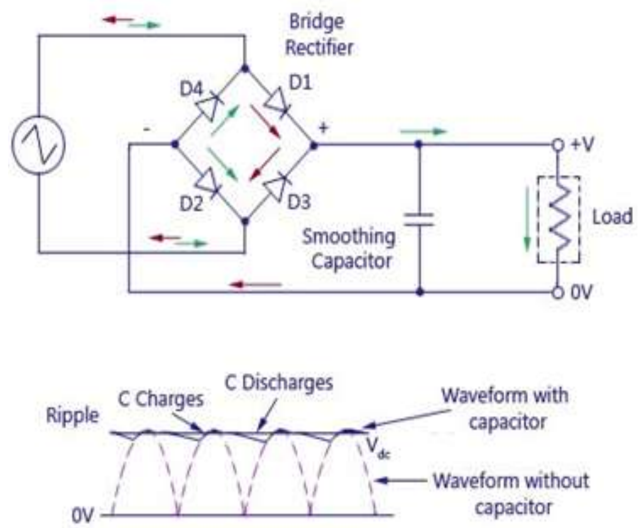

Figure 3

3. Methodology

To explore the peak-to-peakripple voltage, a simulation onPartsim Online Live Simulator (https://www.partsim.com/) a popular site for creating circuit simulations used by educationists worldwide. Initially, an alternating voltage input was added in the circuit with a frequency of 60 Hz and a peak voltage of 2V. To make the output voltage uni-directional, a diode bridge rectifier was added. This uni-directional output voltage was passed through a load of 1 kΩ. Post this a variable capacitor was added whose values in µF were adjusted in accordance with the requirements of the experiment. Additionally, two voltmeters were added in the circuit to determine the output and input voltage separately. The simulation circuit was then ready, and was run for different values of capacitance to determine various graphs of voltage vs time as seen in Figures 4 and 5.

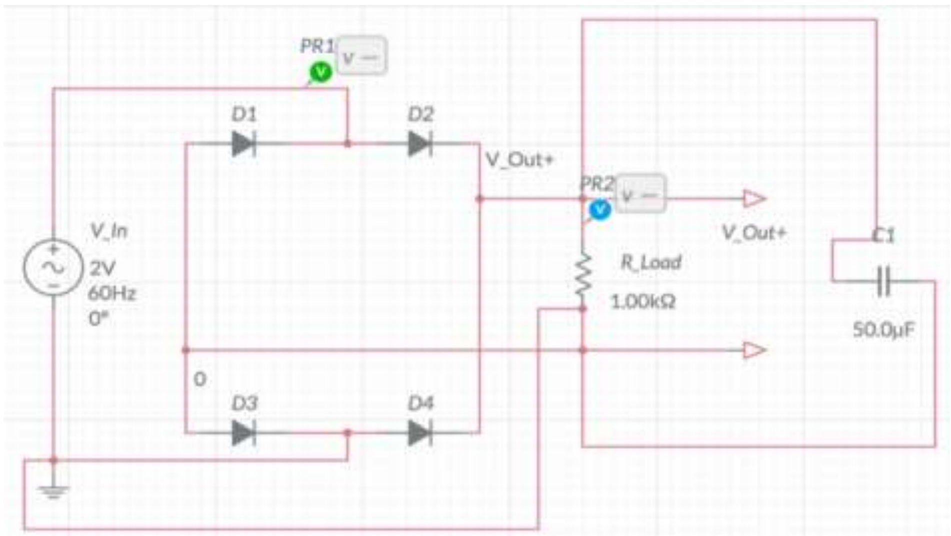

Figure 4

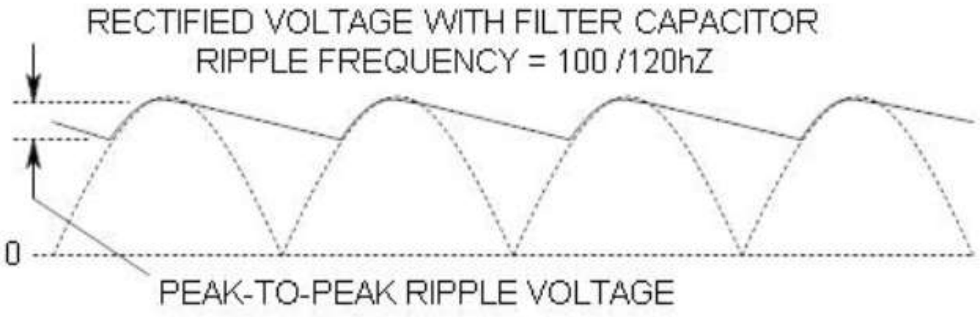

Figure 5

The ripple values were then calculated using the formula given in the Theory/Literature Survey Section. The use of data from the simulation was coupled with the creation and usage of a theoretical model based on the derivation given earlier. This formed as a means to compare and contrast the results derived theoretically and from the simulation, thus gaining a deeper insight into where lies a lack of efficiency in the capacitance filter model. MS Excel was used for the processing of data into tables and graphs for easier and visual comparison and tabulation. Since all values were the same for the theoretical and simulation mode, regardless of the number of trials, they were omitted from the data processing.

Therefore, the experiment used the following variables and control groups:

Table 2

S. No	Variable Name	Variable Type	Variable Unit	Variable Value
1	Peak to Peak Ripple Voltage (V_R)	Dependent	V	Refer to Table 1
2	Peak Input Alternating Current (V_P)	Controlled	V	2 V
3	Load Resistance (R)	Controlled	Ω	1 kΩ
4	Input Voltage Frequency	Controlled	Hz	60 Hz
5	Capacitance (C)	Independent	μF	Refer to Table 1
6	Voltage Drop Across Diode Bridge (V_D)	Dependent	V	Refer to Table 4

Using the simulation a experimental and theoretical model the data was processed.

Theoretical Model

The theoretical model was devised using the formula $V_R = V_P - V_D$ wherein the average value of V_D was found to be 0.687 V and thus the value of V_R was calculated as 1.313 V. The output frequency was calculated as 120 Hz (60 × 2) and the DC current across load was calculated as 0.001313 A. Therefore, the Ripple Voltage was calculated using the relations defined in Section 2.

Experimental Model

The experimental model was devised by using data from the simulation. Although numerous trials were carried out, the simulation returned the same results.

4. Results

Table 3

	Simulation Data				Theoretical Data
S No	Capacitance Value	Maximum Voltage Output	Minimum Voltage Output	Voltage Ripple	Voltage Ripple
1	20	1.3283	0.6691	0.6592	0.5469
2	30	1.3257	0.8338	0.4919	0.3646
3	40	1.3232	0.9416	0.3816	0.2735
4	50	1.3193	0.989	0.3303	0.2188
5	60	1.3165	1.0365	0.28	0.1823
6	70	1.3154	1.0718	0.2436	0.1563
7	80	1.3123	1.1104	0.2019	0.1367
8	90	1.3097	1.1217	0.188	0.1215
9	100	1.3074	1.1337	0.1737	0.1094
10	110	1.3047	1.1447	0.16	0.0994
11	120	1.3034	1.1556	0.1478	0.0912
12	130	1.3018	1.1648	0.137	0.0841
13	140	1.3001	1.1727	0.1274	0.0781
14	150	1.2988	1.1799	0.1189	0.0729
15	160	1.2971	1.1857	0.1114	0.0684

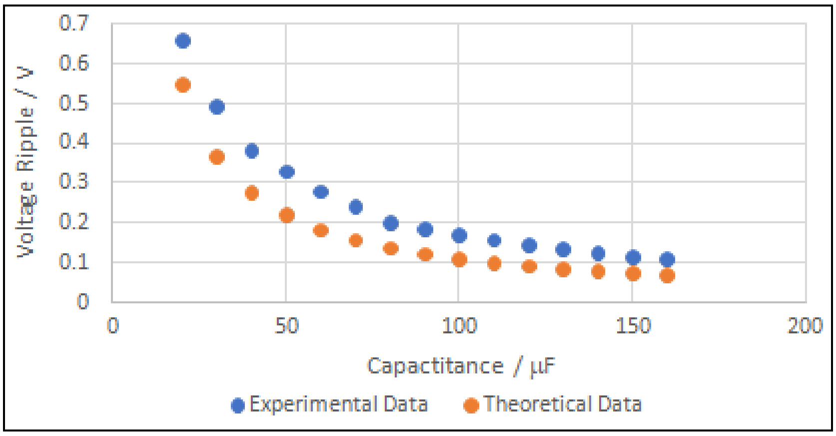

Figure 6

The theoretical model was found to resemble the shape of the simulation data, however, a vertical shift in the two sets of data was observed at each capacitance value. This shows that rel. (1) could only roughly approximate the ripple voltage produced in the full wave bridge rectifier circuit, indicating some kind of systematic error.

To further process the data obtained in the investigation, Ripple Voltage was plotted against 1/Capacitance or Capacitance-1 (see Figure 6). This was done in order to linearize the obtained data as predicted by rel. (1) in the theoretical model.

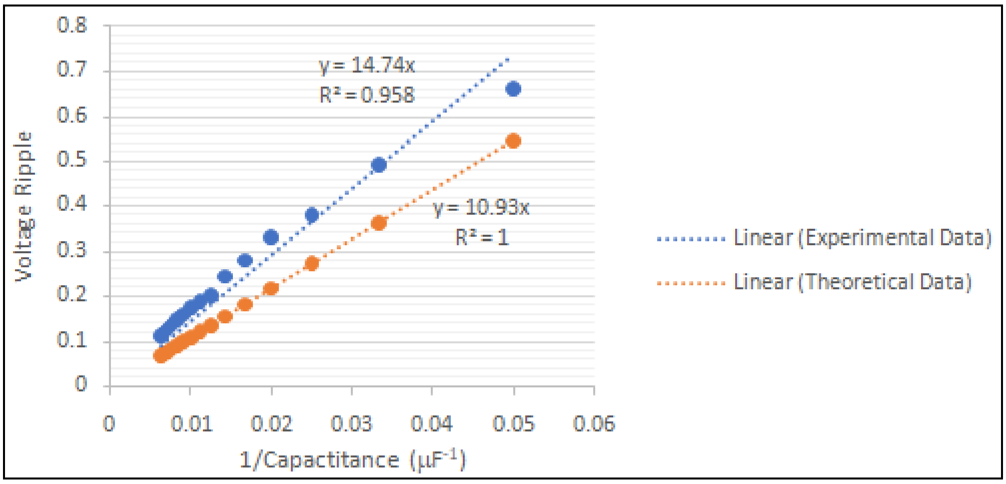

Figure 7

The simulation data was found to have an almost perfectly linear fit with an R2 value of 0.9887. The slope of this linear plot was noted to be numerically equal to 14.74. Through rel. (1), we know that the slope of this graph should, theoretically, be equal to: $Slope = I/f$ Therefore, by substituting the corresponding values of the known constants, the slope was theoretically predicted to be numerically equal to 10.94, which was found to be outside the range of uncertainty of the obtained slope, 14.74 with an uncertainty of ±1.64.

Hence, it is shown that the theoretically predicted slope, i.e. 10.94, is less than the minimum possible value of the obtained slope, 14.74 ± 1.64, taking into account its corresponding range of uncertainty. [The percentage difference between the slope of the theoretically predicted and simulation data was calculated to be equal to 25.78%]. This proves that rel. (1) is just an approximate formula since it assumes T<< RC, which is why it does not provide accurate results for the small values of capacitance and large ripple voltage values obtained in the simulation.

This fact, at first glance, seems to be further reinforced by the decrease in the absolute difference between the simulated and theoretically predicted ripple voltage values with the increase in capacitance. (see Table 3) However, it must be noted that the relative percentage difference between the two data sets, on the other hand, increases with increase in capacitance (see Table 3). Therefore, no definite conclusion can be derived out of this approach.

Table 4

S No	Capacitance Value	Absolute Difference between Theoretical and Simulation Ripple Voltage Values / V	Percentage Difference between Theoretical and Simulation Ripple Voltage Values / %
1	20	0.1123	20.5
2	30	0.1273	34.9
3	40	0.1081	39.5
4	50	0.1115	49.7
5	60	0.0977	53.6
6	70	0.0873	55.9
7	80	0.0652	47.7
8	90	0.0665	54.7

9	100	0.0643	58.8
10	110	0.0606	60.9
11	120	0.0566	62.1
12	130	0.0529	62.8
13	140	0.0493	63.1
14	150	0.046	63.1
15	160	0.043	63

Despite this anomaly, on observing Figures 5 and 6 wherein the two data sets approach closer to each other for low capacitance-1 or high capacitance values, we can assume that rel. (1) is more accurate for high capacitance / low ripple voltage values. This agreement between the theoretical model and the simulation data for high capacitance values is also due to the T<< RC approximation used in rel. (1), which only holds true for large time constant values resulting from high capacitance.

Therefore, in order to search for a solution to this problem, I attempted to calculate the ripple voltage by assuming the voltage drop across the diodes to be zero (or negligible). For these calculations, rel. (2) takes the form:

$$V_{Ripple} = V_{Peak}\,(1 - e^{-T/RC}) \qquad (2)$$

The theoretical data calculated from rel. (2) was tabulated and, in concord with initial data processing and analysis, this predicted ripple voltage was plotted against the inverse of capacitance and compared with the graph for the simulation data. An extraordinary result obtained was that this theoretically predicted ripple voltage, which was computed by assuming a negligible voltage drop across the diode bridge, best matched the simulation data. This can be seen in Figure below, where the two trendlines are observed to roughly overlap each other i.e. the simulation data and the theoretical prediction are almost in agreement with each other

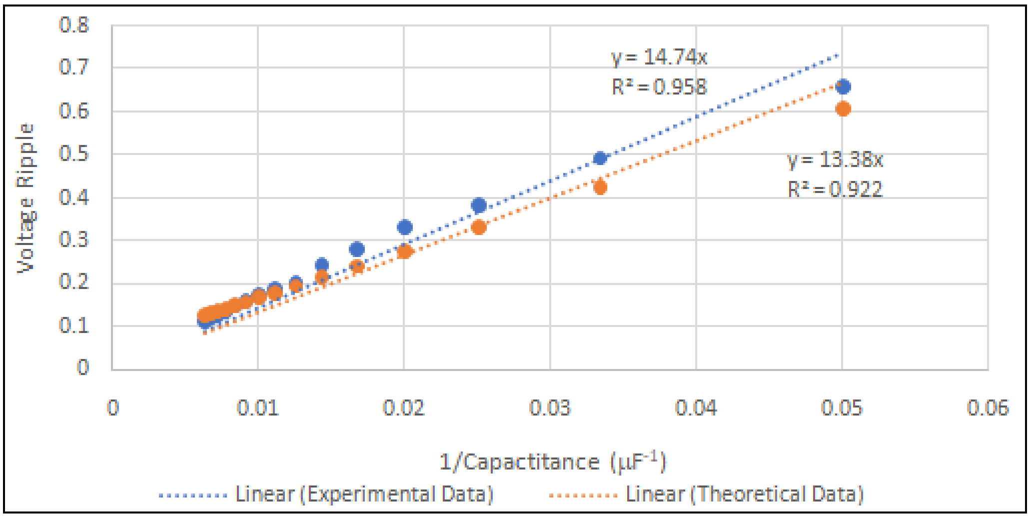

Figure 8

Moreover, the slope of the theoretical prediction in Figure 9 was computed to be equal to 13.38, which interestingly lies within the range of uncertainty of the slope of the simulation data (14.74 ± 1.64). This proves that the simulation, while considering a voltage drop across the diode bridge, disregards this voltage drop while calculating the voltage discharged across the capacitor, which gives the ripple voltage. This is, thereby, noted as a drawback of using the Partsim Online Simulation to collect data for a full wave bridge rectifier circuit. Another drawback of using the simulation is that absolute uncertainties associated with each piece of equipment are unknown and cannot possibly be incorporated into any calculations

5. Conclusion

Through the course of the investigation the original hypothesis that ripple voltage is inversely related to capacitance and produces a rectangular hyperbolic curve in a cartesian plot has been confirmed. Furthermore, the data obtained from the simulation further confirmed this hypothesis by giving an approximately perfect linear fit as shown in Figure 6. However, the differing theoretical relations used in the investigation with their associated assumptions limited the accuracy of the theoretical model, in turn, proving the systematic inaccuracy of the data generated by the full wave bridge rectifier circuit designed in my Partsim Online Simulation. Therefore, it can be concluded that though the simulation incorporates a voltage drop across the diode bridge, it fails to account for this voltage drop while calculating the voltage discharged by the capacitor and, subsequently, the ripple voltage produced in the circuit. Nevertheless, the inverse relationship still stands and the model created in Figure 8 can be used to create and derive optimally allocative circuits and electric components.

6. Future Scope

A major inference drawn from the simulation data in this investigation is that the voltage dropped across the diode bridge increases with increase in the value of capacitance used in the full wave bridge rectifier circuit. Hence, to explain this phenomenon, make further improvements to the method of experimentation, and provide valuable inputs to this investigation will be necessary. It will be crucial to carry out this investigation practically in a laboratory under fixed conditions, instead of using a simulation.

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Furthermore, using a similar circuit design, a real-life full wave bridge rectifier circuit can be designed with appropriate equipment, such as an AC Power Source, a Variable Capacitor with appropriate specifications, Connecting Wires, a Load Resistance, and a Cathode Ray Oscilloscope. This would produce additional set of data values for ripple voltage against capacitance, which can subsequently be plotted and compared with the simulation data and the theoretical models to confirm the conclusion drawn from the investigation, which claims a systematic error in the simulation.

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Author Profile

Varyam is currently in Grade 12th, pursuing the IBDP curriculum at The Doon School, Dehradun. He possesses great aptitude and experience in the field of engineering, economics, finance, and amthematics. He is currently heading various student-led initiatives including Project Pustak, PlanetBag, and Bhavishy Foundation to name a few. He is currently pursuing Mathematics AA, Physics, and Economics at a Higher Level in IBDP. Varyam is a vivid reader and has a penchant for writing. He furthers this hobby by writing for his own blog as well as being part of the editorial board of numerous publications in school. He engages in public speaking by participating and winning awards in various MUNs, and is also an all-rounded sports enthusiast.