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Design and analysis of electrical filters operating at normal voltage and frequency

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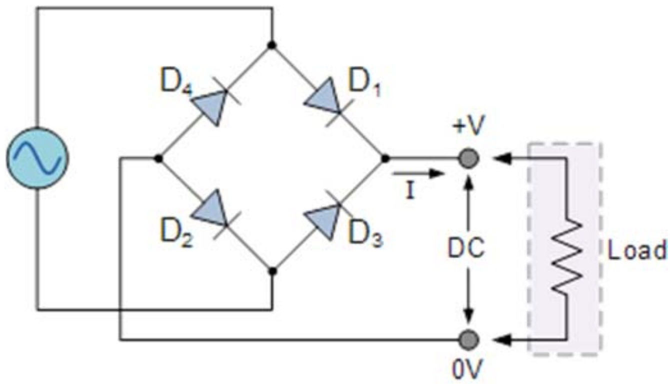
Abstract
Rectifiers are used to convert A.C to D.C. These days rectifiers made of semiconductor diodes are very common. These along with filters are used in low voltage D.C supplies (4.5V, 6V, 12V etc.) But these may also be used to get high voltage D.C output e.g.:-250V. For this full wave bridge rectifier using 4 diodes may be used. Here the filter design becomes complicated because electrolyte capacitors having high capacitances of 2200 µF, 4700 µF etc. have small voltage ratings e.g. 50V. Π filters making use of capacitors and inductors are used to achieve filtration and smooth output. But in this case to the regulation becomes poor for large currents. This research paper discusses and analyzes the characteristics of D.C circuits at high voltage and high loads corresponding to smoothing achieved using π filters (CLC & CRC). A special circuit combining the characteristics of both CRC and CLC was designed and its characteristics have been described. It was found that this filter had higher output voltage for a given load current.

Keywords: Rectifier; Filter; CLC; CRC; Ripple.

1. Introduction

Rectifiers are used to make DC out of AC. Usually equipments such as TV sets or computers, which operate on DC, yet they obtain their power from the AC socket, which is commonly found in buildings use semiconductor rectifiers. A type of circuit that produces D.C output is a ***full Wave Bridge Rectifier***. This type of *single phase rectifier uses four individual rectifying diodes* connected in a closed loop "bridge" configuration to produce the desired output. The circuit of bridge wave rectifier is given below:-



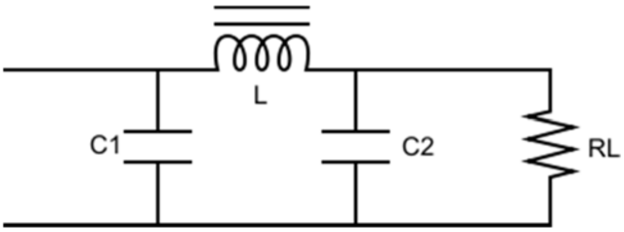
A brief discussion of the working is necessary. During the positive half cycle of the supply, diodes D_1 and D_2 conduct in series while diodes D_3 and D_4 are reverse biased and the current flows through the load. During the negative half cycle of the supply, diodes D_3 and D_4 conduct in series, but diodes D_1 and D_2 switch "OFF" as they are now reverse biased. The current flowing through the load is the same direction as before.

But the output contains considerable *ripple* and hence is not much useful without filtration. The most common meaning of *ripple* in electrical science is the small unwanted residual periodic variation of the direct current (dc) output of a power supply which has been derived from an alternating current (ac) source. This ripple is due to *incomplete suppression of the alternating waveform* within the power supply.

To achieve filtration we generally use the following filters:—

- Capacitor filter
- Inductor filter
- Π filter (consisting of inductors and capacitors)

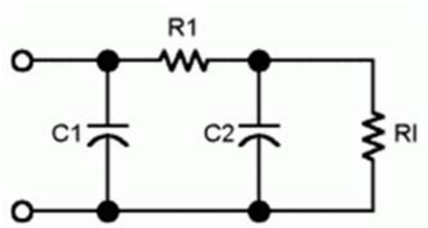
Of these the characteristics of π filter have been dealt with in this paper. A brief description of pi filter has been given.



It works in the following steps:—

A. The capacitor C_1 offers low reactance to the AC component of the rectifier output while it offers infinite resistance to the DC component. As a result the capacitor shunts an appreciable amount of the AC component while the DC component continues its journey to the inductor L.
B. The inductor L offers high reactance to the AC component but it offers almost zero resistance to the DC component. As a result the DC component flows through the inductor while the AC component is blocked.
C. The capacitor C_2 bypasses the AC component which the inductor had failed to block. As a result only the DC component appears across the load R_L.

Another type of filter can be constructed by replacing inductor 'L' by a suitable resistor 'R'. It looks like:—



C_1 works in the same way as a CLC filter. The resistance R_1 is kept higher than X_2, most of the ripple voltage drops across R_1.Any remaining ripple voltage is shunted by X_2 to ground.

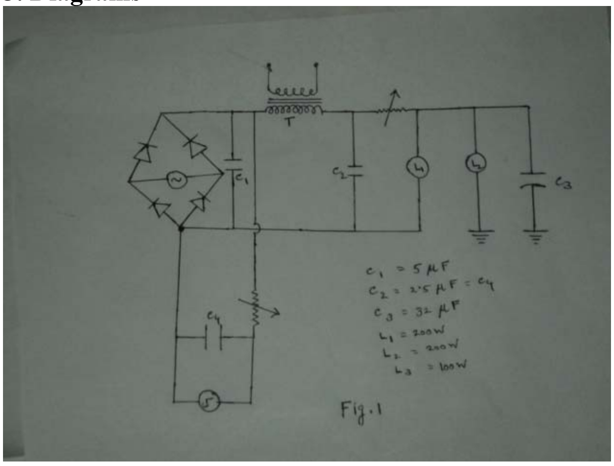
Both the above filters are used for low current devices.

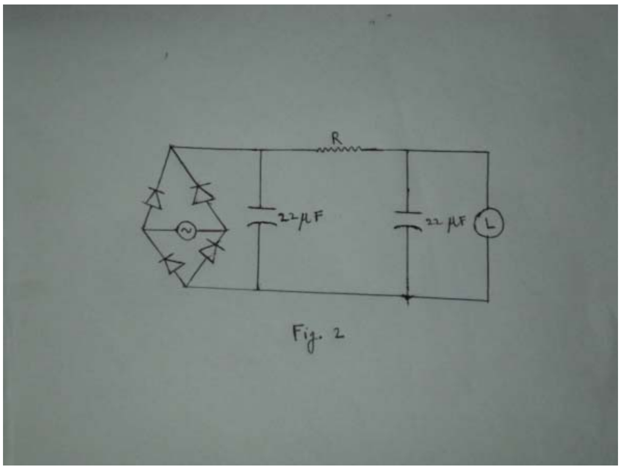
The characteristics of the above filters (CLC and CRC) under varying load condition were studied and the results were analyzed.

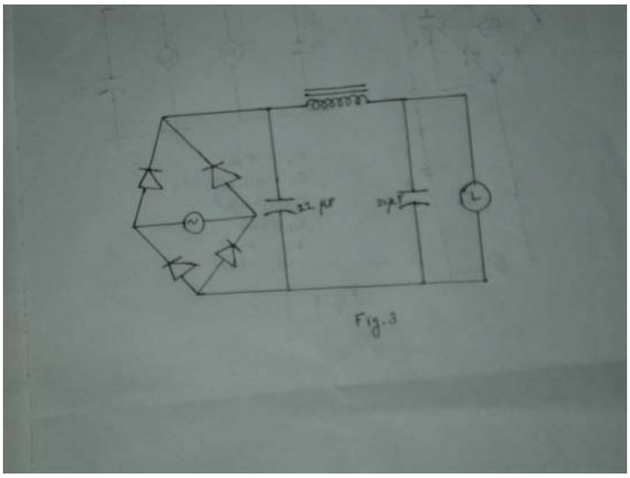
2. Materials and specifications

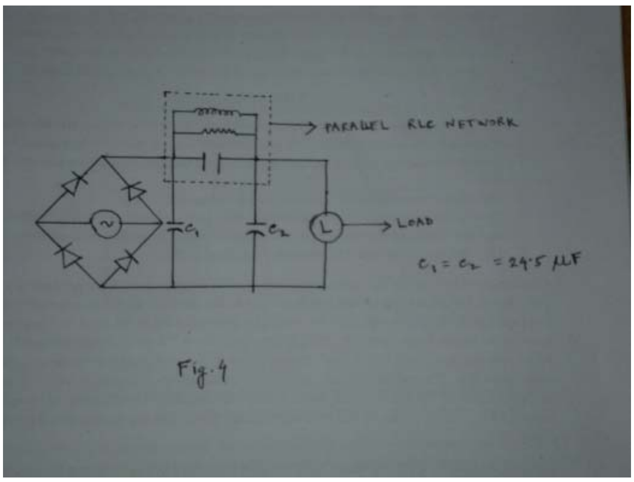
1. 1N5408 diodes
2. 1N4007 diodes
3. Transformer 230-12V, 3A
4. Tungsten filament lamps 10W, 15W, 25W, 40W, 100W & 200W working at normal domestic supply voltage i.e. 220-250VAC, 50Hz
5. Ordinary tube-light choke
6. A.C capacitors 2.5 µF,440V
7. Electrolyte capacitors 10 µF-350V & 22 µF-400V
8. Regulators used for ceiling fans

3. Diagrams









4. Experimental

Before starting with the experiments, a few constants were measured.

Forward resistance of 1N5408 diode=500Ω

D.C resistance of transformer primary=83Ω

D.C resistance of transformer secondary=2Ω

D.C resistance of choke=62Ω

Regulator resistance at various steps:-

Step1=545Ω, step2=383Ω, step3=270Ω, step4=118Ω, step5=4Ω

The entire experiment was divided into 6 sections.

Experiment no.1a

The circuit was set up as in figure 1. The resistor connected to the 100W lamp across the CRC section was fixed at 2Ω. A 32µF (a parallel combination of 22 &10µF) capacitor was connected in parallel with L_2 and the regulator was varied from 0-5 (the step resistances already given). The D.C voltage drops across L_1, L_2, the transformer primary and secondary were recorded and tabulated (refer to table no.1a).

Experiment no.1b

The same circuit as in figure 1 was used. The capacitor in parallel with L_2 was disconnected. The voltages across L_1, L_2 transformer primary and secondary were recorded and tabulated (refer to table 1b).

Experiment no.2

The circuit was set up as in figure 2. The resistance R was varied as R=2Ω, R=53Ω &R=118Ω. The load corresponding to each resistance in the filter section was varied from 0-400W. This was done in 17 steps. The D.C voltage across the load was recorded and tabulated (refer to table no.2).

Experiment no.3

The circuit was set up as in figure 3. For the inductor a choke was used. The load was varied from 0-500W in 22 steps. The voltage across the load was plotted in a graph.

Experiment no.5

A special filter circuit was constructed as in fig.4. The circuit has been referred to in the later sections of the paper as *C (RLC) C filter*. It has been so called because the junction consists of a parallel RLC network. The idea behind it was to *incorporate the characteristics of both CRC & CLC filter in to one unit*. It was found to be more advantageous than CLC or CRC filters and was suitable for high current. *The RLC section consists of R=118Ω, C=2.5µF and a choke.*

Experiment no.6

A final experiment was performed using a simple bridge rectifier circuit *without any filter*. The load was varied in 22 steps and the terminal voltage was recorded in each case. This was done to measure effectiveness of the C (RLC) C filter.

5. Observations

The table corresponding to experiment no.1a is given under:—

Table No. 1a

Step	D.C voltage across L_2	D.C output voltage in the π circuit	D.C voltage drop across transformer primary	D.C voltage at transformer secondary
0	20V	0V	32.8V	6.21V
1	19V	32V	52V	4.24V
2	18V	47V	57.8V	3.97V
3	17.5V	63V	62V	3.7V
4	16V	96V	69.8V	3.35V
5	15.8V	140V	78.1V	3.06V

**Table with 32 µF in parallel with L_2

Table corresponding to experiment no.1b

Table No. 1b

Step	D.C voltage across L_2	D.C output voltage in the π circuit	D.C voltage drop across transformer primary	D.C voltage at transformer secondary
0	58V	0V	31.6V	5.2V
1	41V	30.5V	49.8V	4.04V
2	40V	44.2V	54.4V	3.91V
3	39V	60.1V	57.8V	3.86V
4	37V	92.6V	65.8V	3.8V
5	30V	141V	73.6V	3.7V

**Table without any parallel capacitor across L_2

Here we notice the following effects:—

a. In absence of a parallel capacitor, the voltage across the lamp L_2 increases. This is in contradiction with the fact that *voltage should decrease in absence of capacitance*.
b. The voltage drop across the transformer primary decreases slightly. This indicates that less current is passing through it (*V=IR*).
c. The voltage drop across transformer secondary first decreases then increases.
d. The voltage across the π output decreases in general.

The current flowing through the inductor decreases on removal of the capacitor in parallel. This is evident from the reduced voltage drop. But the current flowing through L_2 (refer to fig.1) increases giving large voltage drop across it.

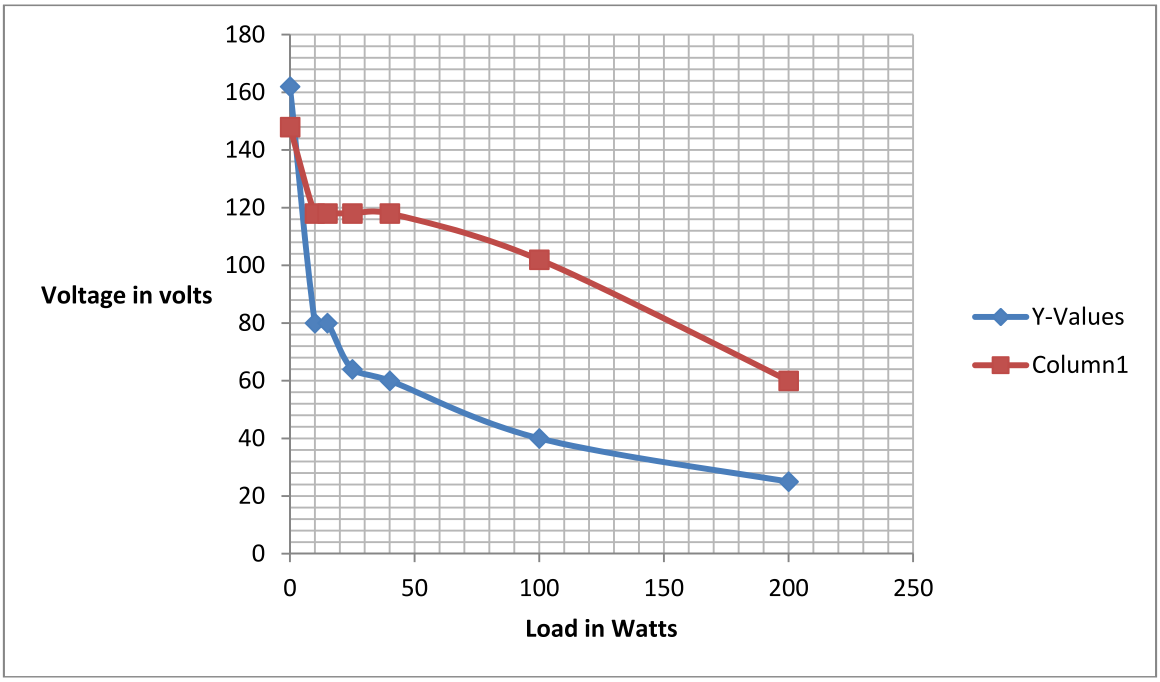
The table pertaining to experiment no.2 is given under:—

Table No. 2

Load	Voltage (R=2Ω)	Voltage (R=53Ω)	Voltage (R=118Ω)
0W	350V	340V	298V
10W	320V	295V	288V
15W	315V	295V	288V
25W	300V	290V	280V
40W	298V	280V	265V
65W	295V	272V	250V
100W	292V	265V	242V
125W	290V	258V	230V
140W	285V	250V	220V
200W	280V	240V	198V
225W	278V	235V	182V
240W	272V	222V	172V
265W	270V	218V	160V
300W	268V	215V	152V
325W	270V	205V	142V
340W	265V	202V	130V
400W	260V	190V	115V

As is expected the voltage across the load decreases with increase in the value of R. The *optimum value of R for a load range of 500W is 10-20Ω*.

In the circuit in fig.1 L_1 and L_3 was switched off and only the voltage appearing across L_2 was plotted once with parallel capacitance of 32µF and once without.



Graph No.1

It is very important that *the L_2 is not connected directly between the positive terminal of the bridge rectifier and the earth; $\underline{L_2}$ is connected between the positive terminal of L_1 and the earth instead (refer to fig.1)*.

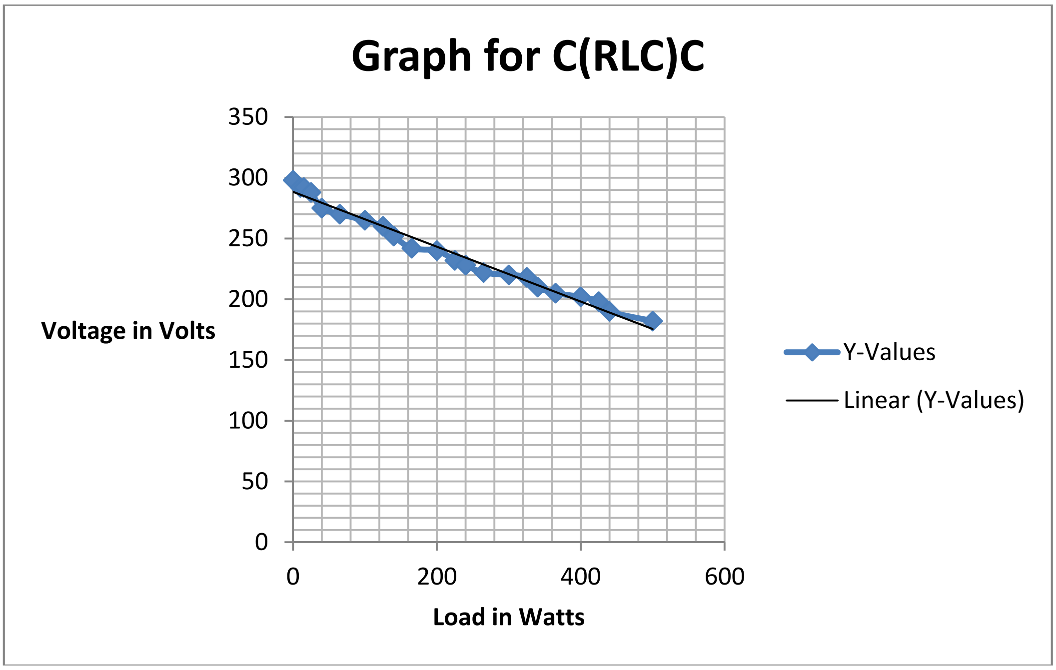
So L_2 is under the influence of the transformer. From the graph it is seen that when a capacitor is connected in parallel, voltage drops more drastically.

In order to prove that the designed C(RLC)C filter has better output voltage than a CLC or CRC filter a table has been plotted to compare the characteristics.

Table No. 3

Load	Voltage for CLC	Voltage for C(RLC)C
0W	300V	298V
10W	290V	292V
15W	290V	292V
25W	282V	288V
40W	270V	275V
65W	260V	270V
100W	250V	265V
125W	240V	260V
140W	230V	252V
165W	218V	242V
200W	212V	240V
225W	205V	232V
240W	200V	228V
265W	192V	222V
300W	190V	220V
325W	188V	218V
340W	180V	210V
365W	172V	205V
400W	170V	202V
425W	162V	198V
440W	152V	190V
500W	142V	182V

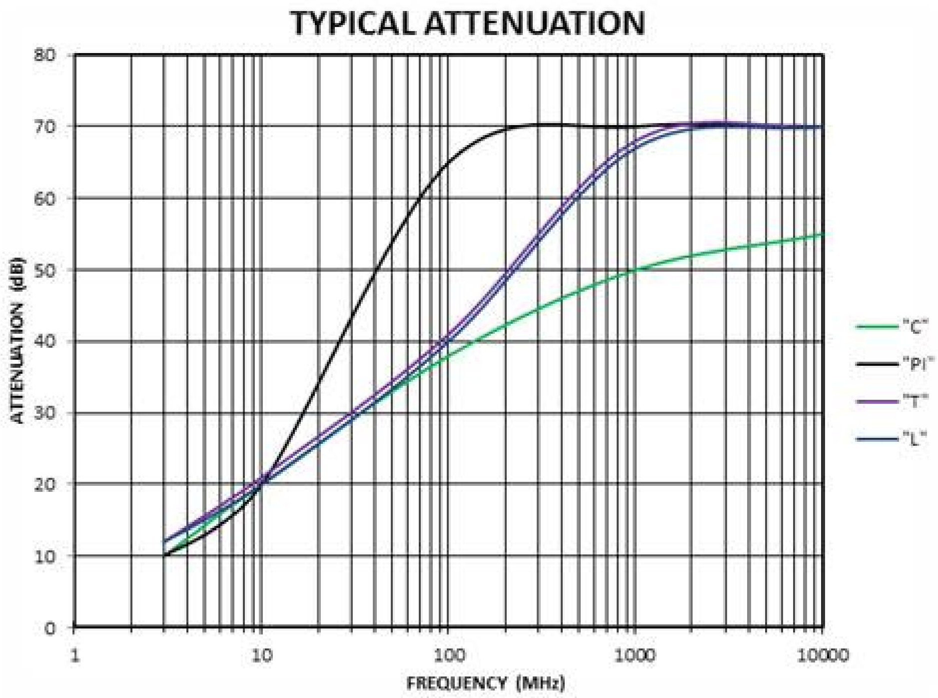
It is visible from the table that *for light loads the voltages are comparable (up to 40W)*. However after 100W the voltage drops very quickly for a simple π filter. But it is much less for the designed C(RLC)C filter. So undoubtedly it is *suitable for high loads*. The power vs. voltage curve is given under:—



Graph No.2

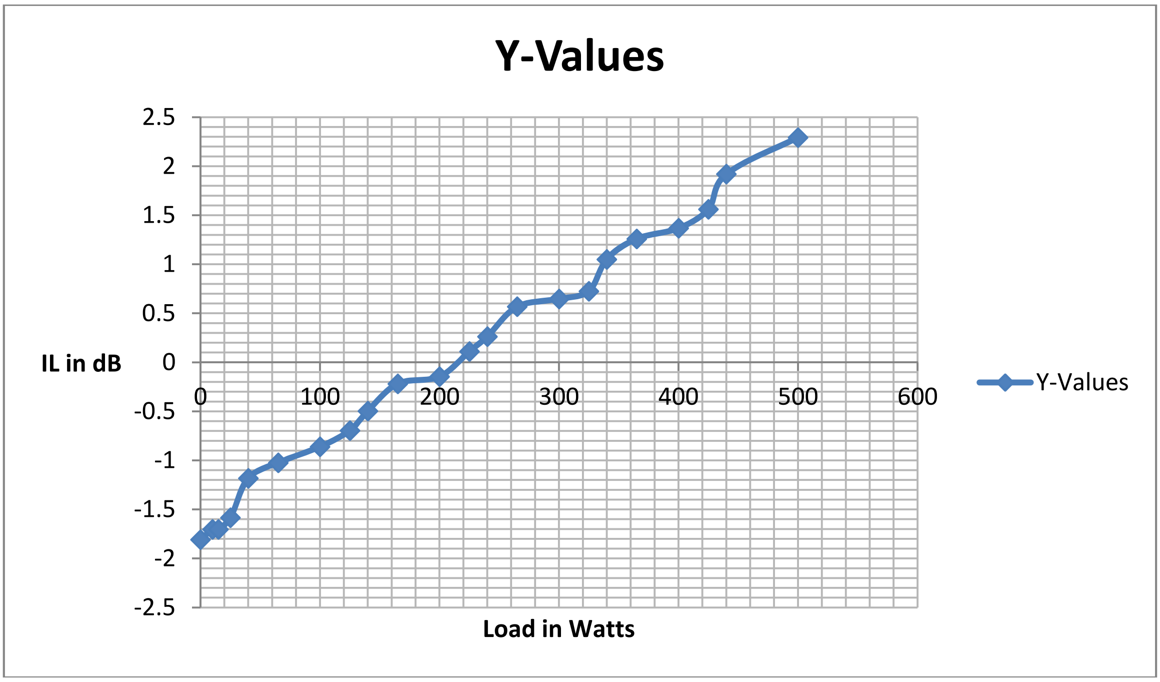
It is evident from the curve that terminal voltage falls linearly with increase of load (shown by the trend line). For higher loads (>500W), the value of 'R' in the RLC section should be decreased i.e. 50Ω.

A general graph plotted on semi log graph paper showing the insertion loss is given under:—



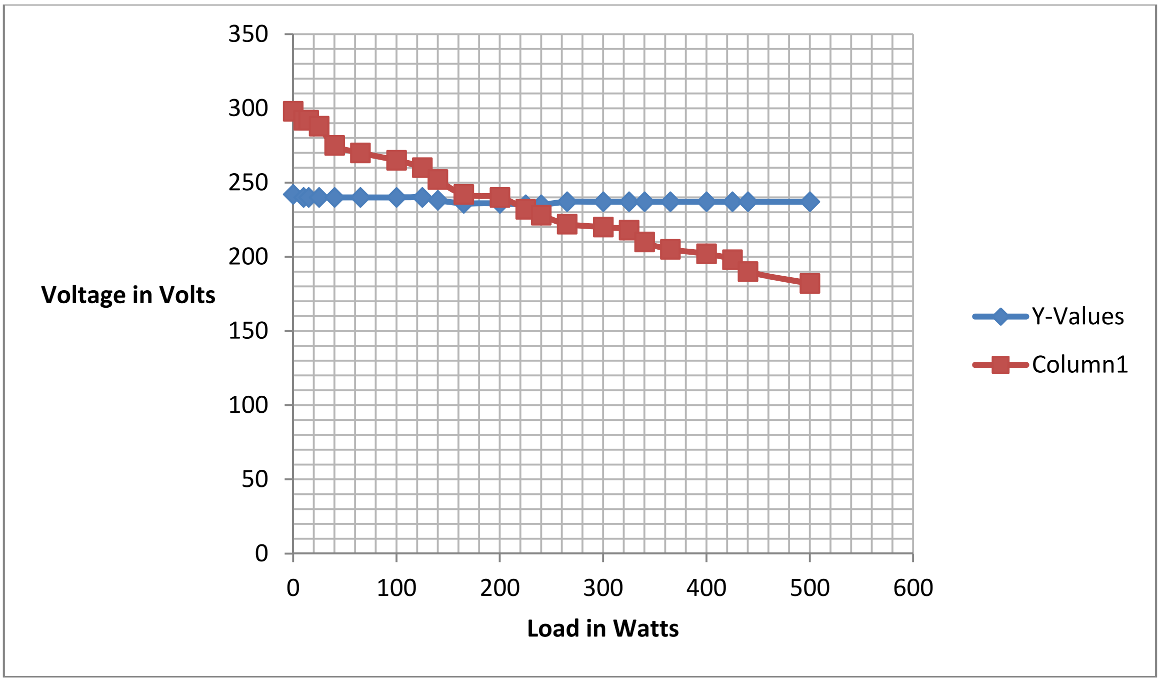
N.B this graph is not a part of the experiment. It is only used to depict the characteristics at various frequencies which are essentially related with communication circuits.

The actual curve showing the insertion loss (effectiveness of the filter) is plotted below:—



Graph No.3

Lastly the power vs. voltage curves for a C (RLC)C filter and a simple rectifier circuit (without any filter) as depicted in experiment no.5 were plotted on a single curve to show the comparison between the two.



Graph No.4

From the curve we see that the circuit without using any filter (shown by blue line) has better voltage regulation (*almost 0%*). This has been discussed later.

6. Results and discussions

As compared to other types of filters π filters have certain advantages like

- Higher D.C voltage
- Smaller ripple factor $\gamma=\sqrt{2}/(8\omega^3C_1C_2LR_{Load})$

But it also has certain disadvantages like

- Poor voltage regulation
- High peak diode current
- High peak inverse voltage

Main cause of these drawbacks is the use of inductor in the circuit. If a resistance is used instead of an inductor as a filter, the drawbacks are overcome. For this i.e. for a CRC filter *the load resistance* R_L *has to be much larger than the capacitive reactance of* C_2 $(X_{C2}=1/2\pi fC_2)$. If more than one section is used, each section reduces ripple by a factor of at least 10. But this too has very poor voltage regulation and hence suitable for light loads. The circuit also develops a lot of heat.

The filter designed in this experiment i.e. the one described in fig. 4 incorporated the characteristics of both CRC as well as CLC filter. For the experimental purpose it was designed for a maximum load of 500W. Its characteristics and advantages have been summarized below:—

1. Voltage drop with increased load is almost linear.
2. Considerable terminal voltage is obtained even at high loads.
3. The insertion loss becomes considerable at high loads.

But if we consider an electrical circuit operating at a frequency *as low as 50Hz*, we find that a *bridge rectifier circuit without any filter is the best*. It has the most effective voltage regulation. An additional filter is absolutely unnecessary. From the graph no. 4 we can conclude that in the presence of a filter the terminal voltage is higher than rated value up to a load of about 125W. As load increases the terminal voltage drops below its rated value. Moreover at a load of 500W for which the filter was designed, the current drawn from the A.C mains was 2.4A while the terminal voltage was 182V. In absence of any filter the current drawn from the mains was only 2A while the terminal load voltage was 237V. Hence we may conclude *the excess current drawn in presence of the filter is required to drive the filter circuit* and is a waste. The power loss occurs in the diodes and the regulator and may be given as $P=I^2R$. Hence this power loss is resistive power loss.

7. Conclusion

The purpose of using filters is to remove ripple from pulsating D.C voltage. They are used mostly in electronic circuits along with transistors, voltage regulators etc. In electrical circuits they are very useful for low current devices. At low currents and light loads e.g. 10W, the device can be made to operate at a voltage higher than rated value. But at high loads the terminal voltage drops. In that case a rectifier *without any filter* is more suitable. Moreover *electrical loads like tungsten lamps are not sensitive to presence of large quantity of ripple in the output voltage waveform* unlike electronic circuits. Hence a simple rectifier circuit without a filter serves quite well. There is no need of a filter.

8. Acknowledgements

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