Modelling, Simulation & Hardware design of Cuk Converter for Medical Application devices.

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Abstract:

When we need to convert the voltage of the power from direct current, we involve the device called DC-DC converter. As direct current voltages cannot be changed using transformer as in AC current DC-DC converters comes into play. These converters are similar DC version of the transformers. For example, when a 24volt direct current from a lorry power source needs to be decreased to 12volt for the car music system and 12Volt car power sources needs to stepped down to 3volt for mobile phones these electronic devices are applied. Here we simply want to change the voltage with a minimal loss of energy. We can also explain this as extracting maximum efficiency while converting. We have to keep in mind with DC-DC converters is that it is essential to alter the input energy into various impedance levels. Hence, the power delivered out of the converter remains the same as given in with a different voltage with no energy produced within the converter. A perfect converter gives an efficiency of 100% but in practical applications 70% to 95% efficiency are usually got. It is normally obtained with the help of switched mode or chopper circuits whose elements wastes very less power. Pulse-width modulation (PWM) helps with controlling and regulating the voltage output. The method is also implemented for circuits that involves AC, which includes highly efficient AC-DC converter (inverters and power amplifiers), ac-ac power converters, as well as few ac-dc power converters (low-harmonic rectifiers).

Key-words: Direct current (DC), operational amplifier (op amp), Pulse Width Modulation (PWM),

I. INTRODUCTION

There are lots of similarities between AC-DC converter and DC-DC converter. DC-DC converters are often used in many places such as for PCs, equipment used in offices , power system of spacecarfts, laptops, as well as tele-communication devices, and motor drives that uses direct current. An un-regulated direct current voltage is given into the converter to give a regulated voltage with a magnitude that varies from the given one.

Few application of the converter includes, conversion of 24volts direct current from the track power source to 12volts direct current for music systems and mobile phones; conversion of 12volts direct current from a car power source to 3volts direct current, for the functioning of video players; conversion of 5volts from the power source of computer mother board to 3-2volts or still low for the modern CPU circuits; obtaining the needed power supply like 12volts, 5volts, etc., from 340volts obtained by conversion of 240volts alternating current; conversion of 1.5volts from a single battery to 5volts or more for the electronic circuits.The above applications are to convert the voltage with a minimal energy loss. We can also explain this as extracting the maximum efficiency while converting.

We have to keep in mind with DC-DC converters is that it is essential to alter the input energy into various impedance levels. Hence, the power delivered out of the converter remains the same as given in with a different voltage with no energy produced within the converter. The fundamental flow of power in converter can be denoted by:

Pin = Pout + Plosses………….. (1.1)

here Pin denotes input power to the converter, Pout denoted power obtained from the converter and Plosses denotes power lost during conversion. In case of an ideal converter there is no loss of power similar to a transformer. When there is no loss of power Pin equals to Pout. Then it gives the following equation

Vin x Iin = Vout x Iout………… (1.2)

When rearranged we obtain

Vout/Vin = In/Iout…………… (1.3)

We can say this as increasing the voltage decreases the current and decreasing the voltage increases the current. We have to take into consideration that 100% output is not possible and no such ideal transformer is possible, hence we have to take into account the efficiency of the transformer which can be represented as

Efficiency (%) = Pout/Pin……. (1.4)

Current trend converters can obtain an efficiency of above 90%, with the help of novel materials as well as circuit approaches. The conventional converters can obtain 80-85%, that can be compared good using the efficiency of the often-used AC transformers.

1.2 Motivation and Approach

Numerous varieties of DC-DC converting electronic devices are available in market which are often used for variety of applications. Each type tends to suit better than other for their applications. They are divided into groups for easy understanding. Few are applied for stepping down, few are for stepping up and the last variety includes both the functions. A perfect converter is supposed to be efficient as good as 100% with no power losses while in practical application the 70 to 95% efficient converters are usually common.

The switched mode or chopper circuits are used to achieve a good effieciency. Pulse-width modulation (PWM) helps with controlling and regulating the voltage output. The method is also implemented for circuits that involves AC, which includes highly efficient AC-DC converter (inverters and power amplifiers), ac-ac power converters, as well as few ac-dc power converters (low-harmonic rectifiers).

II. DESCRIPTION OF CUK CONVERTER:

2.1 Circuit diagram:

A variety of DC-DC converter known as Cuk converter gives an output of either height or lesser compared to the input voltage. Cuk converter in non-isolated type has opposite polarity between input as well as output. While the converters use inductors as their important component the Cuk converter makes use of capacitors are component for energy supply. The naming of this type is done after Slobodan Cuk of the California Institute of Technology. He presented the design.

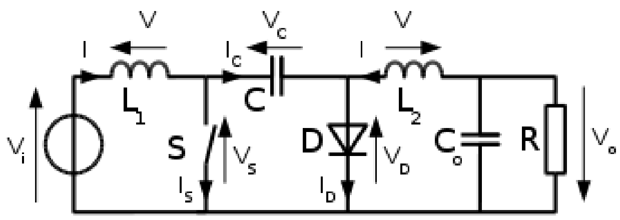


Figure 2.1. Circuit diagram of Cuk converter

2.2 Operating principle:

A non-isolated Cuk converter has 2 inductors, 2 capacitors, a switch (normally transistor), finally a diode. The scheme diagram of a Cuk converter is represented by figure 2.2. This inverting converter, gives an output of negative in terms of input voltage.

This change in voltage is essential due to the reason that in case the capacitor are in direct connection to the source of voltage then the current will be in limit due to simply (parasitic) resistance, thus increasing the loss of energy. When the capacitor is charged with the source of current(the inductor) can prevent the resistive current and limits it from losing energy. Like the similar kind of converters (buck converter, boost converter, buck-boost converter) these Cuk converter operated in continuous or discontinuous current mode. Additionally this type of converter can function in discontinuous voltage also(i.e., the voltage across the capacitor drops to zero during the commutation cycle) which makes it stand out from others.

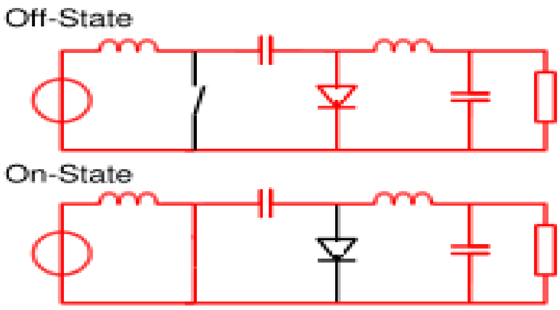


Figure 2.2: two operating states of Cuk converter.

The 2 operating state of a non-isolated Cuk converter is depicted in figure.2, Here a short circuit is used instead of switches and diodes if they are on and open circuit if off. It is noted that the inductor L_1 charges capacitor using input source during off condition and when it is on capacitor C moves the energy to output capacitor via inductance L_2. This has 2 mode of operating. That is continuous and discontinuous modes.

2.3 Continuous mode of operation

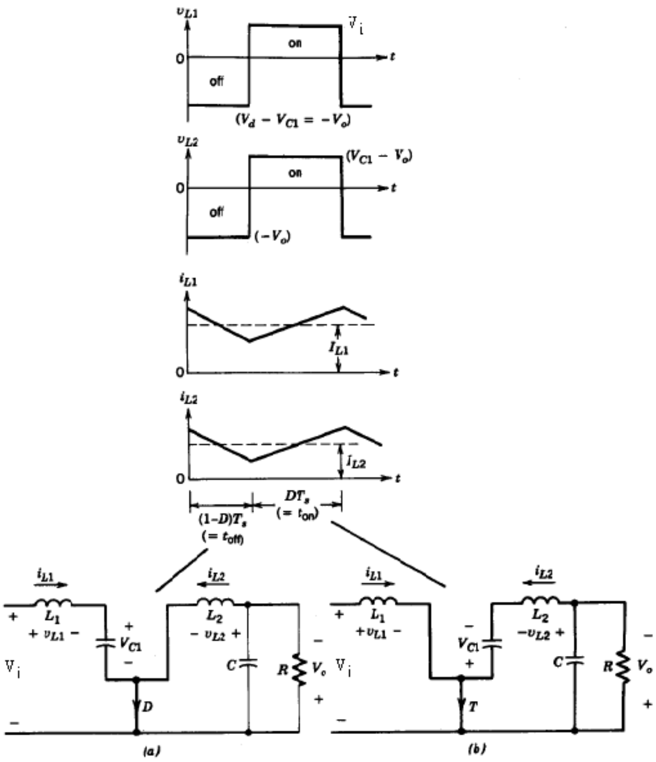


Figure 2.3: Cuk converter waveforms (a) switch off (b) switch on.

During steady state, the energy saved in the inductors has to be constant from the start of the commutation cycle till its end. The equation for the energy of the inductor is depicted by equation:

$$E = \frac{1}{2} L I^2 \qquad (2.1)$$

It shows that the energy reserve in the inductor will have to remain constant from the start of the cycle till the end of the commutation cycle. The current evolved by an inductor is linked to the voltage across it:

$$V_L = L\frac{dI}{dt} \qquad (2.2)$$

It is noted that mean value of voltage in an inductor during the commutation cycle needs to be zero. This has to be maintained in order to fulfill the needs of steady state. When the capacitor C and C_o are considered sufficiently big so that the voltage ripple through them to be insignificant, the inductor voltages become:

The converter functions in on-state from t=0 to t=D·T (D denotes duty cycle); In off state from D·T to T (that is, during a period equal to (1-D) ·T). Hence average values of V_{L1} and V_{L2} :

$$\bar{V}_{L1} = D \cdot V_i + (1-D)\cdot(V_i - V_C) = (V_i - (1-D)\cdot V_C) \qquad (2.3)$$

$$\bar{V}_{L2} = D(V_o - V_C) + (1-D)\cdot V_o = (V_o - D\cdot V_C) \qquad (2.4)$$

To obtain a steady state mean voltage of both has to be zero. This can be written by the equation:

$$V_C = \frac{V_o}{D} \qquad (2.5)$$

Hence the mean voltage through L_1 can be denoted as:

$$\bar{V}_{L1} = \left(V_i - (1-D)\cdot\frac{V_o}{D}\right) = 0 \qquad (2.6)$$

That can be rearranged to be

$$\frac{V_o}{V_i} = \frac{D}{1-D} \qquad (2.7)$$

Assuming lossless circuit:

Pin = Pout

Vin.Iin = Vout.Iout

Iout / Iin = (1-D) / D (2.8)

This can show that the association is similar to that got from the Buck-boost converter. An important benefit of this converter is that the current fed in and the current that feeds the output gives only a minimal ripple or is ripple free.

III. Modelling & Simulation of Cuk converter by using Pspice with hardware.

3.1 Introduction to Pspice:

It is not possible to breadboard the integrated circuits because it is different from the usual board-level design which is often made of discrete parts. Also the costly nature of photolithographic masks as well as other requirements to manufacture creates a necessity to make the circuit to be maximum precise earlier to the integrated circuit is built. Simulation of circuit using SPICE is standardized methodology in industries for verification of circuit function at the transistor level earlier to commit the manufacture of an integrated circuit.

3.2 Steps involved in spice:

For running Spice, the below instructions has to be followed:

- Draft the circuit scheme diagram and specify the nodes.
- Create an input file
- Run the program.

3.3 Simulation Circuit:

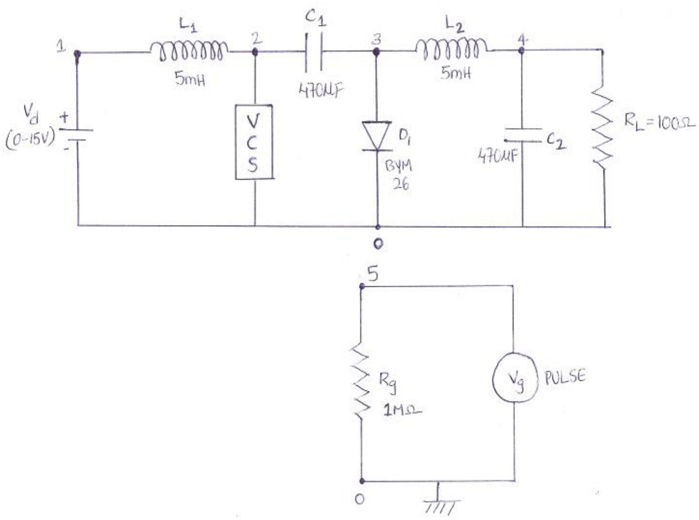


Figure 3.1: Cuk Converter simulation circuit diagram.

3.4 Pspice program for Cuk converter:

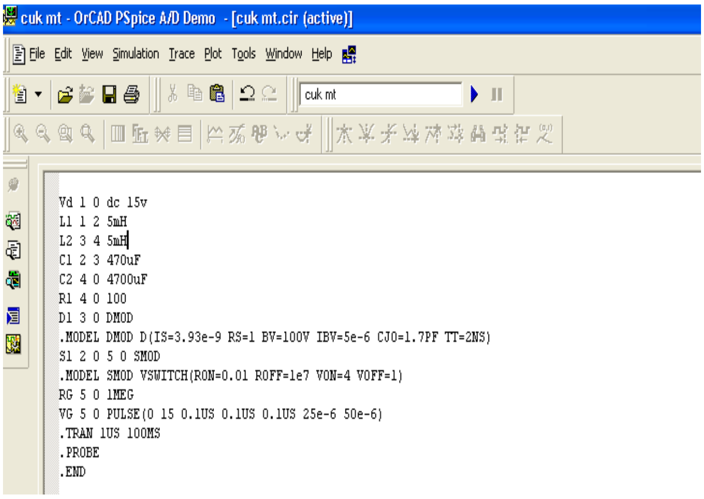


Figure 3.2: Pspice program for Cuk converter circuit.

3.5 Hardware Circuit of Cuk converter:

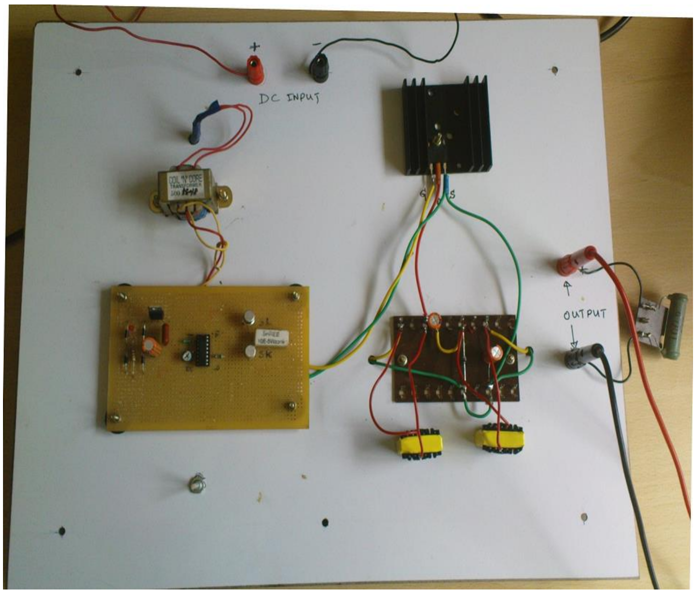


Figure 3.3: Hardware circuit

IV Results & Discussion

The system built in Pspice for Cuk converter by using PWM technique plots, result are given below.

4.1 Change in pulse width and corresponding output voltage.

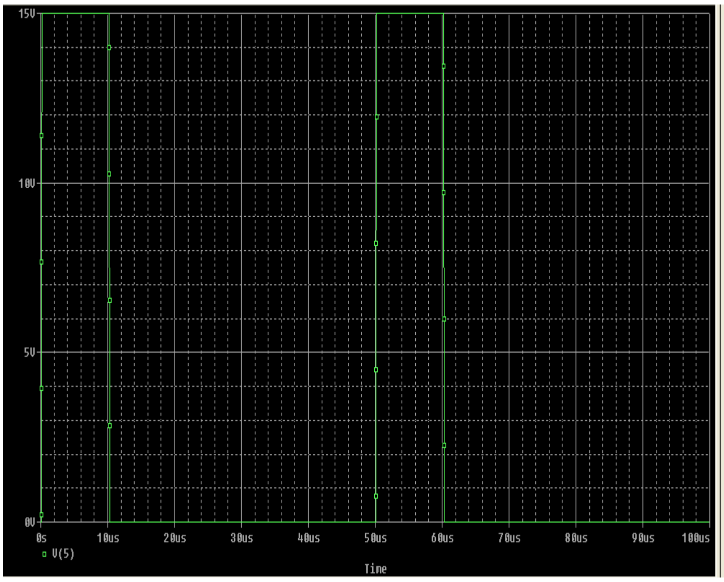


Figure 4.1: Pulse width of 10e-6

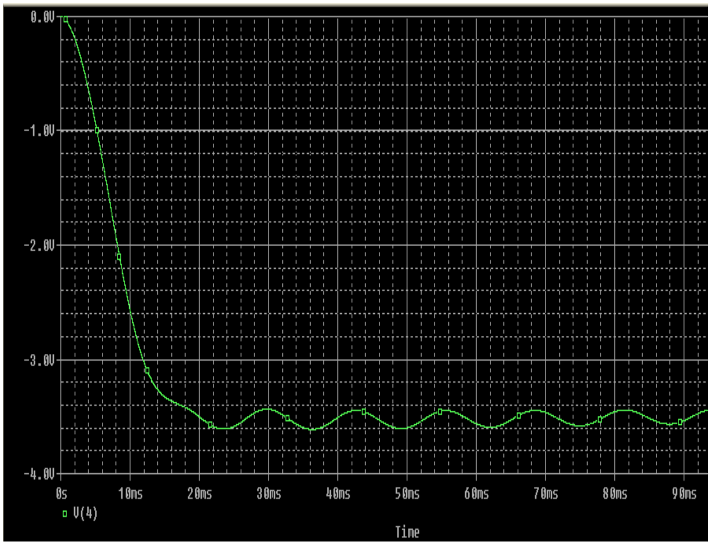


Figure 4.2: Output voltage (V4) at 10e-6

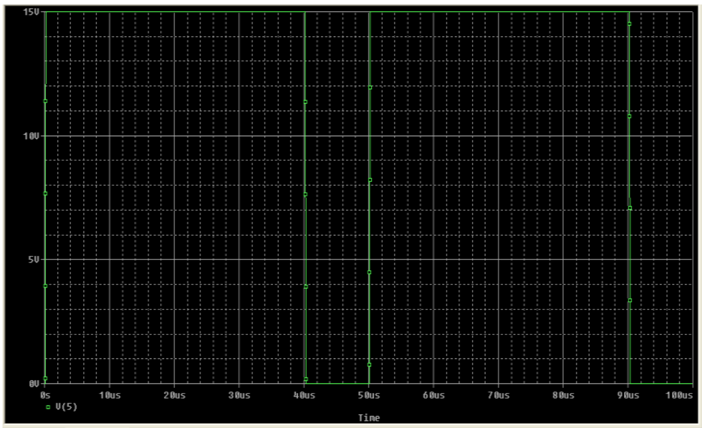


Figure 4.3: Pulse width of 40e-6

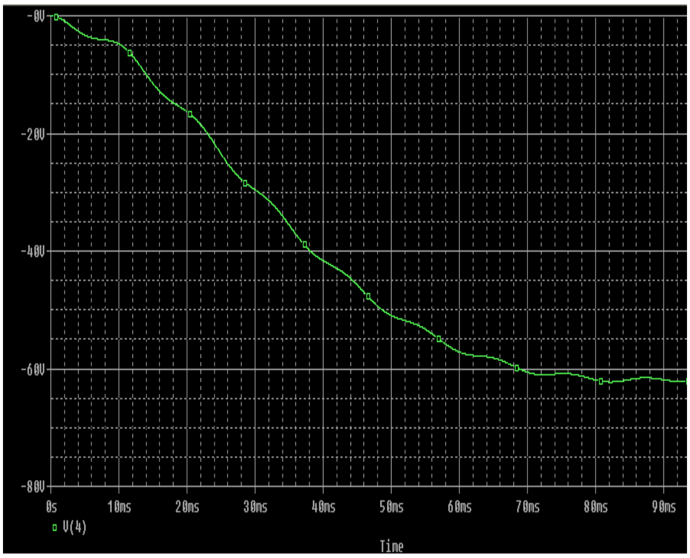


Figure 4.4 Output voltage (V4) at 10e-6

4.2 Hardware circuit results:

4.2.1 Reading of the circuit at constant voltage with variable loads

Input voltage =15volts load = 250 or 100 ohms.

FOR CONSTANT INPUT VOLTAGE(Vin) AND VARIABLE LOAD(Ro)

CASE:1 Ro=250ohm Ts=9*5us=45US

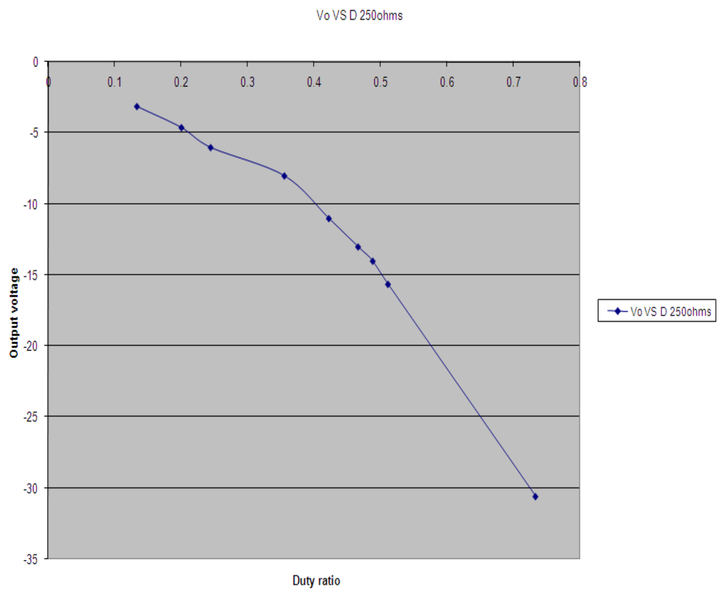
S.NO	ton(us)	DUTYRATIO(D)	Vin(volts)	Iin(amps)	Vo(volts)	Io=(Vo/Ro)amps	Pin=Vin.Iin(watts)	Pout=vo.Io(watts)	Vo=(D/1-D).Vin(volts)
1	6	0.133	15	0.003	-3.11	-0.012	0.045	0.037	2.3
2	9	0.2	15	0.006	-4.6	-0.018	0.09	0.084	3.75
3	11	0.244	15	0.011	-6	-0.024	0.165	0.144	4.84
4	16	0.355	15	0.018	-8	-0.032	0.27	0.256	8.25
5	19	0.422	15	0.035	-11	-0.044	0.525	0.484	10.95
6	21	0.466	15	0.048	-13	-0.052	0.72	0.676	13.08
7	22	0.488	15	0.057	-14	-0.056	0.855	0.784	14.29
8	23	0.511	15	0.068	-15.63	-0.061	1.02	0.933	15.67
9	33	0.733	15	0.27	-30.58	-0.122	4.05	3.73	41.17

CASE:2 Ro=100ohms Ts=9*5us=45us

S.NO	ton(us)	DUTYRATIO(D)	Vin(volts)	Iin(amps)	Vo(volts)	Io=(Vo/Ro)amps	Pin=Vin.Iin(watts)	Pout=vo.Io(watts)	Vo=(D/1-D).Vin(volts)
1	6	0.13	15	0.003	-1.95	-0.019	0.045	0.038	2.24
2	11	0.24	15	0.016	-4.5	-0.045	0.24	0.202	4.73
3	14	0.31	15	0.032	-6.5	-0.065	0.48	0.422	6.73
4	17	0.37	15	0.052	-8.3	-0.083	0.78	0.688	8080
5	18	0.4	15	0.078	-10.1	-0.1	1.17	1.01	10
6	20	0.44	15	0.11	-12.5	-0.125	1.65	1.56	11.78
7	22	0.48	15	0.15	-14.6	-0.146	2.25	2.13	13.84
8	35	0.77	15	0.73	-30.01	-0.3	10.95	9.003	50.21

Figure 4.5 Readings for constant input voltage at variable loads.

Duty ratio:



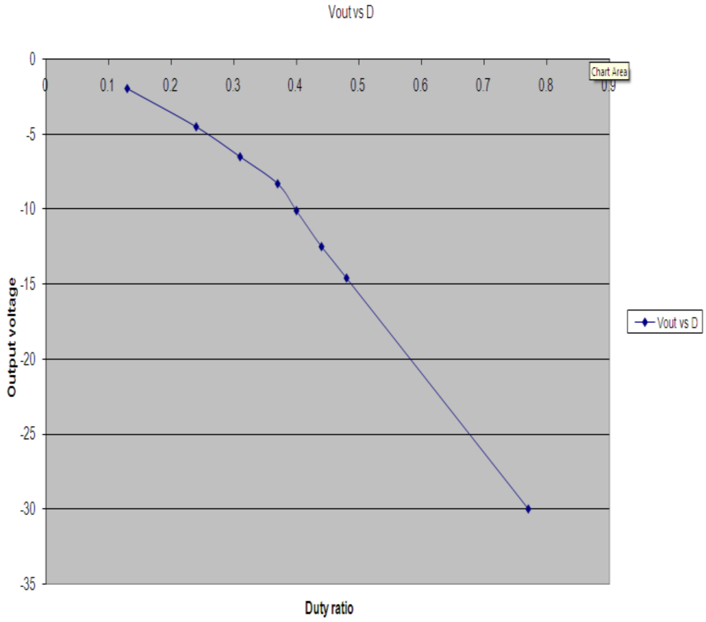


Figure 4.6: Output voltage Vs Duty ratio at constant input voltage & variable loads Vi =15volts Ro= 250 or 100 ohms.

4.2.2 Reading of the circuit at variable voltage with constant loads.

FOR SAME LOADS CHANGE IN INPUT VOLTAGE

Vin=12volts Ro=250ohms Ts=10*5us=50us

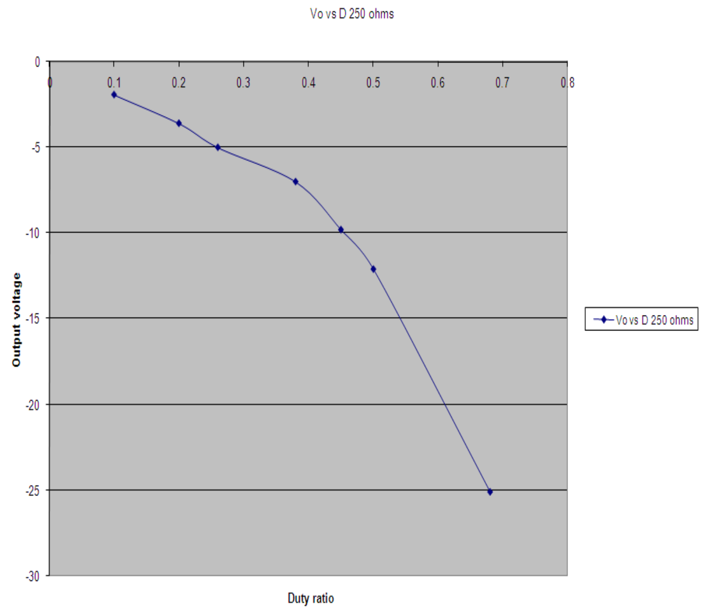
S.NO	ton(us)	DUTYRATIO(D)	Vin(volts)	Iin(amps)	Vo(volts)	Io=(Vo/Ro)amps	Pin=Vin.Iin(watts)	Pout=vo.Io(watts)	Vo=(D/1-D).Vin(volts)
1	5	0.1	12	0.002	-1.93	-0.007	0.024	0.013	1.33
2	10	0.2	12	0.006	-3.6	-0.014	0.072	0.05	3
3	13	0.26	12	0.01	-5	-0.02	0.12	0.1	4.21
4	19	0.38	12	0.018	-7	-0.028	0.216	0.19	7.35
5	22.5	0.45	12	0.034	-9.8	-0.039	0.408	0.38	9.81
6	25	0.5	12	0.055	-12.1	-0.0484	0.66	0.58	12
7	34	0.68	12	0.23	-25.09	-0.1	2.76	2.509	25.5

Vin=12volts Ro=100ohms Ts=10*5us=50us

S.NO	ton(us)	DUTYRATIO(D)	Vin(volts)	Iin(amps)	Vo(volts)	Io=(Vo/Ro)amps	Pin=Vin.Iin(watts)	Pout=vo.Io(watts)	Vo=(D/1-D).Vin(volts)
1	9	0.18	12	0.004	-1.8	-0.018	0.048	0.0324	2.63
2	13	0.26	12	0.01	-3	-0.03	0.12	0.09	4.21
3	15	0.3	12	0.02	-4.4	-0.044	0.24	0.1936	5.14
4	20	0.4	12	0.05	-7	-0.07	0.6	0.49	8
5	22	0.44	12	0.09	-9.5	-0.095	1.104	0.92	9.42
6	24	0.48	12	0.11	-10.9	-0.109	1.32	1.188	11.07
7	26	0.52	12	0.14	-12	-0.12	1.68	1.44	13
8	34	0.68	12	0.59	-23.2	-0.232	7.08	5.382	25.5

Figure 4.7: Readings for change in input voltage at same loads.

Duty ratio:



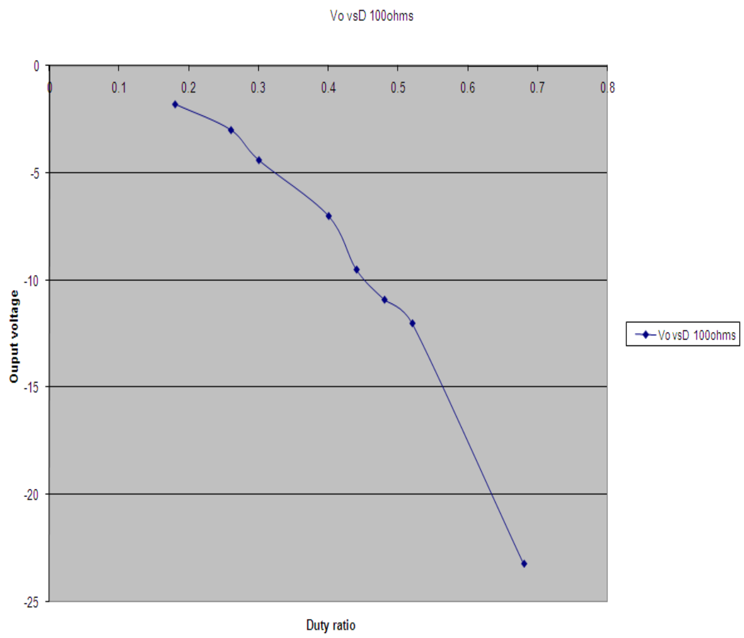


Figure 4.8: Output voltage Vs Duty ratio at variable input voltage & constant loads.

V . CONCLUSION & FUTURE WORK

The buck boost converter's principle is used to obtain the circuit of Cuk converter. Just like the buck-boost converter, the Cuk converter gives a negative polarity regulated output voltage corresponding to the common terminal of the output voltage. A non-isolated Cuk converter has 2 inductors, 2 capacitors, a switch (normally transistor), finally a diode. As this is an inverting converter, the output voltage is negative w.r.t the input voltage.

Like the similar kind of converters (buck converter, boost converter, buck-boost converter) these Cuk converter operated in continuous or discontinuous current mode. Additionally this type of converter can function in discontinuous voltage also (i.e., the voltage across the capacitor drops to zero during the commutation cycle) which makes it stand out from others.

It is shown in the present work, the non-isolated Cuk converter operated in continuous mode only. Further we can work for discontinuous mode of operation, where any one of the inductors will conduct (either L1 or L2 only) present in the circuit**.**

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