Design for Open Loop and Closed Loop ĆUK Converter for Battery Charger

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Abstract— *The design and development of this work highlight an improved ĆUK converter-based battery charger with a high power factor and enhanced efficiency. It provides a charging solution for EV with low cost and high power density.The efficiency of the charger is improved, as this charger includes less number of devices operating over one switching cycle, thereby reducing the conduction loss sustained by a diode bridge rectifier of a conventional charger. The power quality listing and improved efficiency are looked into, demonstrating its adequate charging operation at all conditions. Also, we are describing a closed-loop converter that can be obtained by using a controller. A constant and required level of the output voltage is received by the ĆUK converter. The ĆUK converter requires a lesser number of switches to provide DC output with increased reliability. These converters gained attention due to the single state requirement for DC-link voltage control using the power factor. Results are presented to verify the correctness of the obtained model.*

***Key Words*: Pulse generator, single switch, Less conduction loss, controller, reliability.**

1.INTRODUCTION

Among the various converters present in this world, the DC-DC converters have become more prevalent in multiple domains in advance using semiconductors. And also, the DC-DC converter is also called as DC chopper. The DC-DC converter's primary function is to provide a required output voltage or variable output voltage with a given input voltage. Where the converter is non-isolated here and also where the isolated converter has the AC configuration, which means that the input side and the output side are separated with the transformer. There are many varieties of DC/DC different arrangements.

A DC-DC/AC Non-isolated ĆUK Converter is designed. This system comprises the centralized switching circuit, Non-Isolated ĆUK Converters. Renewable energy resources (Solar and Fuel cell), which are produced, the DC outputs are given as inputs to this proposed system. This is done by proper pulses are given to the converter and inputs to the converters. It need not require additional devices like inverter, transformer, and filter. Non Isolated ĆUK converter is used to improve the input voltage levels. Moreover, this derived controller is suitable for any changes at input voltage; it maintained a constant load.

One of the unique topologies is ĆUK converter named as its configuration is a combination of the step-up and step-down circuit. There are plenty of advantages to this converter. The ĆUK converter is very much advantageous and has few essential features such as continuous input current, buck-boost capability, low-side switch, and provided capacitive isolation between the source and the load. The input and output filter network form a higher-order transfer function.

Closed-loop controlled ĆUK converter is a fourth-order non-smooth dynamical system that shows a variety of non-linear phenomena. The ĆUK converter being a fourth-order dc-dc converter, its analysis and control are involved in both continuous and discontinuous mode of operations. It has been widely used in power factor correction (PFC) applications. It is now extensively used in renewable sources of energy like wind energy conversion system for voltage regulation, under the wind speed uncertainty, specifically in low wind power turbine ratings and also in solar power system, where we can find very low power is developed. Hereby using ĆUK converter, we can increase the output of the solar power system.

INTERNATIONAL RESEARCH JOURNAL OF ENGINEERING AND TECHNOLOGY (IRJET) E-ISSN: 2395-0056
VOLUME: 08 ISSUE: 07 | JULY 2021 WWW.IRJET.NET P-ISSN: 2395-0072

ĆUK converter is a particular type of DC-DC converter, and it is a series combination of boost converter followed by buck converter with capacitive energy transfer. The output voltage can be step-up or step-down, depending on the duty ratio given (d). The converter operates on two modes, namely, switch ON mode and switch OFF mode. L1 acts as a filter inductor, which prevents the large harmonic disturbance from the input side. The energy transfer in the ĆUK converter depends on capacitance C1. To maintain the output voltage, constant output capacitance C2 is used.

Here in the closed-loop. The controlling circuit (i.e., subsystem) consists of a constant value, a comparator, gain, pulse generator, and the output. So when the input is given, depending on the input the output is generated and now the output goes through the subsystem and there we can find constant value, we have the enter the required output and now the generated output and the constant values both get compared each other and thus there will be an error is developed and now this error is given to the pulse generator and depending upon the error the pulse generator gives required amount of pulse to MOSFET. And thus, MOSFET triggers at required values, and finally, we will get the required constant output.

Since the system has discontinuous dynamics, many researchers have used advanced control strategies like the fuzzy logic-based system to accurately investigate the stability of the non-smooth model of the converter. The analytical results have been verified using circuital simulation in MATLAB/Simulation TM tool is used to perform this proposed system, and the simulation outputs are viewed.

The advantage of the ĆUK converter is both continuous input current and output current. The operation is based on capacitive energy transfer, which is more efficient than inductive energy transfer. As the current in the input and output sides are continuous and ripple-free, there is very little chance of the ripple current falling to zero.

By considering inductor as a current source at a short time scale as it maintains a constant current.

Charging a capacitor with the inductor prevents resistive current limiting and its linked energy loss.

2. LITERATURE REVIEW

2.1 Evolution of ĆUK Converter

We know that the ĆUK converter is a combination of BUCK and BOOST converter. And the BUCK converter and the BOOST converter were connected in series, which is shown in the figure below.

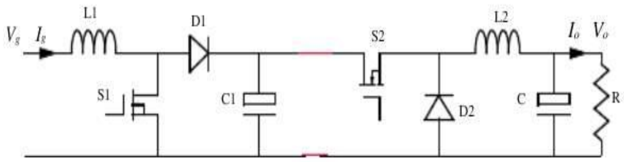


Fig-2.1: Schematic diagram of the Buck-Boost converter

After that, the driving signal is applied to the active switch, the equivalent circuit of the period when the switch is on and the period when the switch been simplified from the BUCK-BOOST converter. That is, the components of the series connection would be less, which means the number of active and passive switches is reduced to one. The new circuit working principle is exactly similar to a cascade converter. The configuration of the new circuit is simpler than the previous one. The evolution process is shown in fig [2.2].

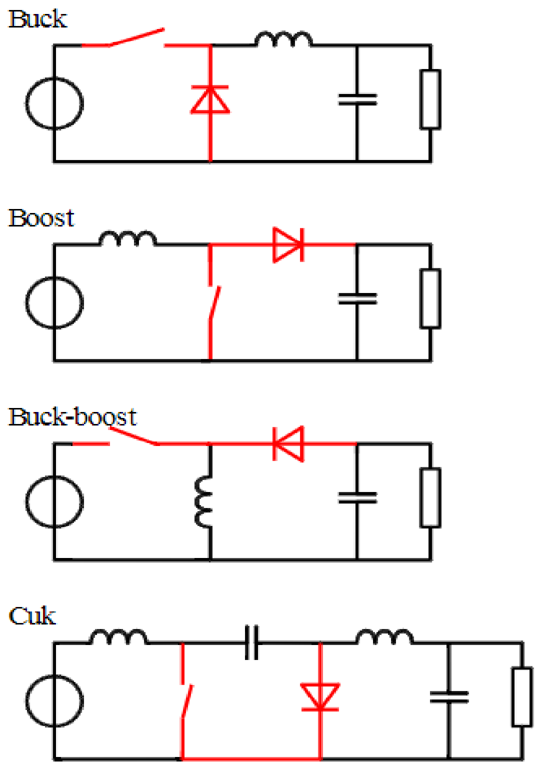


Fig-2.2: Schematic diagrams of evolution from Buck, Boost, Buck-Boost, and ĆUK Converter.

2.2 Model of ĆUK Converter

A ĆUK converter simply a BUCK-BOOST converter where the output voltage is either high or less than the input voltage. This converter consists of four energy storing elements, like two inductors (L) and two capacitors(C), a diode, and a switch. The capacitor mainly functions to transfer energy, and the two inductors L1 and L2 are connected to convert input voltage source and output voltage source into current sources. Let V1 and V2 be the voltages across the capacitors C1 and C2 and Let I1 and I2 be the currents through the

Inductors L1 and L2, respectively.

When MOSFET Switch S is ON, the circuit is in charging mode.

When MOSFET Switch S is OPEN, the circuit is in discharging mode.

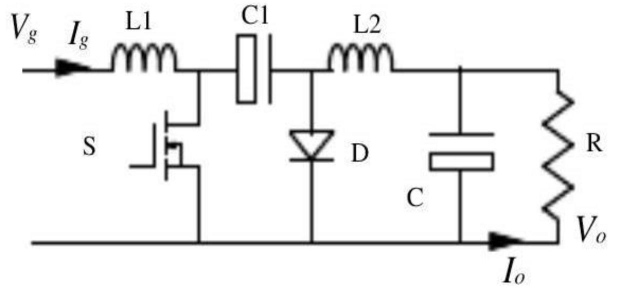


Fig-2.3: Schematic diagram of ĆUK converter.

2.3 An expression for average output voltage and inductor currents

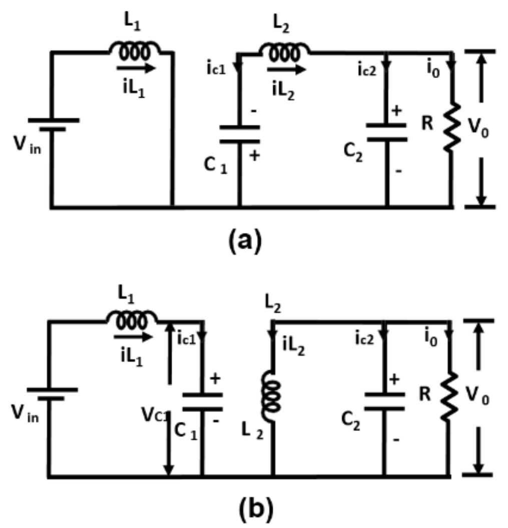


Fig-2.4: Equivalent Circuit of a ĆUK converter during different conduction modes.

(a) $0 < t \leq DT$ (b) $DT < t \leq T$

Applying Volt-sec balance across L_1

$V_{in} DT + (V_{in}-V_{C1})(1-D)T = 0$

$V_{in}(1-D) V_{C1} = 0$

Or $V_{C1} = \frac{Vin}{1-D}$

Applying Volt-sec balance across L_2

$(V_0+V_{C1})DT + V_0(1-D)T = 0$

Or $V_0 + DV_{C1} = 0$

Or $V_0 = -DV_{C1} = -\frac{DVin}{1-D}$

Expression for average inductor current can be obtained from charge balance of C_2

$I_{L2}+V_0 = 0$

$$\therefore I_{L2} = -I_0 = -\frac{V0}{R} = \frac{D}{1-D}\frac{Vin}{R} \qquad \text{eq (1)}$$

From power balance

$$V_{in} I_{L1} = V_0 I_0 = \frac{(v)^2}{R} = \frac{D^2}{(1-D)^2}\frac{(Vin)^2}{R} \qquad \text{eq (2)}$$

$$\therefore I_{L1} = \frac{D^2}{(1-D)^2}\frac{Vin}{R} \qquad \text{eq (3)}$$

I_{L1} is the inductor current.

2.4 Expression for Current Ripple and Voltage Ripple

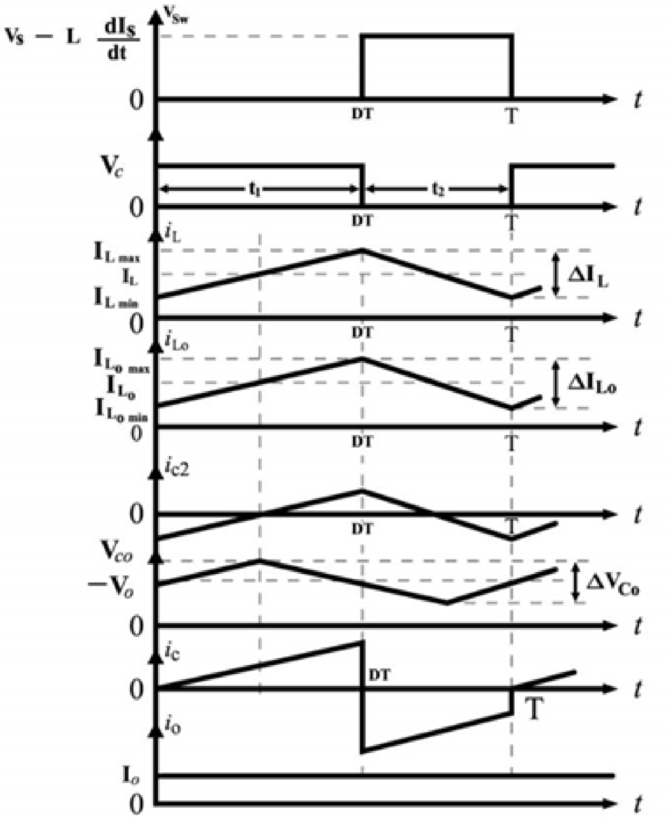


Fig-2.5: Waveform for different circuit variables (a)&(b) of fig 2.4

From the waveforms of fig.2.5

$I_{L1MAX} = I_{L1MAX} + \frac{DVinT}{L1}$

$\hat{I}_{L1}|_{p-p} = I_{L1MAX} - I_{L1MIN} = \frac{VinDT}{L1}$ eq (4)

From eq (3)

$I_{L1MAX} + I_{L1MIN} = 2I_{L1} = \frac{2D^2}{(1-D)^2}\,\frac{Vin}{R}$

$I_{L1MAX} = \left[\frac{D}{(1-D)^2} + \frac{RT}{2L1}\right]\frac{DVin}{R}$

$I_{L1MIN} = \left[\frac{D}{(1-D)^2} - \frac{RT}{2L1}\right]\frac{DVin}{R}$

$I_{L2MAX} = I_{L2MIN} - \frac{V0}{L2}(1 - D)\,T = I_{L2MIN} + \frac{Vin}{L2}DT$

$\hat{I}_{L2}|_{p-p} = I_{L2MAX} - I_{l2MIN} = \frac{VinDT}{L2}$ eq (5)

From eq (1)

$I_{L1MAX} + I_{L1MIN} = -\,2I_0 = \frac{2D}{1-D}\,\frac{Vin}{R}$

$I_{L1MAX} = \left[\frac{1}{1-D} + \frac{RT}{2L2}\right]\frac{DVin}{R}$

$I_{L1MIN} = \left[\frac{D}{1-D} - \frac{RT}{2L2}\right]\frac{DVin}{R}$

For calculating voltage ripples it is noted that

$\hat{V}_{c1} = \frac{1}{C1}\int_0^{DT} i\,c1\;dt$

but for $0 < t \le DT$ $i_{c1} = i_{L2}$

$$\frac{1}{C1}\int_0^{DT} i\,c1\;dt = \frac{1}{C1}\int_0^{DT} i\,L2\;dt$$

Or

$\hat{V}_{c1} = \frac{D^2 VinT}{RC1(1-D)}$ eq (6)

$\hat{V}_{c2} = \left|\frac{1}{C2}\int_{t1}^{t2} i\,c2\;dt\right|$ which is the derived area under ic_2 waveform in fig-2.5

$\therefore\ \hat{V}_{c2} = \frac{1}{C1} \times \frac{1}{2} \times \frac{T}{2} \times \frac{VinDT}{2L2} = \frac{VinDT^2}{8L2C2}$ eq (7)

eq (4), eq (5) & eq (6) can be utilized to design a ĆUK converter of given specification.

3. Working Principle

ĆUK converter transforms the DC voltage at the input to a DC voltage at the output with polarity reversed. Compared to the BUCK, BOOST and BUCK-BOOST converters the ĆUK converter uses an additional inductor and capacitor to store the energy [2].

The MOSFET operates in two states/modes, mode1 is when the switch is ON and mode 2 is when the switch is OFF. The explanation of these two modes are given below.

3.1 Switch ON state

The current through the inductor L_1 increases linearly and as the diode gets reverse biased, thus diode doesn't conduct.
Here forms a current loop Vs, L, Switch and the current through C, S, load, Lo forms another current loop.

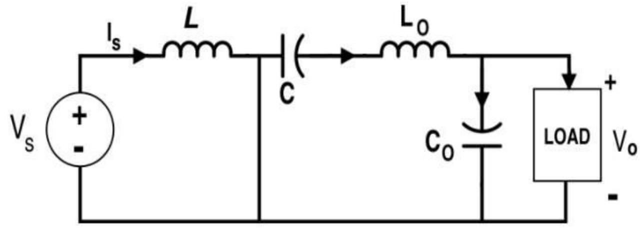


Fig-3.1: ĆUK converter Switch ON state

3.2 Switch OFF state

In this mode, the capacitor C is charged by source voltage and inductor L as the source through the inductor L and diode D.

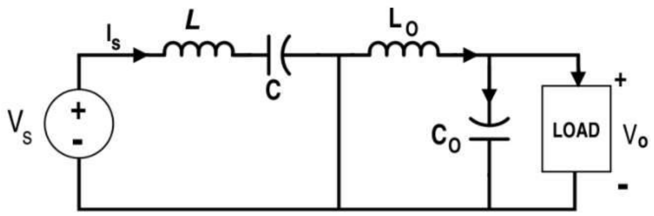


Fig-3.2: ĆUK converter Switch OFF state

When the switch is off the inductor L acts as a source and the IL decreases, and at the same time, the energy stored in the inductor Lo is transferred to the load thereby the current of inductor ILo decreases. This results in the forming of the current loop through Lo, D, load.

4. ĆUK CONVERTER WITHOUT A CONTROLLER

The ĆUK converter designated here is operating in CC mode (CCM) with a frequency operating at 100Hz and duty ratio set to 69. The design process for the parameters mentioned in Table-3.1 is based upon the ripple voltage and current ripple at the output side of the converter. The parameters are obtained by seeing a certain amount of ripple contents in the inductor current and capacitor voltage. The voltage ripple is only measured in the present work. The input capacitor voltage ripple is 1.28%. The output capacitor is suitably large to maintain the output voltage constant.

Table 4.1: Parameters used for open-loop design

Supply Voltage	12 Volts
Output Voltage	-24 Volts
Switching Frequency	100Hz
Load	12 Ohm
Pulse width or Duty Ratio	69.1
L1	68.7 µH
L2	2.2mH
C1	3.7µH
C2	984 µH
Output Ripple	5%

The above parameters are used to perform the simulation in MATLAB.

5. ĆUK CONVERTER WITH A FEEDBACK CONTROLLER

The ĆUK converter with a feedback controller chosen here is operating in CC mode (CCM) with an operating frequency of 10KHz and a duty ratio of 50. The design process for the parameters mentioned in Table-4.1 is based upon the ripple voltage and current ripple at the output side of the converter. The parameters are obtained by seeing a certain amount of ripple contents in the inductor current and capacitor voltage. The voltage ripple is only measured in the present work. The input capacitor voltage ripple is 1.28%. The output capacitor is suitably large to maintain the output voltage constant.

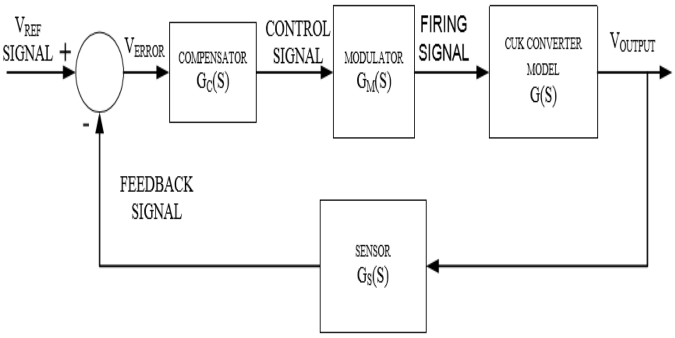


Fig-4.1: Block Diagram **of** ĆUK converter with a Feedback controller

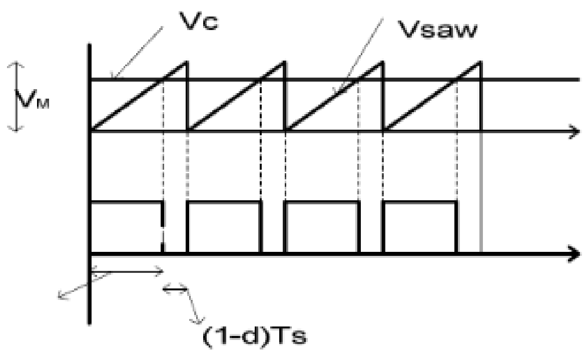


Fig-4.2: Waveform of PWM comparator

Vsaw is the sawtooth voltage of Vm at the PWM comparator.

Table 4.2: Parameters used for closed-loop design

Supply Voltage	12 Volts
Output Voltage	-24 Volts
Switching Frequency	10KHz
Load	12 Ohm
Pulse width or Duty Ratio	50
L1	10 µH
L2	3.2mH
C1	3.7µH
C2	924 µH
Output Ripple	5%

5.COMPARATIVE DISCUSSION ON DIFFERENT TOPOLOGIES BASED ON CHARGING AND PV SYSTEM

The description of the PV application, the PV module is a device that the sunlight energy can be transformed into electrical energy by solar cells. The equivalent circuit of PV is shown below

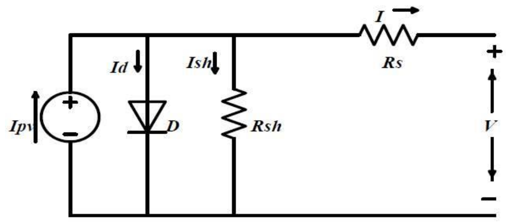


Fig 5.1: Schematic diagram of a single diode solar cell

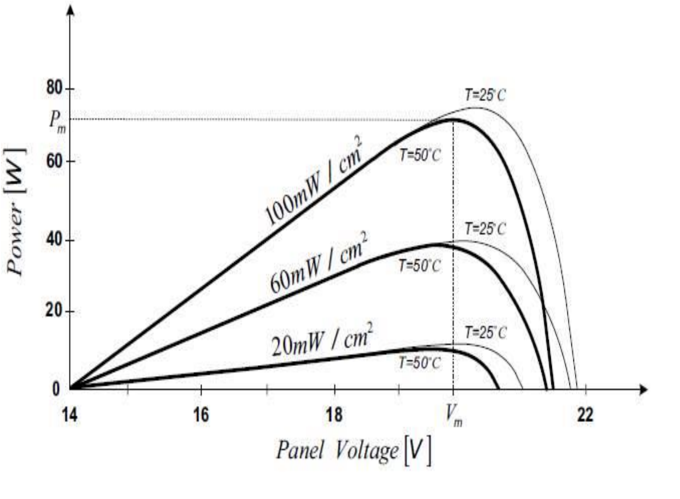
The Ipv is the photovoltaic cell current, which depends on the temperature outside and irradiance. There is a diode that is paralleling with the source Ipv. The R_{sh} and R_s respectively represent the cell's central shunt and series resistances .

In fig 5.2, two different curves are depending on different temperatures. Also, the points that the maximum current with zero voltage

Isc and the maximum voltage with zero current Vo are essential. With this curve, the curve of p-v can be plotted easily, which has been shown in fig 5.3. Referring to this fig 5.3, the maximum point of power Pm generated by the module where the i-v is maximum.

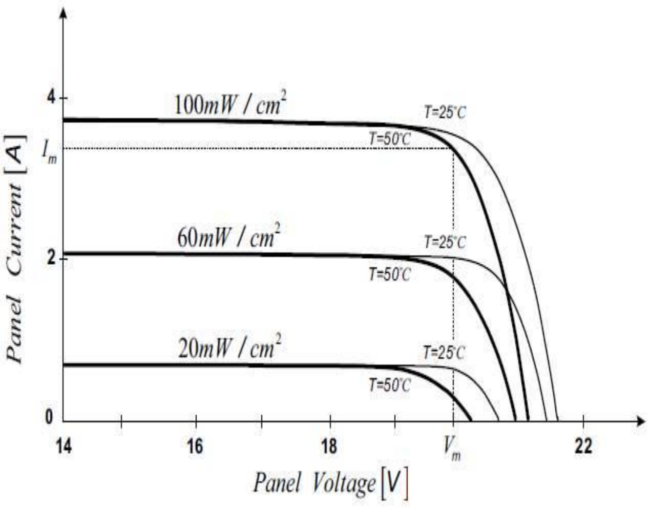
There is an equation to represent the relation between voltage current and the maximum power. This means the coefficient fill factor (FF) of the current multiplying voltage plays an important role in determining the quality of the power. Thereby the magnitude of FF been close to 1 will give a better quality of power.

Pm=FF*Isc*Voc



b) P-V Curve.

Fig-5.2: I-V Characteristics curves of a PV module [6].



a) I-V Curve.

Fig-5.3: P-V Characteristics curves of a PV module.

In standings of the converter of MMPT, the features of the converter are vital to meet the requirement of MPPT application.

Here is the comparison of the characteristics between different converters applied to MPPT techniques.

Compared with buck converter and boost converter, the ĆUK converter has a high output voltage level and low output voltage level with a fixed input voltage depending on the duty ratio.

Table 5.1: Different types of converter and shows the comparison of different converters with respective to their losses and applications

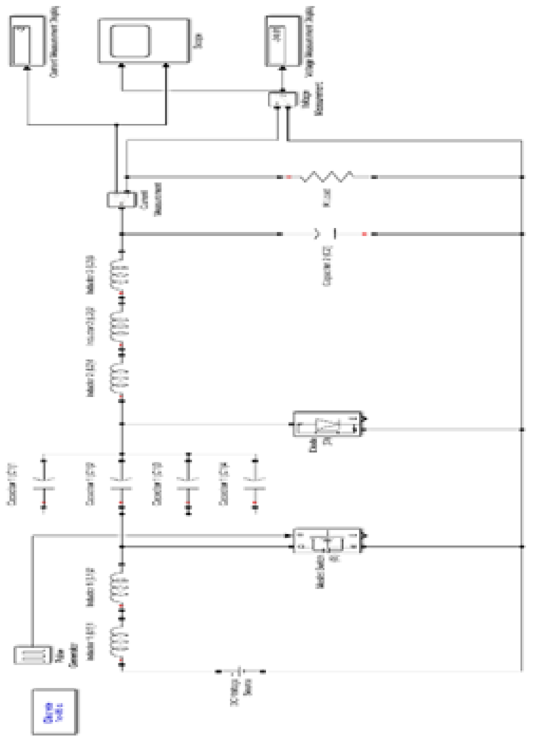
Converter	$K_{crit.}$	R_i(CCM)	R_i (DCM)
Buck Converter	$1-D$	$\frac{R}{D^2}$	$\frac{R}{4}\cdot\left(1+\sqrt{1+4K/D^2}\right)^2$
Boost Converter	$D\cdot(1-D)^2$	$R\cdot(1-D)^2$	$\frac{4\cdot R}{\left(1+\sqrt{1+4D^2/K}\right)^2}$
Buck-Boost-Derived Converters	$(1-D)^2$	$\frac{R\cdot(1-D)^2}{D^2}$	$\frac{K\cdot R}{D^2}$
With $K=\frac{2L_{eq}}{RT_S}$	and	$\frac{1}{L_{eq}}=\frac{1}{L_1}+\frac{1}{L_2}$	DCM occurs for: $K<Kcrit$.

TABLE 5.2: COMPARISION IN DUE OF MODES

Converter	R_{in}	θ	Switching Loses	η	Application
Buck	$\frac{1}{D^2}*R_L$	$0\le\theta\le\phi$	High	Low	Low load-high module voltage
Boost	$(1-D)^2*R_L$	$\phi\le\theta\le90^0$	High	Low	High load-low module voltage
Buck-Boost	$\frac{(1-D)^2}{D^2}*R_L$	$0\le\theta\le90^0$	Low	High	Nearly matched battery and module voltage
Cuk	$\frac{(1-D)^2}{D^2}*R_L$	$0\le\theta\le90^0$	Low	High	Same rating battery and module voltage
Sepic	$\frac{(1-D)^2}{D^2}*R_L$	$0\le\theta\le90^0$	Low	High	Higher rating battery and module voltage

Abbreviation used: D-Duty cycle; R_L-Load Resistance; θ -convergence angle; R_{in} -Input Resistance; $\phi=\tan^{-1}(1/R_L)$

The above table shows the CCM and DCM modes are relevant to the input resistance (*Ri*, is the emulated resistance on the terminals of the PV panel), the equivalent inductance (L_{eq}), and the load connected to the converter (*R*). with the assumption of converters without losses. 'K' parameter determines the ĆUK converter operation in different modes. If the magnitude of K is large, the converter will operate in the CCM. In contrast, the DCM is due to small K values. The boundary-value of K between two modes is a function of the duty cycle. Nevertheless, the converter would operate in CCM for all duty cycles with the condition of the magnitude of k being above one. Occasionally the mode boundary is always given based on the load resistance R. the determinant is the duty cycle D ranging from 0 to 1. [7]

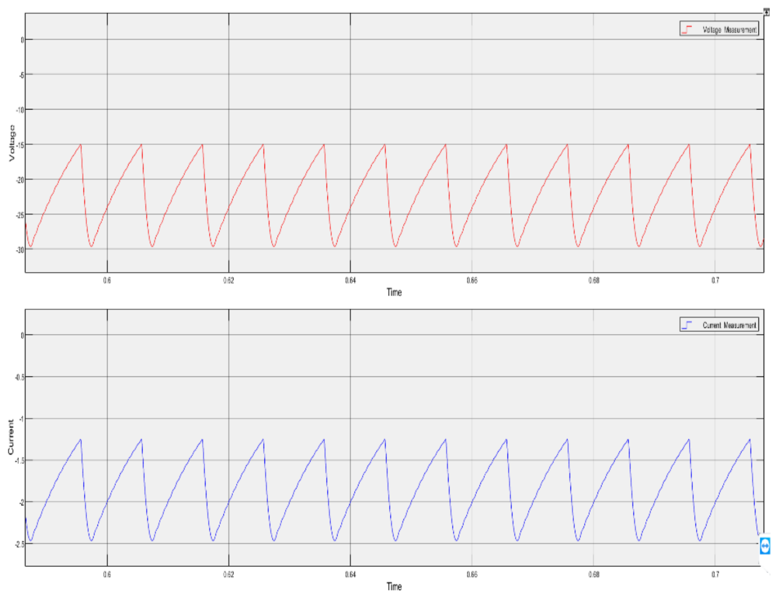


6.SIMULATION CIRCUIT OF OPEN-LOOP ĆUK CONVERTER

Observed Output voltage: -24.01Volts

6.1 OUTPUT WAVEFORMS OF OPEN-LOOP ĆUK ONVERTER

In the above graph,

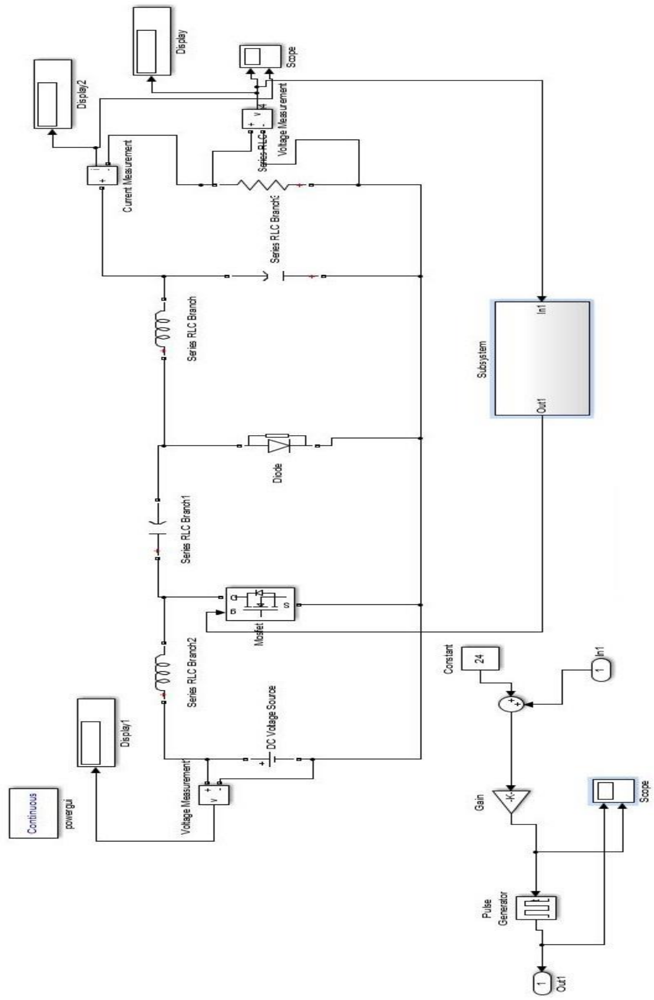


The first waveform shows the voltage measurement across the load

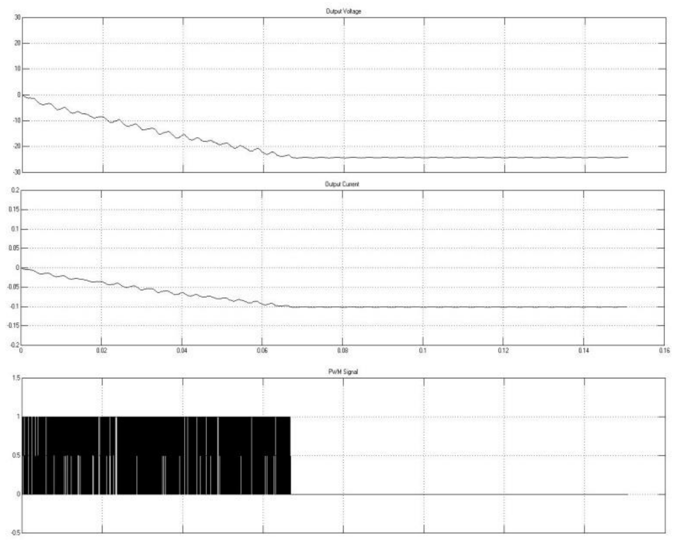
The second waveform shows the current across the load.

7. SIMULATION CIRCUIT OF CLOSED-LOOP ĆUK CONVERTER

Observed Output voltage: -24Volts



7.1 Output waveforms of closed-loop ĆUK converter



In the above graph,

The first waveform shows the voltage measurement across the load.

The second waveform shows the current across the load.

The third waveform shows the PWM signal wave.

8. CONCLUSIONS

The ĆUK Converter output voltage values can be higher or lower than the input voltage. Also, the harmonics of input and output current will be over because of the inductors. This dominance corresponding to PV Applications compared with different converters when it is operated in CCM Mode. In CCM mode, the ĆUK Converter can sweep the whole I-V Curve of the circuit. To get a more smooth output current, it is necessary to have the close loop control strategy and the control strategy P&O for PV Application.

The ĆUK Converter improves the dynamic response without affecting stability. To improve the steady-state performance and converter conversion efficiency, various control methods such as zero voltage, zero current switching's, and chaotic PWM were implemented in ĆUK Converter. The ripple content was examined for each method experimentally and inferred that chaotic PWM based control minimized the ripples in the output voltage and improved spectral performance of the ĆUK Converter. Here in this documentation 12v, i.e., The input voltage of the ĆUK Converter was regulated for the change in the output to a voltage of -24v, for normal ĆUK Converter. We are now using a closed-loop controller circuit. We have developed a closed-loop ĆUK Converter that is now the circuit output becomes independent of the input. And if we go on changing the input, the output remains the same as -24v. This is one of the most significant advantages of using the closed-loop circuit.

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