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Design and Implementation of Dual Input Cuk-SEPIC converter for Energy Storage

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Abstract

In this paper the design of a Dual input Cuk-SEPIC fused DC-DC converter is proposed, using solar and wind sources as input and providing a constant 12V output which is used for battery charging applications. Since Solar and Wind sources usually complement one another i.e. if a solar output is unavailable the wind output is available and vice-versa, this system would provide a constant voltage throughout. Also a feedback system has been designed which would ensure that the output obtained is 12v regardless of the input variations. The designed converter has been used to charge a 12V, 2000 mA-h Li-ion battery using MATLAB/Simulink. It can be seen from the result that the feedback system drastically decreases the variation in the output voltage with the variations in the input voltage.

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I. INTRODUCTION

The ever increasing energy demand, the fast depleting fossil fuel sources which have left their repercussions on the environment have made it mandatory for man to explore into alternate – green energy sources to tide over a forthcoming energy crisis. Lately, a spotlight has fallen on renewable energy sources and issues of sustainability. The world in its critical state is beckoning a change, in the way we think and act. Among the non-conventional, renewable energy sources, solar energy affords great potential for conversion into electric power. The conversion of solar light into electrical energy represents one of the most promising technologies, being clean, silent and reliable, with a very low maintenance cost and minimal ecological impact. Solar energy is free, practically inexhaustible, and involves no polluting residues or greenhouse gas emissions [1].

The renewable energy sources are profusely available throughout the world and hence if they are used more often than the conventional sources of energy it would have great advantages. Unlike the conventional sources of energy, the renewable energy sources do not cause pollution when used, they are by and large pollution free sources. Also, these renewable energy sources are recyclable that is the same source of energy can be used again and again for our purpose Despite being environmentally benign, these renewable energies are unreliable due to the varying climate conditions. This explains why renewable-based power generation requires complex design, planning and control optimization methods. Along with this problem, their initial cost of installation is very high. It i

s too costly to install an effective renewable energy at first even though it becomes economically feasible later on. Also the energy conversion efficiency of renewable energy systems is very low [2].

A. *Hybrid Renewable Energy Systems*

Hybrid renewable energy systems are becoming popular for remote area power generation applications due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. A hybrid energy system usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.

In a developing country like India one of the major problems that needs immediate attention is poverty. Poverty eradication and growth needs energy. According to official estimates, the generation capacity will have to increase by seven times the present figure to meet the country's growth needs. The major part of energy mix consists of fossil fuels. They are finite sources and have serious environmental consequences. In times of depleting resources and climate threats, the best way forward for India is to take the dual path of energy efficiency and renewable. India is rich in renewable resources and must focus on exploiting the abundance to its advantage [3]-[6].

To achieve this, the hybrid renewable energy system helps by investing in supporting mechanisms that strengthen the call for clean energy policies through advocacy and awareness building and creating a supportive renewable energy implementation environment. It's also aimed at helping compliance with evolving renewable energy deployment targets; and building supportive policy evidence through research around grid as well as off-grid business models.

A hybrid renewable energy system utilizes two or more energy production methods, usually solar and wind power. The major advantage of solar / wind hybrid system is that when solar and wind power productions are used together, the reliability of the system is enhanced. Additionally, the size of battery storage can be reduced slightly as there is less reliance on one method of power production. Often, when there is no sun, there is plenty of wind.

B. *Limitations*

These generating systems have some or the other drawbacks, like Solar panels are too costly and the production cost of power by using them is generally higher than the conventional process, it is not available in the night or cloudy days. Similarly Wind turbines can't operate in high or low wind speeds. Also the energy conversion efficiency is quite low.

II. DC-DC CONVERTERS

DC-DC converters convert a source of direct current from one voltage level to another. It comes under the class of power converters. DC -DC converters are important in portable electronic devices such as mobiles and laptops, which are supplied with power from batteries. Such electronic devices often contain several sub-circuit, each has its own voltage level requirement different from that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage). The battery voltage declines as its stored energy is drained. Switched DC -DC converters offer a method to increase voltage from a partially lowered battery voltage hence saving space instead of using multiple batteries to accomplish the same thing. DC - DC converters also regulate the output voltage. DC to DC converters developed to maximize the energy harvest for PV systems and for wind turbines are called power optimizers.

A. *Cuk Converter*

The Cuk converter is a step-down/step-up converter based on a switching boost-buck topology. Essentially, the converter is composed of two sections, an input stage and an output stage. The input voltage is fed into the circuit via inductor L_1. When the switch is on, current I_1 builds the magnetic field of the inductor in the input stage. The diode is reverse biased, and energy dissipates from the storage elements in the output stage. When the switch turns off, inductor L_1 tries to maintain the current flowing through it by reversing polarity and sourcing current as its magnetic field collapses. It thus provides energy to the output stage of the circuit via capacitor C_0. The inductor currents are the input and output currents, therefore, if the principle of conservation of energy is applied [13]:

$$V_o/V_{in}=D_s/\ (1-D_s) \quad (1)$$

Where Ds is the duty cycle of the switch:

$$D_s= T_{on}/\ (T_{on}+T_{off}) \quad (2)$$

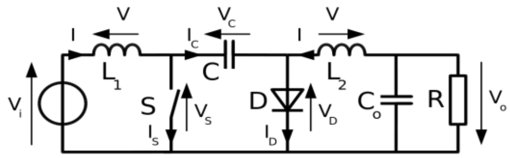


Fig 1. Cuk converter basic topology

The voltage ratio of a Cuk converter is the same as that of a buck-boost converter, but its main advantage over other converters is that the input and output inductors result in a filtered current on both sides of the converter, while buck, boost, and buck-boost converters have a pulsating current that occurs on at least one side of the circuit i.e either on input side or output side.

This pulsation will increase the ripple in the circuit and due to this ripple, the efficiency of battery gets lowered. To ensure good efficiency ripple should be reduced. By controlling the duty cycle of the switch, the output voltage V_o can be controlled and can be higher or lower than the input voltage V_{in}. By using a controller to vary the duty cycle during operation, the circuit can also be made to reject disturbances ,as second part of circuit consists of parallel resonance circuit and it work as a tank circuit for specific frequency (resonant frequency) , and during resonance current will not be allowed to enter in the circuit.

B. SEPIC Converter

The SEPIC is a DC to DC converter in which the output voltage is having same polarity as that of input voltage. One benefit of the SEPIC converter is that the input ripple current in the input capacitor is continuous. This reduces the amount of input capacitance necessary for low-ripple voltage, which reduces EMI (Electro Magnetic Interference). SEPIC converter maintains a fixed output voltage regardless of whether the input voltage is above, equal or below the output voltage. Fig.2 shows the SEPIC basic diagram.

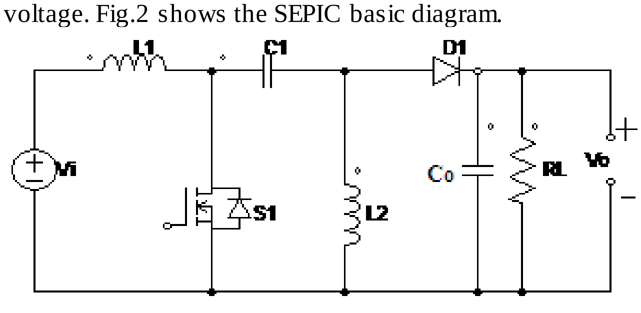


Fig 2. SEPIC Converter basic Topology

V_I is the input voltage of the converter, V_o is the output voltage, L_1 is the inductor connected at the input end and the maximum load current flows in this inductance. L_2 is connected in parallel to the load. The switch s_1 is connected parallel with the input voltage. The switch can be made on and off during the operation.C_1 is the coupling capacitor which stores the voltage. The duty cycle D is defined by the general equation [13] & [26]:

$$M=V_o/V_i \quad (3)$$

$$D=T_{on}/T \quad (4)$$

Where T_{ON} is the on-time of the switch and T is the switching period. The duty cycle is a function of M, where M is the voltage conversion ratio,

$$D= M\ /M+1 \quad (5)$$

$$M=D/1-D \quad (6)$$

So,

$$V_o= (D/1-D)\ Vin \quad (7)$$

The innate nature of these two converters dispels the need for separate input filters, Step up as a well as step a down operations can be used for either of the two renewable energy sources. Both an individual as well as simultaneous operations are supported [13].

A lot of PV/Wind systems with MPPT control have been proposed. A simple Multi input structure has been suggested by [14] which combine the sources from the DC end while still achieving MPPT for each renewable source. Most of the systems that have been proposed use a separate DC/DC boost converter connected in parallel in the rectifier stage as to perform the MPPT control for each of the renewable energy power sources [15]-[18].

However, since we are looking for a constant output voltage the MPPT technique becomes redundant. The voltage across the output will keep varying because the MPPT technique will detect the maximum power. Hence we look for some other methods to get the desired output.

Feedback is a process in which the output or outputs of that system are fed back as inputs as part of a train that forms the circuit. Such a system is then said to have feedback. The feedback technique can be used to get a constant output for battery charging purposes. It is one of the most convenient techniques available [19]. The circuit can be easily designed using the various formulas available.

Out of all the available renewable energy systems, the energy obtained from the photovoltaic source is considered to be one of the most essential sustainable resources because it is ubiquitous, readily available and sustainable.

Despite the fact that sunlight is highly sporadic in nature, solar energy is readily available and free. PV system has more recently become recognized as the forefront in electric power generation amongst renewable energy systems. It can be used to generate dc current electricity without even having an environmental impact and contamination when exposed to solar radiation. As it is a semiconductor device, the photo-voltaic system is static, free of any moving parts, quiet and has little or no operation and maintenance costs. The PV array represents the fundamental power conversion unit of a PV generator system. The output characteristics of a PV module depend on the solar insulation, the cell temperature and the output voltage of the PV module. Due to its nonlinear characteristics, it is necessary to model it for the design.

A solar cell is nothing but a pn junction having a thin wafer of semiconductor. The electro-magnetic radiation emitted by the solar energy can be converted directly into electricity through the photovoltaic effect. Photons when exposed to sunlight with energy greater than the band gap energy of the semiconductor create electron hole pairs proportional to the irradiation [20]. The Photovoltaic Module can be modelled using the equations given in [21]-[23].

III. Dual Input Cuk and SEPIC Converter

Due to increasing concern caused by global warming and excessive usage of most fossil fuel reserves, there has been a shift towards renewable energy solutions to preserve the planet for posterity. Hydro, wind and photovoltaic energy hold the most potential to full fill the required energy demands. Wind energy is capable of supplying humungous amounts of power but its presence is very sporadic as its presence varies during the whole day. Analogous a to wind energy solar energy is present all day but the solar irradiation levels may vary due to change in the intensity levels of the sun and appearance of shadows cast by clouds, trees, etc. An innate drawback of wind and photovoltaic systems are that they are sporadic in nature and hence become unreliable by combining these sporadic sources of energy the power transfer efficiency and reliability can be improved.

An alternative Dual-Input rectifier structure has been suggested for wind and solar energy systems. The proposed design is an amalgamation of Cuk and SEPIC converters.
The hallmarks of the proposed topology are:

- The innate nature of these two converters dispels the need for separate input filters.
- Step up as a well as step a down operations can be used for either of the two renewable energy sources.
- Both an individuals as well as simultaneous operations are supported.

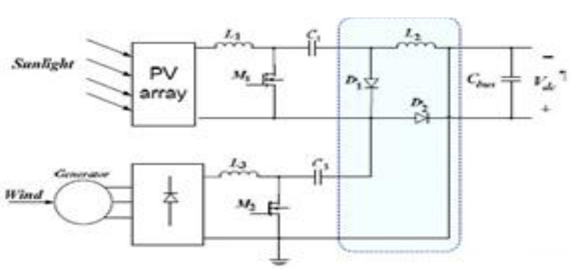


Fig 3 Basic Dual Input Cuk SEPIC Converter

In fig 2.1 a basic system of the proposed rectifier circuit of a dual energy system is shown. One of the inputs is a connected to the output a of a PV array while the other input has been connected to the output of a generator. The amalgamation of a two converters has been achieved by configuring the two existing diodes from each converter and the shared use of the Cuk output inductor by the SEPIC converter. This configuration allows each a converter to operate normally individually if only one source is unavailable. Both converters a have step-up/down a capability, which provide a more design flexibility a in the system.

$$V_{dc}/V_w=d_2/(1-d_2) \quad (8)$$

$$V_{dc}/V_{pv}=d_1/(1-d_1) \quad (9)$$

Table 1: Renewable Energy Sources Table

Source	Current Rating	Voltage Rating	Power Rating
Solar Panel	1.72A (I_1)	21.5V (V_1)	37W
Wind Turbine(PMDC)	1.3A (I_2)	24V (V_2)	31W

Assuming the Duty cycle across the switch M_1 (solar) as 0.2, the duty cycle across M_2 is found to be 0.212 using the formula:
Output voltage $Vo= (D_1/(1-D_1))*V_1 + (D_2/(1-D_2))*V_2$ (10)

Table 2: Duty cycle selection

Switch	M1(Across Solar)	M2(Across Wind)
Duty Cycle	0.20	0.212

where V_1 is 21.5V and V_2 is 24V and V_0 is 12V.

Let us take the switching frequency equal to 20 kHz, so sampling time becomes

$$Ts=1/fs=50 \mu s$$

Now,

$$L_1= (V_1*d_1*T_s)/(I_{1rip}) \quad (11)$$

$$=(21.5*0.2*50*10^{(-6)})/(0.3*1.72) \quad =416.67 \mu H$$

Similarly for L_2 and L_0 and they are found to be:

$$L_2=664.61\mu H$$

$$L_0=75.92\mu H$$

$$L_{eq1}=(L_1*L_0)/(L_1+L_0)=64.21\mu H \quad (12)$$

$$L_{eq2}= (L_2*L_0)/(L_2+L_0)=68.13\mu H$$

$$L_{1'}= (L_1L_{eq1})/(L_1-L_{eq1}) =75.9\mu H$$

$$L_{2'}= (L_2L_{eq2})/(L_2-L_{eq2}) =75.91\mu H$$

Taking the resonant frequency f_r =1000Hz

$$\omega_r = 2*pi*1000$$

So now the values of the capacitances can be found out as:

$$C_1=1/((\omega_r ^2)*(L_1+L_{1'})) =51.42\mu F \quad (13)$$

$$C_2=1/((\omega_r ^2)*(L_2+L_{2'}) =34.20\mu F$$

The values of voltages are as follows:

$$V_{c1}=V_1/(1-d_1) =26.875V$$

$$V_{c2}=V_2/(1-d_2) =18.61V$$

Also,

ΔI_{L1}= $((V_1\text{-}V_{c1})/L_1)*(1\text{-}d_1)*T_s$=0.56A (14)

ΔI_{L2}= $((V_2\text{-}V_{c2})/L_2)*(1\text{-}d_2)*T_s$=0.32A

Now the peak current through M_1

$=I_{L1} + I_{L0}$

=1.7+5.6 A

= 7.4A

Voltage through switch M1= $V_{c1} + V_{d1}$

=26.875+0.8 V

=27.675 V

Voltage through switch M2= $V_{c2} + V_{d2}$

=30.61 V

Peak current through M_2 = I_{L2}+ I_{L0}

= 1.3 + 5.69 A

= 6.99 A

Table 3. Selected parameters value

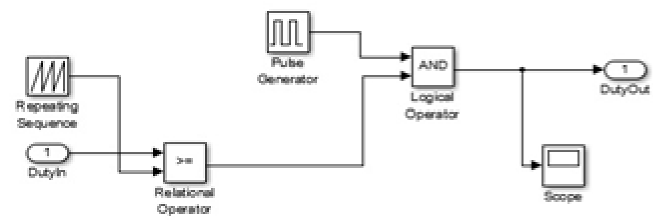
Sl.No.	Component	Value
1	L_1	416.67 µH
2	L_2	664.61µH
3	C_1	51.42µF
4	C_2	34.20µF
5	L_0	75.92µH
6	C_0	300 µF
7	Load Resistance	5Ω
8	Switching Frequency	20kHz
9	L_1	416.67 µH

Table 4. Calculated values

Sl.No.	Parameter	Value
1	Current Ripple across L_1	30%
2	Current Ripple across L_2	30%
3	Current Ripple across L_0	30%
4	Voltage across C_1	26.875V
5	Voltage across C_2	18.61V
6	Peak Current Through Switch M_1	7.4A
7	Switch M_1 Voltage	27.675V
8	Peak Current Through Switch M_2	7A
9	Switch M_2 Voltage	30.61V
10	Current Ripple across L_1	30%

Table 5 Solar PV module values

Sl.No.	Parameter	Value
1	Open circuit voltage V_{oc}	21.5 V
2	Short Circuit Current I_{sc}	2.42 A
3	T_r	298K
4	A (Ideality Factor)	1.6
5	Λ (Irradiation)	1000W/m^2
6	N_s	36
7	N_p	1
8	k (Boltzman constant)	1.3806488 × 10^(-23) J/K
9	q (electron Charge)	1.60217657 × 10^(-19) C
10	K_i	0.0017A/ C^0
11	Power rating	37W



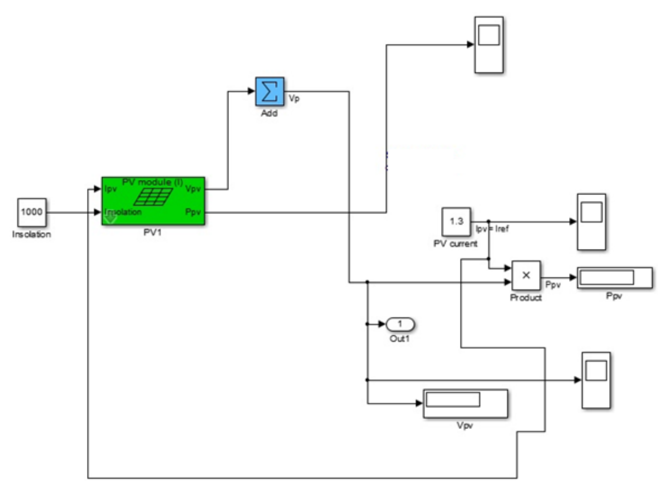


Fig 4. PV Panel Design Simulink model

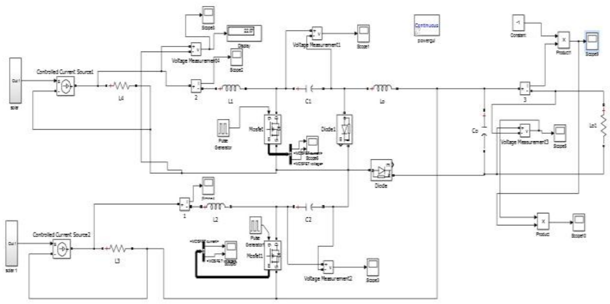


Fig 5. Converter Simulink Design Without feedback

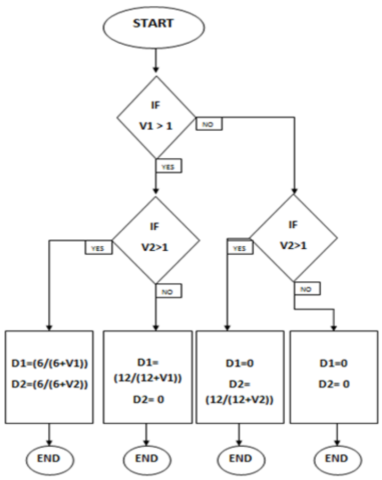


Fig 6. Flow chart for control circuit

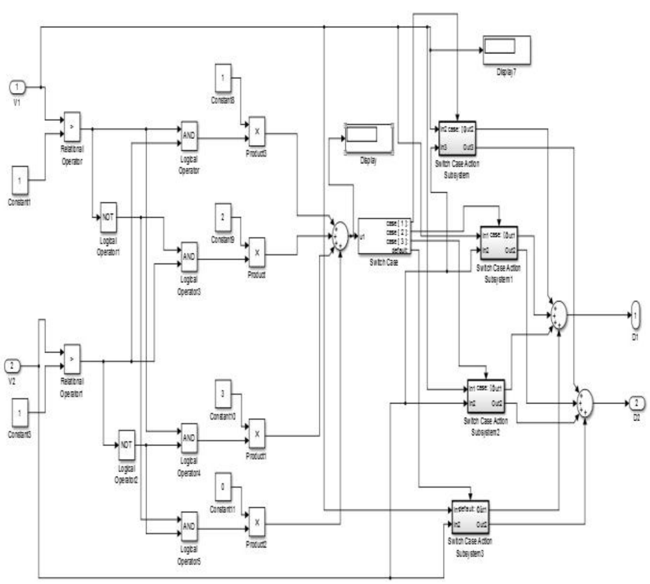


Fig. 7 Control Logic Design using Matlab

IV. SIMULATION RESULTS

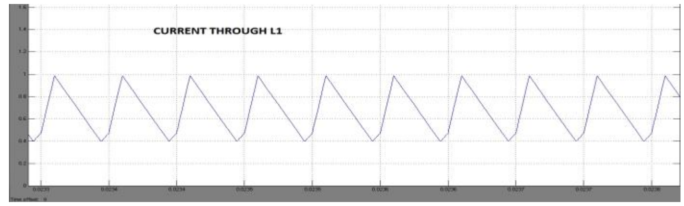


Fig. 8 Current through L1

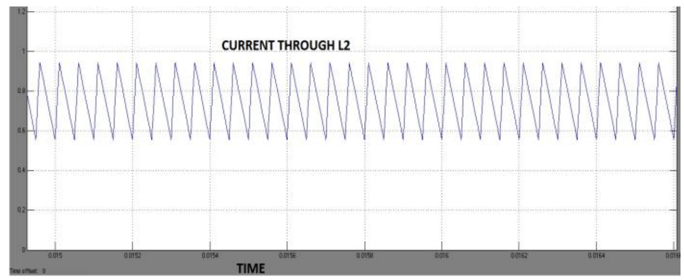


Fig. 9 Current through L2

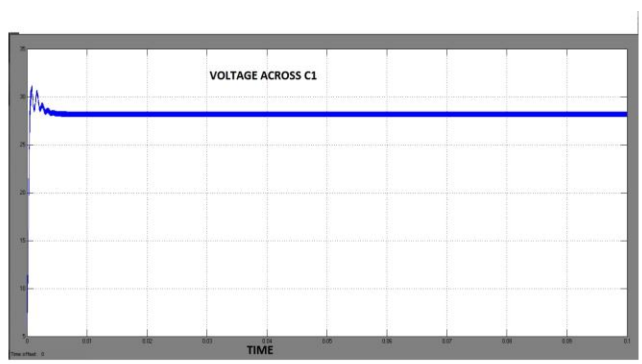


Fig. 10 Voltage across C1

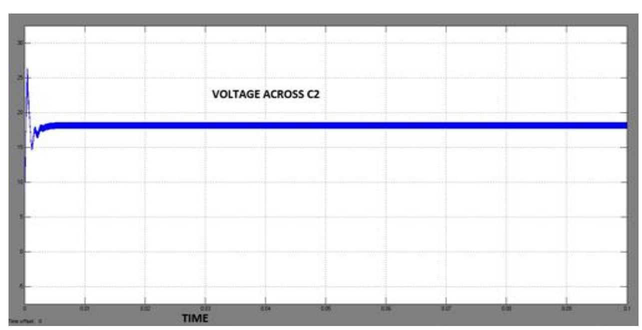


Fig. 11 Voltage across C_2

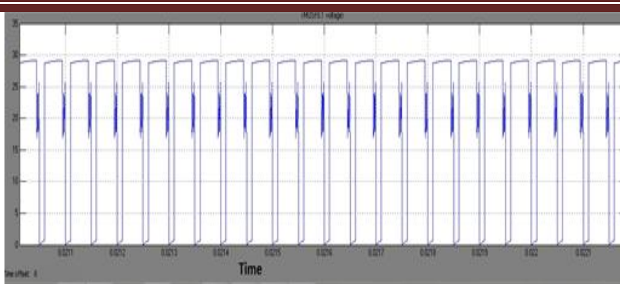


Fig. 12 Voltage across the switch M_1

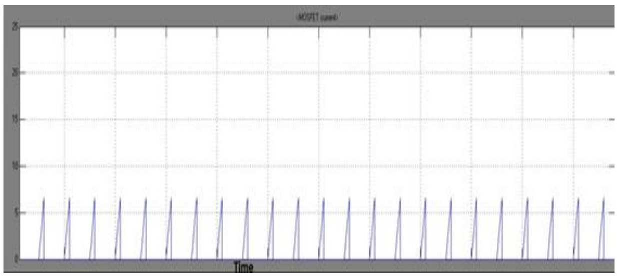


Fig. 13 Current through the switch M_1

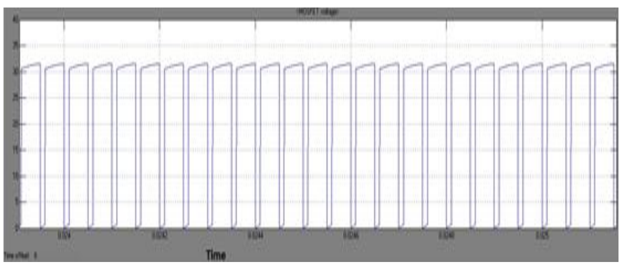


Fig. 14 Voltage across switch M_2

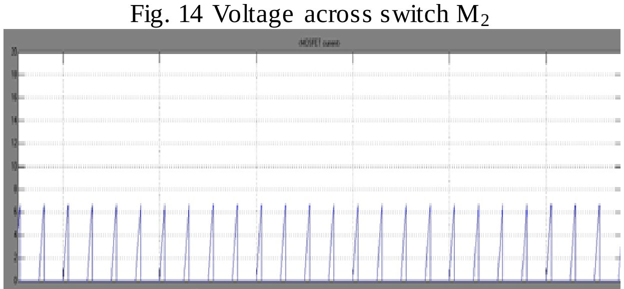


Fig. 15 Current through M_2

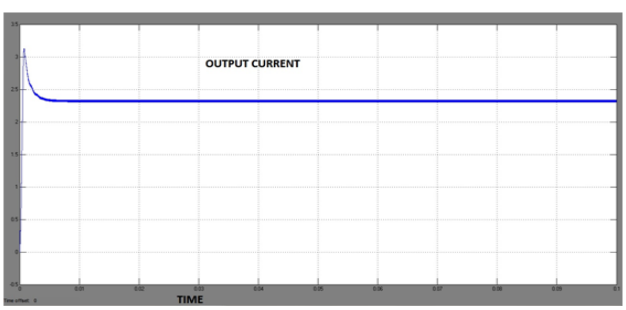


Fig. 16 Output current

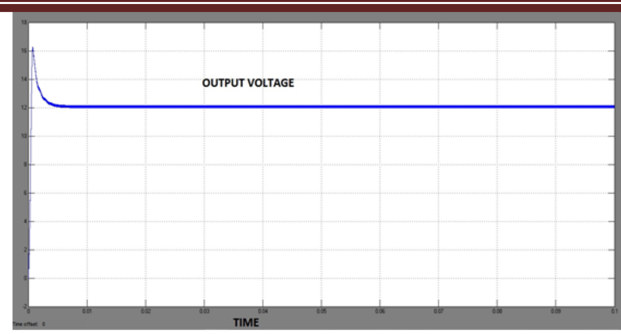


Fig 17. Output voltage across C_0

Table 6 Voltage values with and without feedback

Voltage From PV Panel	Voltage from Wind Turbine	Output Voltage without Feedback	Output Voltage with Feedback
21.5V	24V	11.5V	12.6V
14V	17.5V	7.7V	11.7V
6V	9.8V	3.5V	11.6V
21.5V	0V	5.3V	11.6V
14.5V	0V	3.3V	11.4V
0V	24V	6V	11.5V
0V	18V	4.5V	11.4V

Thus, it can be seen from the table 6 that even with heavy variations in the input sources due to fast changing climate, the feedback circuit ensures that the variations at the output are minimized. The output voltage varies as little as 1V, ranging from 11.4V to 12.5V with the feedback system, but without the feedback, heavy variations can cause the output voltage to drastically decrease, ranging from as low as 3V to as high as 12V.

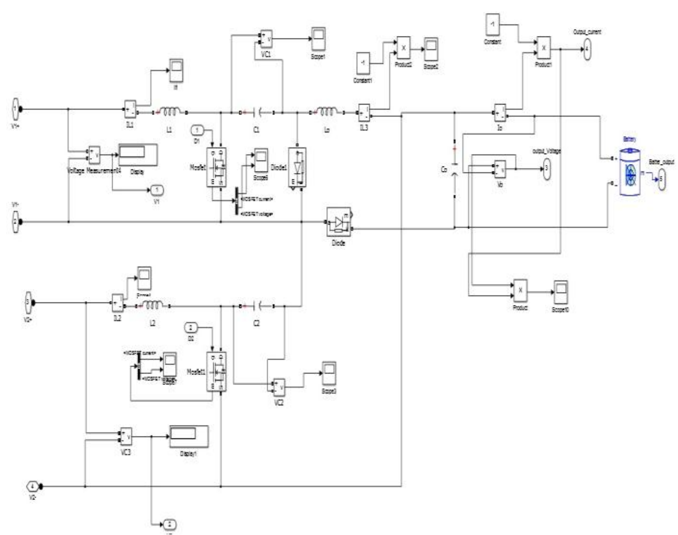


Fig. 18 Converter Simulink design with Battery charging circuit

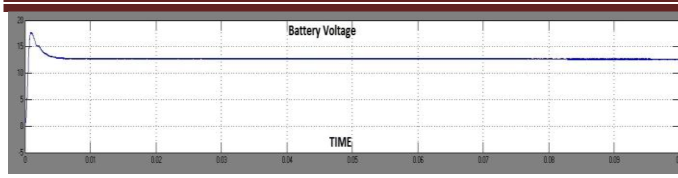


Fig. 19Voltage across the Battery

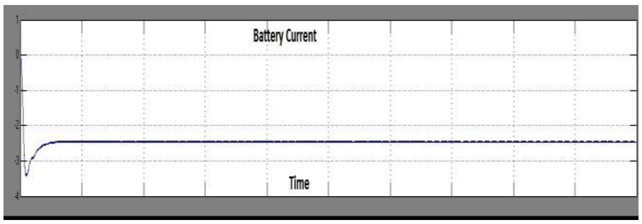


Fig. 20 Current through the battery

V. CONCLUSION

In this project, a dual input Cuk-SEPIC DC-DC converter with a feedback circuit has been presented. The converter uses a hybrid renewable energy source, namely the solar and wind power sources, at its input and provides a constant 12V at its output, which has been used to charge a 12V Li-ion battery. An advantage of using a hybrid Solar-Wind system is that at most times at least one of the sources is available. A major drawback of using renewable energy as the primary source is its irregularity. The irregularity in the input sources causes the output voltage to fluctuate. Rapidly changing environments can cause very large fluctuations which would not satisfy the constant voltage requirement. This limitation has been overcome using a feedback network, which ensures that the output obtained is constant.

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