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Research Article

Performance Enhancement of Hybrid Wind/Photo Voltaic System Using Z Source Inverter with Cuk-sepic Fused Converter

[1]A. Nazar Ali and [2]R. Jayabharath
[1]K. Ramakrishnan College of Technology, Trichy-621 112, Tamilnadu, India
[2]K.S.R. Institute for Engineering and Technology, Tiruchengode, Namakkal, Tamilnadu, India

Abstract: This study presents a new method of design of z source inverter for improving the performance of the hybrid wind/photo voltaic system with cuk-sepic fused converter. The various drawbacks of the conventional converter are, it requires passive input filters, the generator current decreases its lifespan, increases the power loss due to heating. In proposed method, the Cuk-SEPIC fused converter is used, which eliminates the need of additional input filters to filter out high frequency harmonics. This configuration makes it possible for the wind source and photo voltaic source to supply the load separately or simultaneously depending on their availability. A simulation model for the hybrid wind/photovoltaic system has been developed using MATLAB/SIMULINK.

Keywords: Cuk converter, SEPIC converter, solar PV, wind energy, z source inverter

INTRODUCTION

Conventional energy sources based on oil, coal and natural gas have proven to be highly effective drivers of economic progress, but at the same time damaging to the environment and to human health. Fuel cells, as one of the most promising energy sources, have attracted awareness from automotive engineers as well as power electronics engineers and have been used in a variety of areas, such as domestic applications, utility applications and traction applications (Hansen *et al*., 2001) Unlike batteries that have fairly constant output voltage, the fuel cell has a unique V-I characteristic and wide voltage change range as shown in Fig. 1. As can be seen from the figure, the output voltage of the fuel cell decreases as the output current increases. This results in difficulty for high speed and high power operation to achieve a great Constant Power Speed Ratio (CPSR).

In addition, a larger inverter is required. Currently, there are two existing inverter topologies used for hybrid electric and fuel cell system: the conventional single phase Pulse Width Modulation (PWM) inverter and a single phase PWM inverter with a DC-DC boost converter, which is also very popular in other applications. Because of the wide voltage range and limited voltage level of fuel cell stack, the conventional PWM inverter topology imposes high stresses to the switching devices and motor and limits the motor's constant power speed ratio. The dc/dc boosted PWM inverter topology can alleviate the stresses and limitations, however, suffers problems such as high cost and complexity associated with the two stage power conversion.

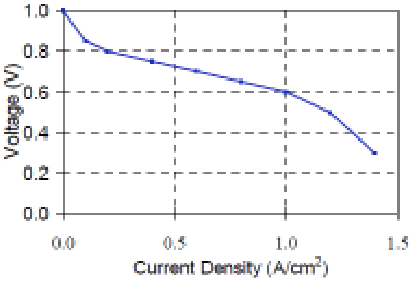

Fig. 1: Typical fuel cell polarization curve

The newly proposed Z-source inverter has the unique feature that it can boost the output voltage by introducing shoot through operation mode, which is forbidden in traditional voltage source inverters (Ahmed *et al*., 2008). With this unique feature, the Z-source inverter provides a cheaper, simpler, single stage approach for applications of fuel cell. Moreover, it highly enhances the reliability of the inverter because the shoot through can no longer destroys the inverter (Arsudis and Vollstedt, 1989). This study presents a new method of design of z source inverter for improving the performance of the hybrid wind/photo voltaic system with cuk-sepic fused converter.

CONVENTIONAL METHOD

The various drawbacks of the below conventional converter are, it requires passive input filters, the generator current decreases its lifespan, increases the power loss due to heating.

Corresponding Author: A. Nazar Ali, K. Ramakrishnan College of Technology, Trichy-621 112, Tamilnadu, India

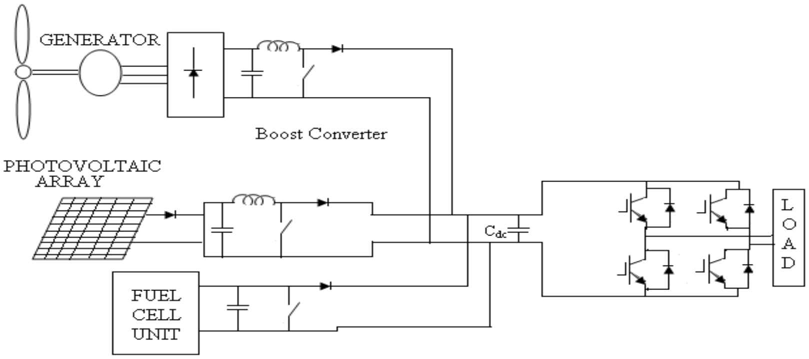

Fig. 2: Conventional converter hybrid system

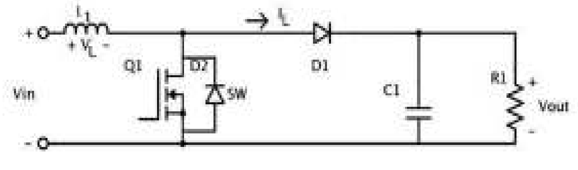

Fig. 3: Circuit diagram of boost converter

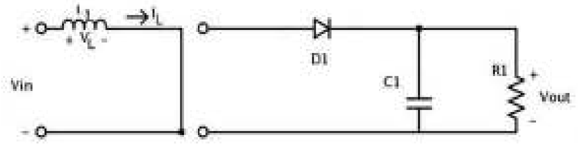

Fig. 4: Mode 1 circuit diagram of boost converter T_{ON}

The conventional converter hybrid system shown in the Fig. 2. In conventional method of energy production of power supply the wind and solar energy are separately used to produce the power.

When a source is unavailable or insufficient in meeting the load demands it is impossible to maintain the power demand. The common inherent drawback of wind and photovoltaic systems are there intermittent natures which make them unreliable.

Boost converter: A simple boost converter consists of an inductor, a switch, a diode and a capacitor as shown in Fig. 3. Boost converter circuit can be divided into two modes. Mode 1 begins when the switch SW is turned on at $t = T_{ON}$ as shown in Fig. 4. The input current which rises flows through inductor L and switch SW. During this mode, energy is stored (Arsudis and Vollstedt, 1989) in the inductor. Mode 2 begins when the switch is turned off at $t = T_{OFF}$. The current that was flowing through the switch would now flow through inductor L, diode D, capacitor C and load R as shown in Fig. 5. The inductor current falls until the switch is turned on again in the next cycle. Energy stored in the inductor is then transferred to the load. Therefore, the output voltage is greater than the input voltage and is expressed as (Mohan *et al*., 2003):

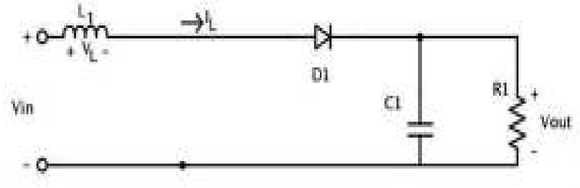

Fig. 5: Mode 2 circuit diagram of boost converter T_{OFF}

$$V_{out} = \frac{1}{1-k} V_{in} \tag{1}$$

where,

V_{out} = The output voltage

k = Duty cycle

V_{in} = Input voltage which in this case will be the solar panel voltage

In order to operate the converter in Continuous Conduction Mode (CCM), the inductance is calculated such that the inductor current (Bogalecka, 1993) flows continuously and never falls to zero as shown in Fig. 6. Thus, L is given by (Mohan *et al*., 2003):

$$L_{min} = \frac{(1-k)^2 kR}{2f} \tag{2}$$

where,

L_{min} = The minimum inductance

k = Duty cycle

R = Output resistance

f = The switching frequency of switch SW

The output capacitance to give the desired output voltage ripple is given by (Mohan *et al*., 2003):

$$C_{min} = \frac{k}{RfV_r} \tag{3}$$

$$V_r = \frac{\Delta V_{out}}{V_{out}} \tag{4}$$

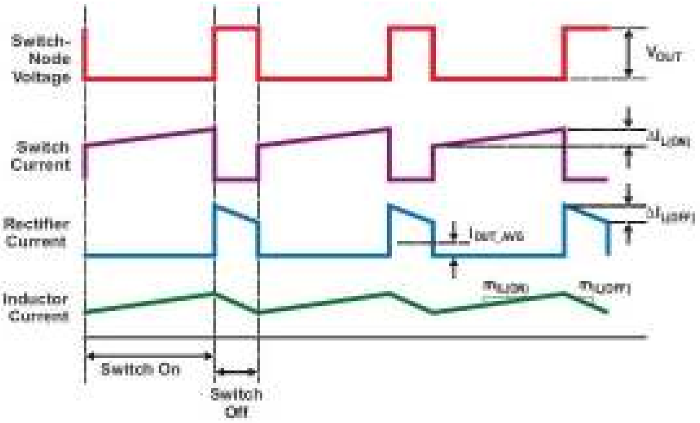

Fig. 6: Waveforms for boost converter operating under CCM

where,

$C_{\min}$ = The minimum capacitance
k = Duty cycle
R = Output resistance
f = Switching frequency of switch SW
Vr = Output voltage ripple factor. Vr can be expressed as (Mohan *et al*., 2003)

Proposed method: This proposed converter includes an alternative multi-input rectifier structure and Z source inverter for hybrid wind/solar energy systems. The proposed design involves a combination of the Cuk and SEPIC converters.

The Z source inverter employs a unique impedance network with split inductor L_1. L2 and capacitor C1, C2 connected in X shape. With the impedance network, the Z source inverter can advantageously use the shoot through state to boost voltage. The inductor and capacitor in the Z source inverter are both energy storage devices, so their value can be optimally designed to ensure small size and low cost. The relevant characteristic features of the proposed converter constitute the following: the inherent nature of these two converters eliminates the necessity for separate input filters (Tan, 2004).

In this proposed converter one of the inputs is connected to the output of the photovoltaic array and the other input is connected o the output of a generator. The fusion of the two converters is achieved by reconfiguring the two existing diodes from converter and the shared utilization of the cuk output inductor by the sepic converter (Simonetti *et al*., 1997).

The Structure proposed is a fusion of the buck and buck-boost converter. The systems in literature require passive input filters to remove the high frequency current harmonics injected into wind turbine generators (Marques *et al*., 2003). The harmonic content in the generator current decreases its lifespan and increases the power loss due to heating. The inherent nature of these two converters eliminates the need for separate input filters power factor correction. It can support step up/down operations for each renewable source (can support wide ranged of PV and wind input), MPPT can be realized for each source. Individual and Simultaneous operation is supported (Lipo, 1984).

Mode of operation: Here the circuit uses a Z source converter which is nothing but a combination of voltage source and current source circuit. Here the advantages of Z source inverter is that it can handle both ac-ac conversion as well as dc-dc conversions. This configuration makes each converter to operate individually even if only one source is available (Kim *et al*., 2008). Figure 7 illustrates the case when only the wind source is available. When, only the wind source is available, the Diode, D1 turns off and Diode D2 turns on (Bhowmik *et al*., 1999). The proposed circuit becomes a SEPIC converter. The input to output voltage relationship is given by Eq. (5). In the case, if only the PV source is available, then Diode D2 turns off and Diode D1 will turn on and always be on and the circuit becomes a CUK converter. This is illustrated in the Fig. 7. The input to output voltage relationship is given by Eq. (6):

$$\frac{V_{dc}}{VW} = \frac{d2}{1-d2} \tag{5}$$

$$\frac{V_{dc}}{VPV} = \frac{d1}{1-d1} \tag{6}$$

In both of the cases, both converters have step-up/down capability. The mode of operation briefly explains by the Fig. 8 to 10.

If the turn on duration of $M1$ is longer than $M2$, then the switching states will be state I, II, IV. Similarly, the switching states will be state I, III, IV, if the switch conduction periods are vice versa (Chen and Spooner, 1998).

Mode 1 ON, mode 2 ON:

$$i_{L1} = I_{LPV + \frac{V_{PV}}{L_1}t} \; 0 \angle t \angle d_{1T_S} \tag{7}$$

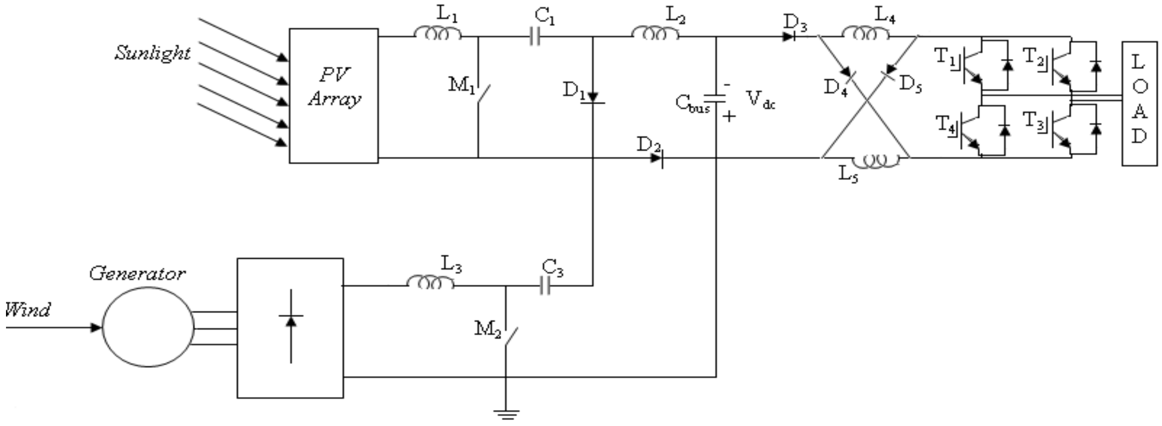

Fig. 7: Proposed converter hybrid system

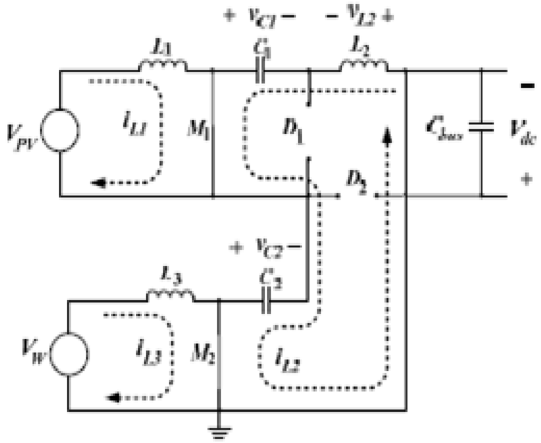

Fig. 8: M1 ON, M2 ON

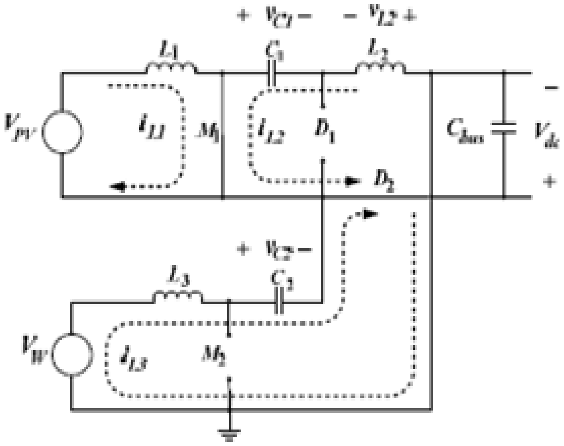

Fig. 9: M1 ON, M2 OFF

$$i_{L2} = I_{dc} + \left[\frac{V_{c1} + V_{c2}}{L_2}\right] t \ \ 0 \angle \ t \angle \ d_{\ 1\,Ts} \qquad (8)$$

$$i_{L3} = \ I_{LW} + \frac{V_W}{L_3} t \qquad 0 < t < d_1 T_s \qquad (9)$$

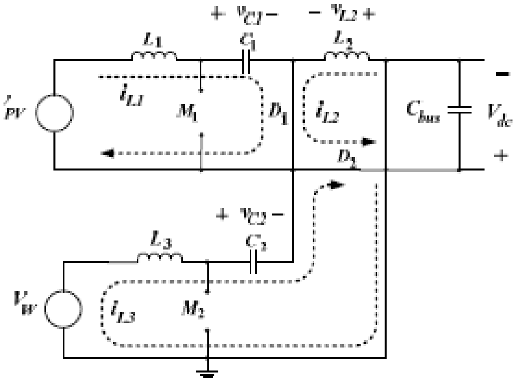

Fig. 10: M1 OFF, M2 OFF

Mode 1 ON, mode 2 OFF:

$$i_{L1} = I_{LPV} + \frac{V_{pv}}{L_1} t. \ \ o < t < d_1 T$$

$$i_{L2} = I_{LPV} + \left(\frac{V_{dc} - V_{CL}}{L_2}\right) t. \ \ \ d_2 T_s < t < T_s$$

$$i_{L3} = I_{LW} + \left(\frac{V_m - V_{c2} - V_{dc}}{L_3}\right) t \ d_2 T_s < t < T_s$$

Mode 1 OFF, mode 2 OFF:

$$i_{L2} = I_{LPV} + \left(\frac{V_{pv} - v_{c1}}{L_1}\right) \qquad d_1 T_s < t < d_2 T_s$$

$$i_{L2} = I_{dc} + \frac{v_{c2}}{L_2} t \qquad d_1 T_s < t < d_2 T_s$$

$$i_{L3} = I_{LW} + \frac{V_w}{L_3} t \qquad d_1 T_s < t < d_2 T_s$$

Mode 1 OFF, Mode 2 OFF:

$$i_{L1} = I_{LPV} + \left(\frac{V_{PV} - v_{c1}}{L_1}\right) \qquad d_2 T_s < t < T_s$$

$$i_{L2} = I_{dc} - \frac{V_{dc}}{L_2} t \qquad d_2 T_s < t < T_s$$

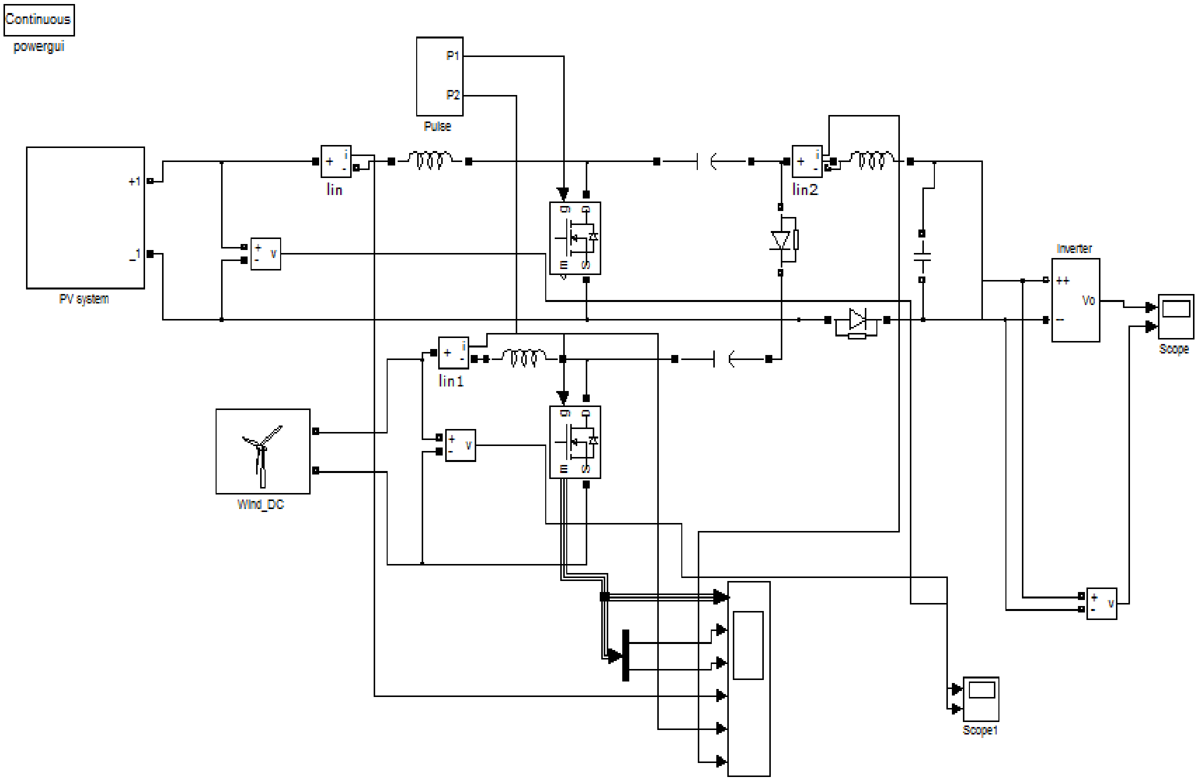

Fig. 11: Simulation diagram

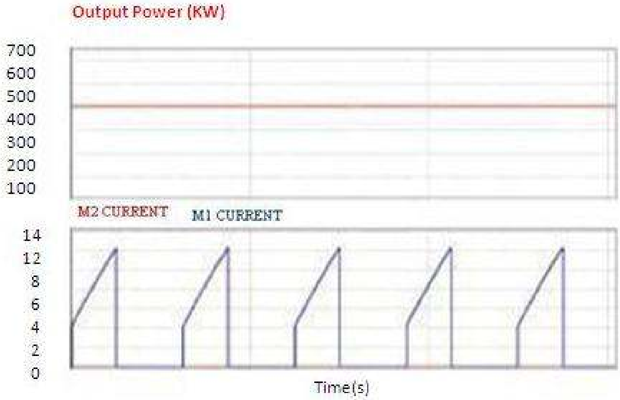

Fig. 12: Individual operation with only PV source (Cuk operation) top: output power, bottom: switch currents (M1 and M2)

$$i_{L3} = I_{LW} + \left(\frac{V_W - v_{c2} - V_{dc}}{L_3}\right)t \qquad d_2T_s < t < T_s$$

Both the Cuk and Sepic Mosfet current consists of both the input current and the capacitors (c1 or c2) current the pv output current, which is also equal to the average input current of the cuk converter, it can be observed that the average inductor current is a function of its respective duty cycle (d1), (Pang *et al*., 2008) therefore by adjusting the respective duty cycles for each energy source, maximum power point tracking can be achieved.

RESULTS AND DISCUSSION

SIMULINK is a software package for modeling, simulating and analyzing dynamic systems. It supports linear and non linear systems, modeled in continuous time, sampled time, or a hybrid of the two. Figure 11 shows the overall model of the simulation diagram. Its consists of wind source and pv cell module.

Systems can have different parts that are sampled or updated at different rates. A MATLAB and SIMULINK are integrated, analyze and revise our models in either environment at any point. Thus using

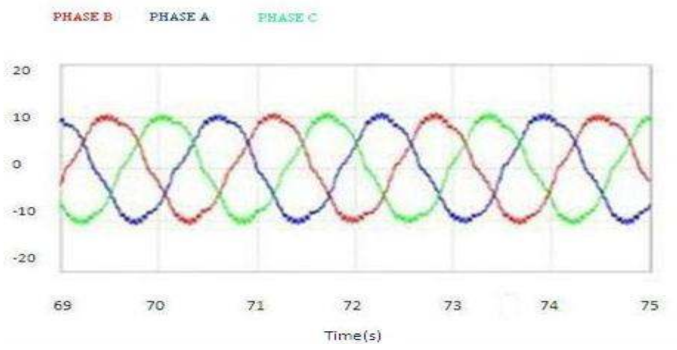

Fig. 13: The injected three phase generator current

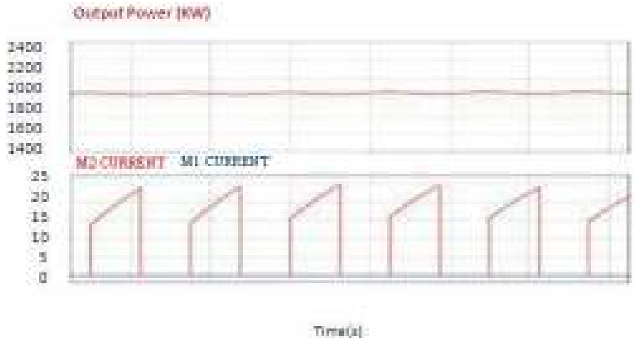

Fig. 14: Top: output power, bottom: switch currents (M1 and M2)

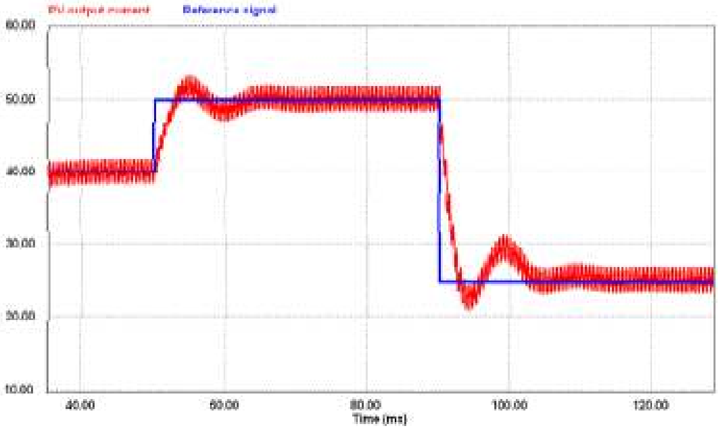

Fig.15: Solar MPPT-PV output current and reference current signal (cuk operation)

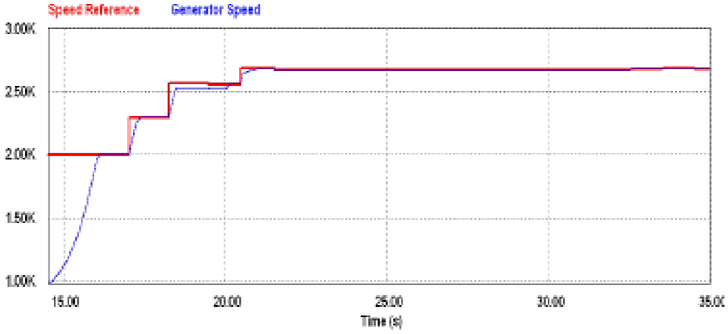

Fig. 16: Wind MPPT-generator speed and reference speed signal (sepic operation)

SIMULINK, MATLAB models have been created for soft switched boost converter and its triggering circuit and their simulation results have been obtained. Figure 12 to 16 shows the Output Power, Bottom: Switch Currents wave forms for Individual Operation with only PV Source.

In this section, simulation results from psim 8.0.7 are given to verify that proposed multi-input rectifier stage can support individual as well as simultaneous operation:

Output power	:-	3 kW
Switching frequency	:-	20 kHz
Output voltage	:-	500 V

CONCLUSION

This project presents a new method of configuration of the front-end rectifier stage for a hybrid wind/photovoltaic energy system. This Configuration makes it possible for the wind source and photo voltaic source to supply the load separately or simultaneously depending on their availability. Here the Cuk-SEPIC fused converter is used, which eliminates the need of additional input filters to filter out high frequency harmonics. Harmonic contents greatly affect the generator lifespan, heating issues and efficiency. Here it uses a z source inverter which gives the maximum output by obtaining both voltage and current to be maximum.

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