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A Soft-Switching DC/DC Converter With High Voltage Gain for Renewable Energy Application

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Abstract- A soft-switching dc/dc converter with high voltage gain is proposed in this paper. It provides a continuous input current and high voltage gain. Moreover, soft-switching characteristic of the proposed converter reduces switching loss of active power switches and raises the conversion efficiency. The reverse-recovery problem of output rectifiers is also alleviated by controlling the current changing rates of diodes with the use of the leakage inductance of a coupled inductor. Hybrid power system consists of a combination of renewable energy sources such as: photovoltaic (PV), wind generators, hydro, etc., to charge batteries and provide power to meet the energy demand. Finally, a simplified design procedure is proposed in hybrid system by using stand-alone application.

Index Terms— **Soft Switching, Boost converter, High voltage gain, Hybrid power system(photo voltaic, wind generators, hydroelectric systems), stand-alone system.**

1.INRODUCTION

Recently, the demand for dc/dc converters with high voltage gain has increased. The energy shortage and the atmosphere pollution have led to more researches on the renewable and green energy sources such as the solar arrays and the fuel cells.

Moreover, the power systems based on battery sources and super capacitors have been increased. Unfortunately, the output voltages of these sources are relatively low. Therefore, the step-up power conversion is required in these systems. Besides the step-up function, the demands such as low current ripple, high efficiency, fast dynamics, light weight, and high power density have also increased for various applications. Input current ripple is an important factor in a high step-up dc/dc converter [5]. Especially in the fuel cell systems, reducing the input current ripple is very important because the large current ripple shortens fuel cell's lifetime as well as decreases performances. Therefore, current fed converters are commonly used due to their ability to reduce the current ripple.

In applications that require a voltage step-up function and a continuous input current, a continuous-conduction-mode (CCM) boost converter [3][4] is often used due to its advantages such as continuous input current and simple structure. However, it has a limited voltage gain due to its parasitic components.

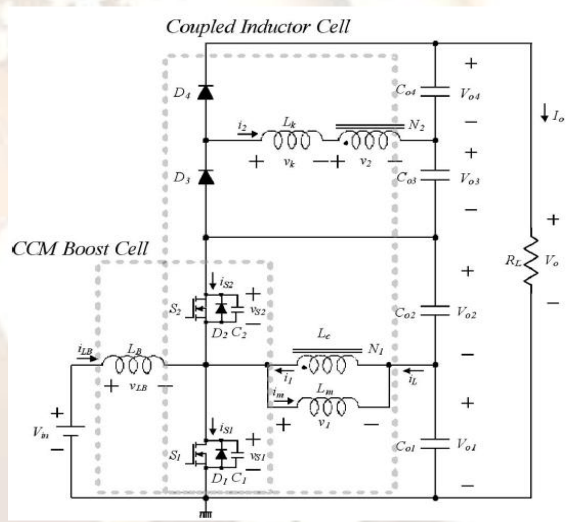

Fig. 1. Circuit diagram of the proposed dc/dc converter.

The reverse-recovery problem of the output diodes is another important factor in dc/dc converters with high voltage gain. In order to overcome these problems, various topologies have been introduced. In order to extend the voltage gain, the boost converters with coupled inductors are proposed[2]. Their voltage gains are extended, but they lose a continuous input current characteristic and the efficiency is degraded due to hard switchings of power switches. For a continuous input current, current-fed step-up converters are proposed. They provide high voltage gain[1] and galvanic isolation. However, the additional snubbers are required to reduce the voltage stresses of switches. In order to increase the efficiency[6][7] and power conversion density, a soft-switching technique is required in dc/dc converters.

Increasing population growth and economic development are accelerating the rate at which energy and in particular electrical energy is being demanded. All methods of electricity generation have consequences for the environment, so meeting this growth in demand, while safe- guarding the environment poses a growing challenge.

Renewable energy technology offers the promise of clean, abundant energy gathered from self-renewing resources such as sun, wind, water, earth and plants. Virtually all regions of the world have renewable resources of one type or another. Renewable energy technology offer important benefits compared to those of conventional energy sources.

Hybrid power systems consists of a combination of renewable energy sources such as: photovoltaic (PV), wind generators, hydro, etc., to charge batteries and provide power to meet the energy demand, considering the local geography and other details of the place of installation. These types of systems, which are not connected to the main utility grid, are also used in stand-alone applications and operate independently and reliably. The best applications for these systems are in remote places, such as rural villages, in telecommunications, etc.

2. ANALYSIS OF THE PROPOSED CONVERTER

Fig. 1 shows the circuit diagram of the proposed soft switching dc/dc converter with high voltage gain. Its key waveforms are shown in Fig. 2. The switches S1 and S2 are operated asymmetrically and the duty ratio *D* is based on the switch S1. D1 and D2 are intrinsic body diodes of S1 and S2. Capacitors *C*1 and *C*2 are the parasitic output capacitances of S1 and S2 .The proposed converter contains a CCM boost cell. It consists of *LB*, S1, S2, *Co*1, and *Co*2.

The CCM boost cell provides a continuous input current. When the switch S1 is turned on, the boost inductor current *iLB* increases linearly from its minimum value *ILB*2 to its maximum value *ILB*1. When the switch S1 is turned off and the switch S2 is turned on, the current *iLB* decreases linearly from *ILB*1 to *ILB*2. Therefore, the output capacitor voltages Vo1 and Vo2 can be derived easily as

$$V_{01} = V_{in} \qquad (1)$$

$$V_{02} = \frac{D}{1-D} V_{in}. \qquad (2)$$

The coupled inductor current *iL* varies from its minimum value −*IL*1 to its maximum value *IL*2. The operation of the proposed converter in one switching period *Ts* can be divided into six modes as in Fig.3.

Mode 1 [t0, t1]: At *t*0 , the switch S2 is turned off. Then, the boost inductor current *iLB* and the coupled inductor current *iL* start to charge *C*2 and discharge C1. Therefore, the voltage Vs1 across S1 starts to fall and the voltage Vs2 across S2 starts to rise.

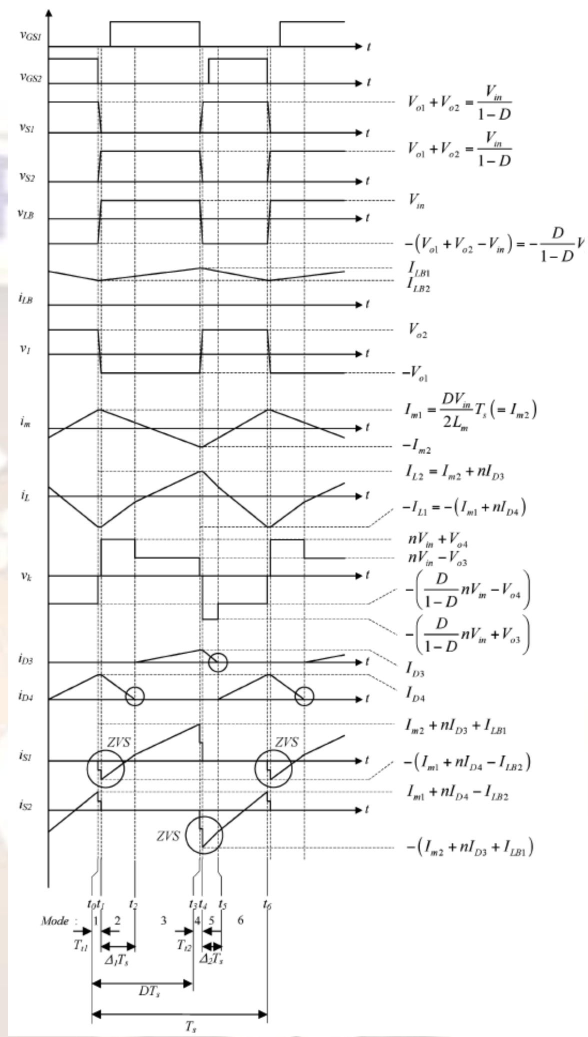

Fig. 2. Key waveforms of the proposed converter.

$$T_{t1} = \frac{(C_1 + C_2)V_{in}}{(1-D)(I_{L1} - I_{LB2})}. \qquad (3)$$

Mode 2 [t1, t2]: At *t*1, the voltage *v*S1 across the lower switch S1 becomes zero and the lower diode D1 is turned on. Then, the gate signal is applied to the switch S1.

Mode 3 [t2, t3]: At *t*2, the secondary current *i*2 changes its direction. The diode current *i*D4 decreases to zero and the diode D4 is turned off.

Mode 4 [t3, t4]: At *t*3, the lower switch S1 is turned off. Then, the boost inductor current *iLB* and the coupled inductor current *iL* start to charge *C*1 and discharge *C*2.

$$T_{t2} = \frac{(C_1 + C_2)V_{in}}{(1-D)(I_{L2} + I_{LB1})}. \quad (4)$$

Mode 5 [t4, t5]: At $t4$, the voltage v_{S2} across the upper switch S2 becomes zero and the diode D2 is turned on. Then, the gate signal is applied to the switch S2. From modes 3 and 5, the currents i_{D3} can be written as follows:

$$I_{D3} = \frac{nV_{in} - V_{03}}{L_k}(D - \Delta_1)T_s \quad (5)$$

Where, the output voltage Vo3 can be obtained

$$V_{03} = \frac{D - \Delta_1 - \left(\frac{D}{1} - D\right)\Delta_2}{D - \Delta_1 + \Delta_2} nV_{in} \quad (6)$$

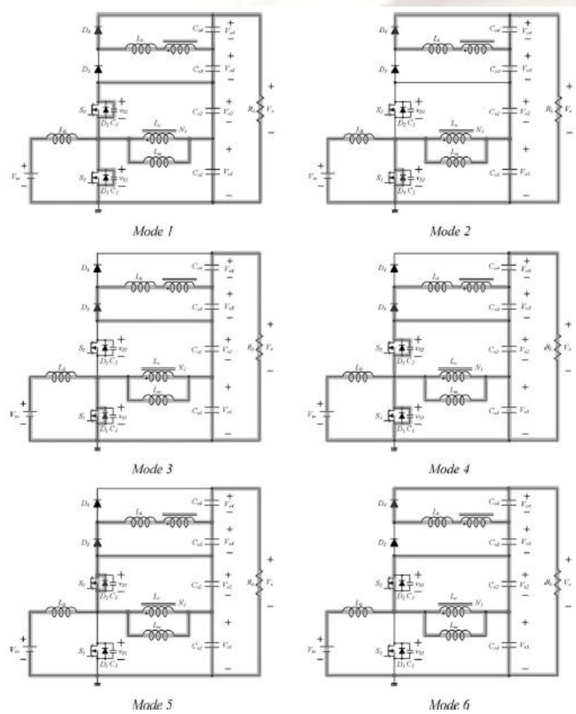

Fig. 3. Operating modes.

Mode 6 [t5, t6]: At $t5$, the secondary current $i2$ changes its direction. The diode current i_{D3} decreases to zero and the diode D3 is turned off. From modes 2 and 6, the current i_{D4} can be written as follows:

$$I_{D4} = \frac{nV_{in} - V_{03}}{L_k}\Delta_1 T_s \quad (7)$$

Where, the output voltage Vo4 can be obtained

$$V_{04} = \frac{D - \Delta_1 - \left(\frac{D}{1} - D\right)\Delta_2}{1 - D + \Delta_1 - \Delta_2} nV_{in} \quad (8)$$

Where, $\Delta_1 = \alpha D$, $\Delta_2 = \alpha(1-D)$ and

$$\alpha = \frac{1}{2}\left(1 - \sqrt{1 - \frac{8L_k I_o}{nV_{in} D T_s}}\right) \quad (9)$$

This paper proposes a new soft-switched CCM boost converter suitable for high-power applications such as power factor correction, hybrid electric vehicles, and fuel cell power conversion systems. The proposed converter has the following advantages:

1) ZVS turn-on of the main switches in CCM;
2) negligible diode reverse recovery due to ZCS turn-off of the diode;
3) voltage conversion ratio is almost doubled compared to the conventional boost converter;
4) significantly reduced components' voltage ratings and energy volumes of most passive components.

3. MODELLING THE COMPONENTS OF A HYBRID POWER SYSTEM

3.1 Modelling of PV system

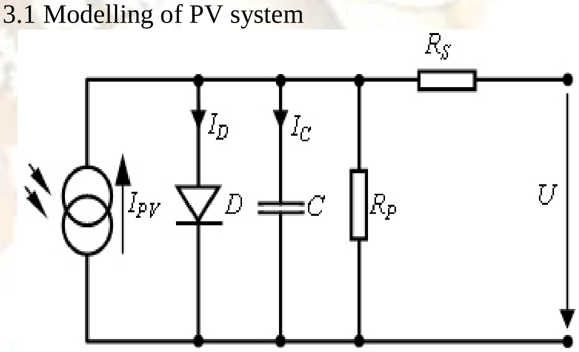

Fig. 4. Equivalent circuit diagram of a solar cell

The use of equivalent electric circuits makes it possible to model characteristics of a PV cell. The method used here is implemented in MATLAB programs for simulations. The same modeling technique is also applicable for modeling a PV module. There are two key parameters frequently used to characterize a PV cell. Shorting together the terminals of the cell, the photon generated current will follow out of the cell as a short-circuit current (Isc). Thus, Iph = Isc, when there is no connection to the PV cell (open-circuit), the photon generated current is shunted internally by the intrinsic p-n junction diode. This gives the open circuit voltage (Voc). The PV module or cell manufacturers usually provide the values of these parameters in their datasheets.

$$I = I_{PV} - I_0\left(e^{\frac{qU}{kT}} - 1\right) \quad (10)$$

$$U = \frac{kT}{q}\ln\left(1 - \frac{I - I_{PV}}{I_0}\right) \quad (11)$$

Where:

- k-Boltzmann constant;
- T-reference temperature of solar cell;
- U-solar cell voltage;

Equations (10) and (11) lead to development of a Matlab/Simulink model for the PV model presented in Fig. 5.

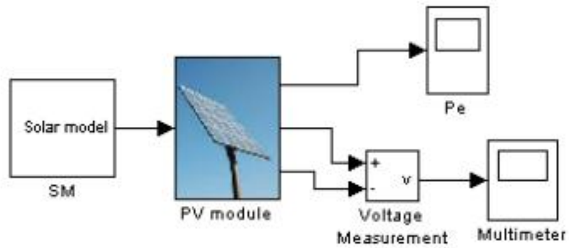

Fig. 5 Matlab/Simulink Library PV module

The solar system model consists of three Simulink blocks: the solar model block, the PV model block and energy conversion modules.
The output of the PV module is processed by an energy conversion block implemented with a PWM IGBT inverter block from standard Simulink / Sim Power Systems library.

3.2 Modelling the Wind Energy System

Modelling the wind energy converter is made considering the following assumptions:

- friction is neglected;
- stationary wind flow;
- constant, shear-free wind flow;
- rotation-free flow;
- incompressible flow (ρ=1.22 kg/m³);
- free wind flow around the wind energy converter.

The kinetic energy W taken from the air mass flow m at speed v1in front of the wind turbine's pales and at the back of the pales at speed v2 is illustrated by equation:

$$W = \frac{1}{2} m \left(v_1^2 - v_2^2 \right) \quad (12)$$

The resulted theoretical medium power P is determined as the ratio between the kinetic energy and the unit of time and is expressed by the below equation:

$$P = \frac{W}{t} = \frac{1}{2}\frac{m}{t}\left(v_1^2 - v_2^2 \right) = \frac{1}{2}\frac{V\rho}{t}\left(v_1^2 - v_2^2 \right) \quad (13)$$

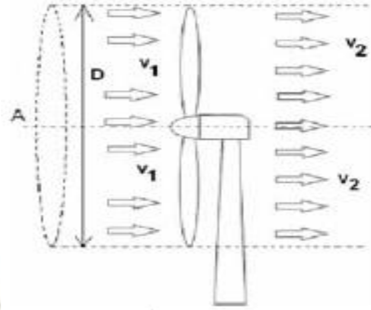

Fig. 6. Flow through a wind energy converter

The electrical power obtained under the assumptions of a wind generator's electrical and mechanical part efficiency is given by:

$$P_{wind} = \frac{1}{2} \rho A v_1^3 \quad (14)$$

$$P_{el} = \frac{1}{2} C_e \rho A v_1^3 \quad (15)$$

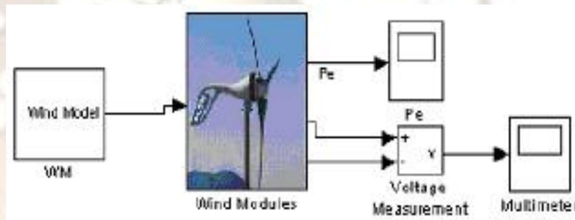

Fig. 7. The Matlab Simulink model of the wind generator module.

The wind energy generator model was implemented by a module having configurable parameters based on equation(15) and using the equivalent model of a generator. This model takes the following form and is shown in Figure 8.

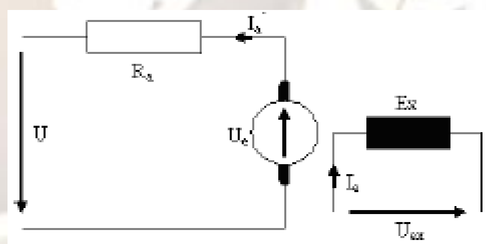

Fig. 8. Equivalent circuit diagram of a small wind generator

The output of the wind energy generator module is processed by an energy conversion block implemented with a PWM IGBT inverter block from the standard Simulink/Sim Power System library.

3.3 Modelling the Hydroelectric System

Hydroelectrical system is characterized by different particular kinetic and potential energy at both sites. The correct identification of the resulting energy differences of the out-flowing water can be assumed by considering a stationary and friction-free flow with incompressibility. The hydrodynamic Bernoulli pressure equation applied in such conditions is written according to equation(16).

$$p + \rho_{water} gh + \frac{1}{2}\rho_{water} v_{water}^{2} = const. \qquad (16)$$

Speed of water flow and can be identified by the term of kinetic water energy. The energy losses are represented by the part of the rated power which is converted into ambient heat by friction and cannot be used technically.

$$P_{water,th} = \rho_{water} g \dot{q}_{water} \left(h_{up} - h_{down}\right) \qquad (17)$$

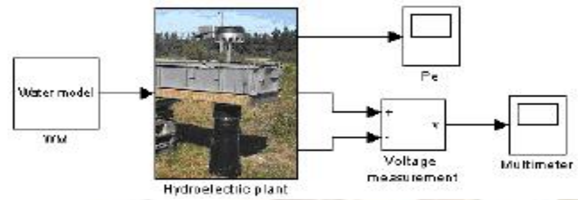

Fig. 9 The Matlab Simulink model of the hydroelectrical system.

$$P_{turbine} = \eta_{turbine} \rho_{water} g \dot{q}_{water} h_{util} \qquad (18)$$

3.4 Modelling the Storage Device

The energy storage devices/equipments are used basically for three purposes: energy stabilization, ride through capability and dispatchability.

The energy stabilization permits the hybrid system to run at a constant stable output level with the help of the energy storage device, even if the load fluctuations rapidly.

Rate of charge and discharge should not be too high in order to extend service life of the battery; the frequency of charging and discharging cycles affects the battery life significantly.

In figure 10 the Thevenin equivalent battery model is presented.

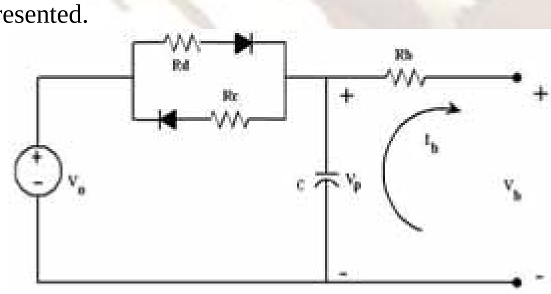

Fig. 10. Thevenin equivalent battery model.

The equations of the circuit model are:

$$\dot{V}_P = \frac{1}{c}\left(\left(\frac{V_0 - V_p}{R_d}\right) - I_b\right) \qquad (19)$$

$$V_b = V_p - I_b R_b \qquad (20)$$

Based on this model and the equations above, a Matlab/Simulink model was developed for the battery storage device.

4. HYBRID SYSTEM

In order to implement a real hybrid system a theoretical preliminary study is required. Such study can be performed on simulation model[8]. A simulation model is presented in Fig. 11.

The simulation model basically consists of the models presented above connected together to form an isolated hybrid system. The proposed model allows studies of modeled DC and AC consumers in stand-alone application[9][10][11].

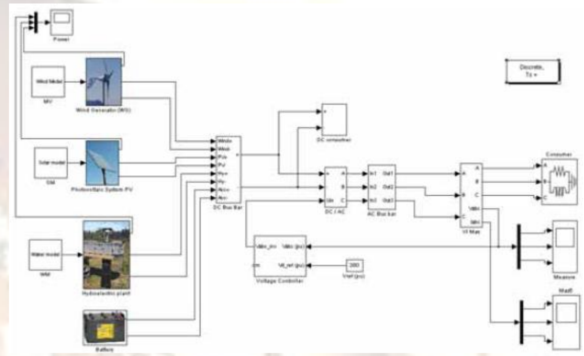

Fig. 11 Simulation model of a hybrid renewable energy system

5.MATLAB/SIMULINK MODEL AND SIMULATION RESULTS OF A SOFT SWITCHING DC/DC CONVERTER USING HIGH VOLTAGE GAIN

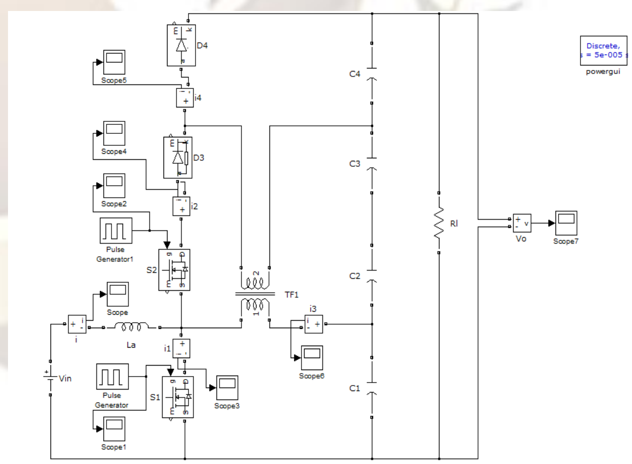

Fig. 12. Shows the Matlab/Simulink diagram of a Soft Switching DC/DC Converter

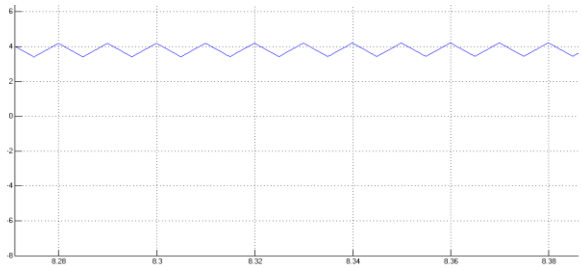
Fig. 13. Inductor Current ILB

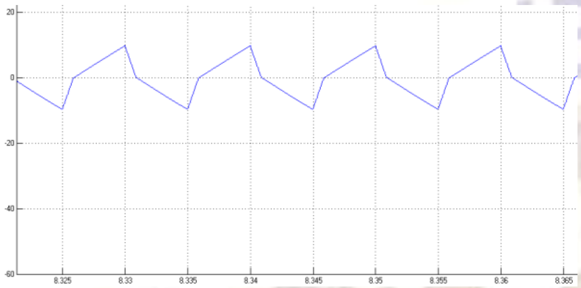
Fig. 14. Inductor Current IL

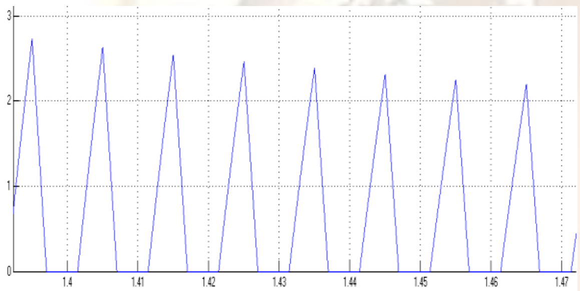
Fig. 15. Diode Current ID3

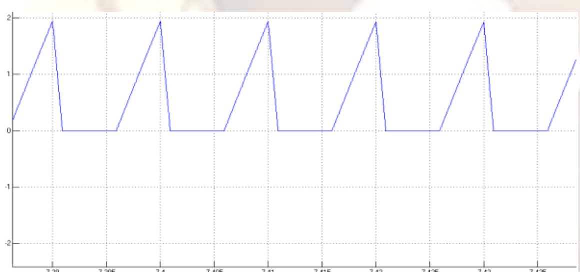
Fig. 16 Diode Current ID4

Fig. 13 and 14 shows the inductor currents input current ILB and IL. Fig. 15 and 16 shows the diode currents of D3 and D4.

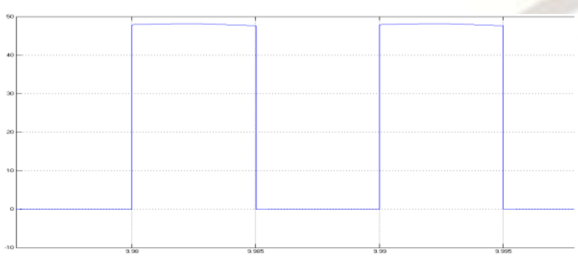
Fig. 17 Voltage across switch S1

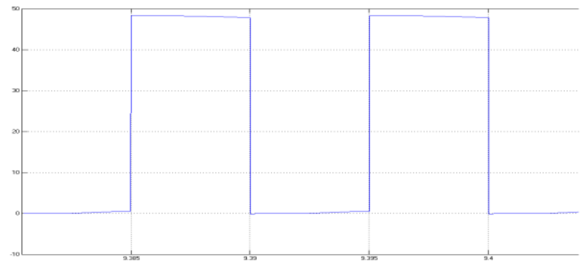
Fig. 18 Voltage across switch S2

Fig. 17 and Fig.18 shows the voltage across switch s1 and s2.

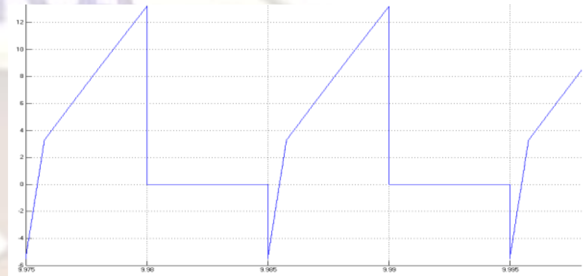
Fig. 19 Secondary side currents IS1

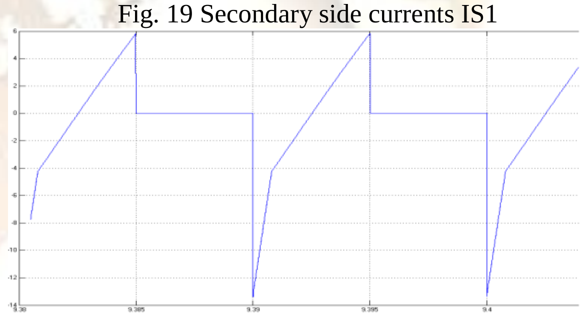
Fig. 20 Secondary side currents IS2

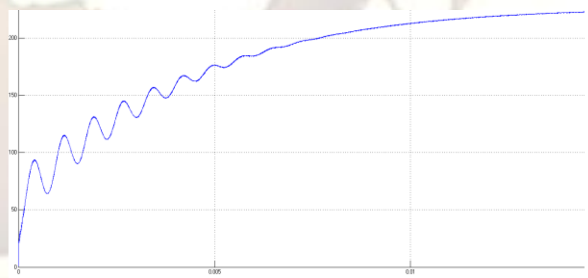
Fig. 21 Capacitor output voltage

Fig. 19 and 20 shows the secondary side currents of IS1 and IS2 respectively. Fig.21 shows the capacitor output voltage.

HYBRID RENEWABLE ENERGY SYSTEM

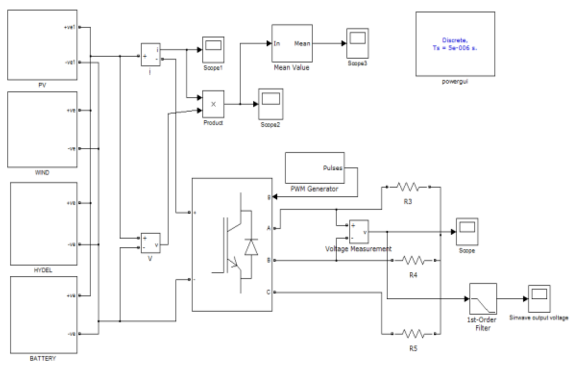

Fig. 22 Matlab/Simulink model of hybrid Renewable Energy system

Fig. 22 shows the block diagram of standalone renewable energy source.Here we have considered PV, Wind, Hydral.

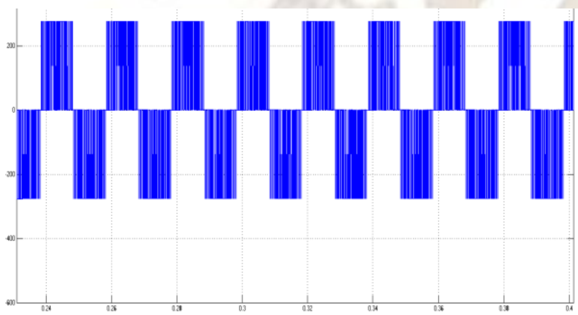

Fig. 23. PWM output of inverter

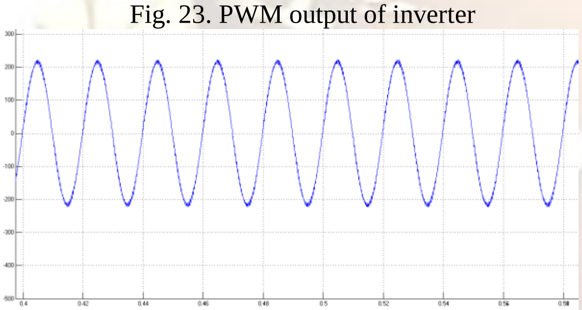

Fig. 24. Sinusoidal output

Fig.23 and Fig.24 shows the PWM output of inverter with and without filter.

6. CONCLUSION

A soft-switching dc/dc converter with high voltage gain has been proposed in this paper. The proposed converter can minimize the voltage stresses of the switching devices and lower the turn ratio of the coupled inductor. It provides a continuous input current, and the ripple components of the input current can be controlled by using the inductance of the CCM boost cell. Finally the proposed converter is applied in standalone renewable application. A Matlab/Simulink model is developed and simulation results are presented.

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