Design and Analysis of Interleaved Boost Converter For Renewable Energy Applications

S. Kamtip and K. Bhumkittipich

Abstract—*This paper presents the design and analysis of interleaved boost converter for renewable energy sources. According to the changing of the input command of renewable energy sources, the output voltage has been changed. Therefore this paper proposes the interleaved boost converter for controlling the output voltage at 600V. The structure of interleaved boost converter covers an input voltage span from 100V to 300 V and has an output voltage of 600V. The converters are controlled by interleaved switching signals, which have the same switching frequency and the same phase shift. By virtue of the converters, the input current can be shared among the cells or phases, so that high reliability and efficiency in power electronic systems can be obtained. In addition, it is possible to improve the system characteristics such as maintenance, repair, fault tolerance, and low heat dissipation. Moreover, the overall performance of the compromised design was shown to be quite good. All this was verified by simulation.*

Keywords— *Interleaved Boost Converter, Renewable Energy System, Sharing Current.*

1. INTRODUCTION

The energy consumption is steadily increasing and the deregulation of electricity has caused that the amount of installed production capacity of classical high power stations cannot follow the demand. A method to fill out the gap is to make incentives to invest in renewable energy sources like wind turbines, photovoltaic systems, and also fuel cell systems. The output voltage of renewable energy sources has been changed and not enough. The developments of power converter are very important, in order to achieve a good operation for supplying the load when the main sources aren't enough.

To transfer the energy from renewable energy sources to conventional 380 Vrms AC systems, it is necessary to step the voltage up using a DC/DC converter. The boost converter is strongly suitable for this purpose, but, to obtain a high voltage gain, the boost converter must operate with duty cycle greater than 0.95, which is very hard to achieve due to operational limitations. Besides, the converter must work in a bidirectional way, due to its two operation possibilities: as source, supplying energy to the load, helping the main sources, and as a load, storing exceeding energy. To solve the drawback of the low voltage gain in conventional boost converters, some topologies were suggested, as in [1-4]. In [1] and [2], the use of an interleaved boost converter associated with an isolated transformer was introduced, using the high frequency AC link. Despite of the good performance of such topology, it uses three magnetic cores. In [3], the converter presents low input current ripple and low voltage stress across the switches. However, high current flows through the series capacitors at high power levels. In [4] converters with high static gain based on the boost flyback topology are introduced. These converters present low voltage stress across the switches, but the input current is pulsed, as it needs an LC input filter. This paper will propose the design and analysis of interleaved boost converter for renewable energy sources. According to the changing of the input command of renewable energy sources, the output voltage has been changed. The structure of interleaved boost converter covers an input voltage span from 100V to 300 V and has an output voltage of 600V. The converters are controlled by interleaved switching signals, which have the same switching frequency and the same phase shift.

This paper will first explain the basic principle of renewable energy sources. Next, the operation and design of interleaved boost converter are obtained. The simulation results are also presented. Finally, a general conclusion and discussion are proposed.

2. RENEWABLE ENERGY SOURCES

Three different renewable energy sources are briefly described. There are Fuel cell, wind power and photovoltaic.

A. Fuel Cell Energy

The fuel cell is a chemical device, which produces electricity directly without any intermediate stage and has recently received much attention. The most significant advantages are low emission of green house gases and high power density. The emission consists of only harmless gases and water. The noise emission is also low. The energy density of a typical fuel cell is 200 Wh/l, which is nearly ten times of a battery. Various fuel cells are available for industrial use or currently being investigated for use in industry, including

⇒Proton Exchange Membrane

⇒Solid Oxide

⇒Molten Carbonate

⇒Phosphoric Acid

⇒Aqueous Alkaline

The efficiency of the fuel cell is quite high (40%-60%). Also the waste heat generated by the fuel cell can usually be used for cogeneration such as steam, air-conditioning, hot air and heating, then the overall

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efficiency of such a system can be as high as 80%. Equation (1)-(3) express the voltage and power equation of fuel cell and Fig. 1 shows the equivalent circuit of fuel cell.

$$V_{cell} = E_{cell} - V_{act,cell} - V_{ohm,cell} - V_{conc,cell} \quad (1)$$

$$P_{FC} = N_{cell} E_{cell} I_{cell} \quad (2)$$

$$E_{cell} = E_{o,cell} - k_E (T - 298) + \frac{RT}{4F} \ln\left(\frac{P_{o2} (P_{H2})^2}{(P_{H20})^2} \right) \quad (3)$$

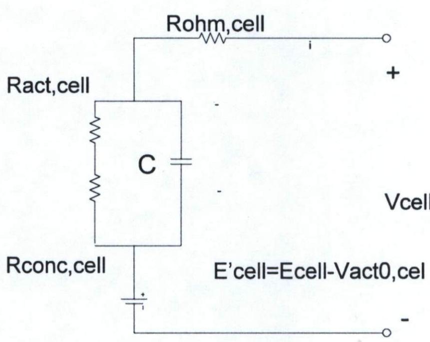

Fig.1 Equivalent circuit of fuel cell.

B. Photovoltaic Cell

Photovoltaic (PV) power supplied to the utility grid is gaining more and more visibility due to many national incentives. With a continuous reduction in system cost, the PV technology has the potential to become one of the main renewable energy sources for the future electricity supply. The PV cell is an all-electrical device, which produces electrical power when exposed to sunlight and connected to a suitable load. Without any moving parts inside the PV module, the tear-and-wear is very low. Thus, lifetimes of more than 25 years for modules and easily reached. However, the power generation capability may be reduced to 75%-80% of nominal value due to ageing. A typical PV module is made up around 36 or 72 cells connected in series, encapsulated in a structure made of e.g. aluminum and tedlar. An electrical model of the PV cell is depicted in Fig. 2.

Several types of proven PV technologies exist, where the crystalline (efficiency=10%-15%) and multi-crystalline (efficiency=9%-12%) silicon cells are based on standard microelectronic manufacturing processes. Other types are: thin-film amorphous silicon (efficiency=10%), thin-film copper indium diselenide (efficiency=12%), and thin-film cadmium telluride (efficiency=9%). Novel technologies such as the thin-layer silicon (efficiency=8%) and the dye-sensitised nano-structured materials (efficiency=9%) are in their early development. The reason to maintain a high level of research and development within these technologies is to decrease the cost of the PV-cells, perhaps on the expense of a somewhat lower efficiency, this is mainly due to the fact that cells based on today's mocroelectronic processes are rather costly, when compared to other renewable energy sources. Fig. 2 shows the equivalent circuit of PV cell that has the current source, parallel diode, two resistors. Equation (4) to (7) show the basic equation of PV cell.

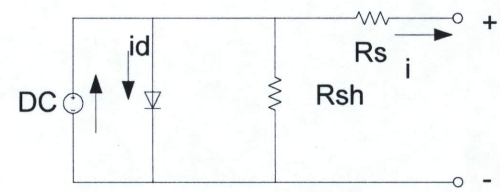

Fig.2 Equivalent circuit of photovoltaic cell.

$$I = I_{sc}\left[1 - \exp\left(\frac{V - V_{oc} + IR_s}{V_t}\right)\right] \quad (4)$$

$$Rs = \frac{V_{oc}^* - V_M^* + V_t \ln\left(1 - \frac{I_M^*}{I_{sc}^*}\right)}{I_M^*} \quad (5)$$

$$I_{sc} = I_{sc}^* \cdot \frac{G}{G^*}\left[1 + \frac{dI_{sc}}{dT_e}(Tc - Tc^*)\right] \quad (6)$$

$$V_{oc} = \left[V_{oc}^* + \frac{dV_{oc}}{dT_c}(T_c - T_c^*)\right]\left[1 + \sigma_{oc} \ln\left(\frac{Geff}{G_{oc}}\right) \ln\left(\frac{Geff}{G^*}\right)\right] \quad (7)$$

C. Wind Energy

The function of a wind turbine is to convert the linear motion of the wind into rotational energy that can be used to drive a generator, as illustrated in Fig. 3. Wind turbines capture the power from the wind by means of aerodynamically designed blades and convert it into rotating mechanical power. At present, the most popular wind turbine is the Horizontal Axis Wind Turbine where the number of blades is typically three.

The aerodynamic power, P, of a wind turbine is given by:

$$P_{WT} = C_P(\lambda, \beta)\frac{1}{2}\rho A V_W^3 \quad (8)$$

Where is the air density, R is the turbine radius, v is the wind speed and Cp is the turbine coefficient which represnts the power conversion efficiency of a wind turbine. Cp is a function of the tip-speed ratio ( ), as well as the blade pitch angle ( ) in the pitch contrlloed wind turbine. is defined as the ratio of the tip speed of the turbine blades to wind speed, and given by:

$$\lambda = \frac{r\omega_T}{V_W} \quad (9)$$

Where is the rotational speed of the wind turbine.

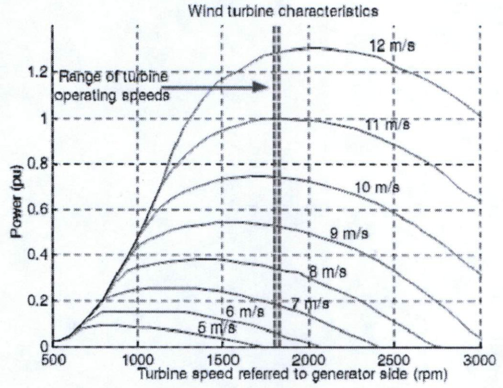

Fig. 3 The relation during wind speed with Energy of wind system.

3. INTERLEAVED BOOST CONVERTER.

The dual boost converter is circuit of up level for voltage higher. It was simulating for design and analysis of inductance, capacitance, resistance. The voltage control is important and need to study carefully. This article was provided control of small signal analysis to determine the gain of PI controller with the output voltage.

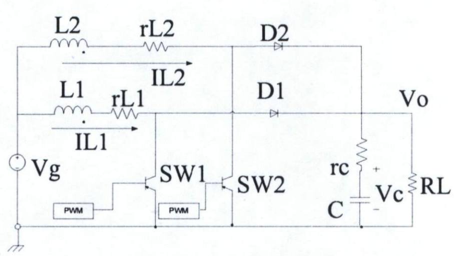

Fig.4 Resistance in the dual boost converter.

Fig. 4 shows the dual boost converter using power electronic switch 2 psc. It operations at frequency of 20 kHz. The elements and parameters of the circuit are designed based on energy from renewable sources. The operation gain of the boost circuit in each period can be express as equation (10).

$$G_1 = K_1 G_{ON} + K_2 G_{OFF} \tag{10}$$

when K_1 and K_2 are Mode operation of dual boost converter.

$$K_1 = \begin{cases} 1, & 0 < t < t_{on}, \\ 0 & t_{on} < t \le T, \end{cases} \tag{11}$$

$$K_2 = \begin{cases} 0, & 0 < t < t_{on}, \\ 1 & t_{on} < t \le T, \end{cases} \tag{12}$$

This can explain on state and off state operation.

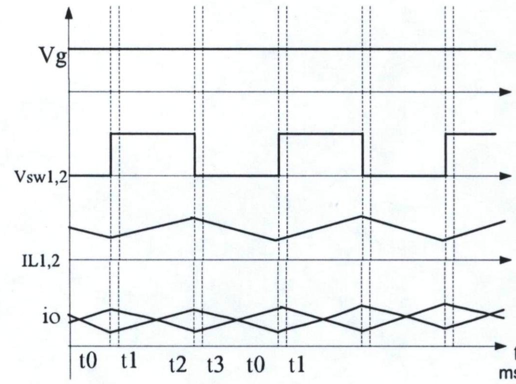

Fig.5 Voltage and current of dual boost converter.

3.1 Off state operation.

Fig.6 shows the small signal of the dual boost converter in off state operation. The current will be through inductor of circuit after that through to load of circuit. The equation can be shown (13) to (16).

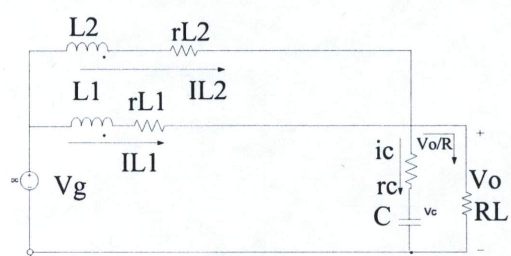

Fig.6 Off state operation of dual boost converter.

$$Vin = L\frac{di_L}{dt} + i_L r_L + V_o \tag{13}$$

$$i_c = C\frac{dv_c}{dt} \tag{14}$$

$$i_L = i_c + \frac{V_o}{R} \tag{15}$$

$$V_o = V_c + r_c i_c \tag{16}$$

3.2 On state operation.

Fig.7 shows the small signal of the dual boost converter when on state operation. The current can not through inductor of circuit. The equation can be shown (17) to (21).

$$L = \frac{L_1 L_2}{L_1 + L_2} \tag{17}$$

$$Vin = L\frac{di_L}{dt} + i_L r_L \tag{18}$$

$$i_c = C\frac{dv_c}{dt} \tag{19}$$

$$V_c = -i_c\left(R + r_c\right) \tag{20}$$

$$V_o = V_c + r_c i \tag{21}$$

when switch on state operation, the current will be through L_1 and L_2 reactance in circuit L_1, L_2.

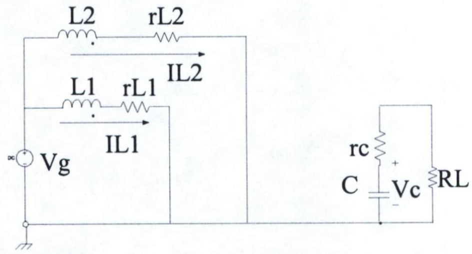

Fig.7 On state operation of dual boost converter.

According status of voltage output has been swing before supply to converter so we have to keep the voltage stable for supply energy to system. we have to analysis small signal for derive formula of mathematic. The main element is consider inductor, capacitor, diode, electronic switching divice. So that we have to fine dynamic equation. Than the electronic device has switching T_{on} and T_{off} equation (22) to (26) .

$$\frac{dX}{dt} = AX + bVin \tag{22}$$

$$V_o = cX \tag{23}$$

$$X = \begin{bmatrix} i_L \\ V_c \end{bmatrix} \tag{24}$$

$$\frac{d}{dt}\begin{bmatrix} i_L \\ V_c \end{bmatrix} = \begin{bmatrix} -\frac{1}{L}\left(r_L + \frac{D'R \cdot r_c}{R + r_c}\right) & -\frac{D'R}{L(R+r_c)} \\ \frac{D'R}{C(R+r_c)} & -\frac{1}{C(R+r_c)} \end{bmatrix} \begin{bmatrix} i_L \\ v_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{in} \tag{25}$$

$$Vo = \begin{bmatrix} \frac{D'R \cdot r_c}{R + r_c} & \frac{R}{R + r_c} \end{bmatrix} \begin{bmatrix} i_L \\ V_c \end{bmatrix} \tag{26}$$

Fig.6 and Fig.7 the small signal has analysis for fine evaluation average near the performance by calculating loss in the transfer function.

$$\frac{\hat{v}_o(s)}{\hat{d}(s)} = \frac{V_s}{(1-D)^2} \frac{\left(1 - s\frac{L}{R(1-D)^2}\right)}{1 + s\frac{L}{R(1-D)^2} + s^2\frac{LC}{(1-D)^2}} \tag{27}$$

For Equation,

$$= \frac{3460.2 - 0.069s}{8.34 \times 10^{-8}s^2 + 2 \times 10^{-5}s + 1}$$

Determine of the value is Kp and Ki for tranfer function.

$$G_C(S) = K_p + \frac{K_I}{S} \tag{28}$$

Selected K_p is 0.49693 K_I is 0.1813.

4. DESIGN OF IBC

Table 1 shows the parameter of interleaved boost converter that is designed by using dynamic model.

Table 1 Parameter for evaluation.

Parameter	Value
Input voltage	100-300 V
Output voltage	600 V
Power output	1,000 W
Frequency Switching	20 kHz
Riple of voltage inductor	5% of V_o
Riple of current inductance	10% of I_L
Inductance	15,750 μH
Capacitance	350 μF

Fig. 8 shows the output voltage of the dual boost converter that can be controlled the voltage to 600 V. The output current is measured as Fig 8.

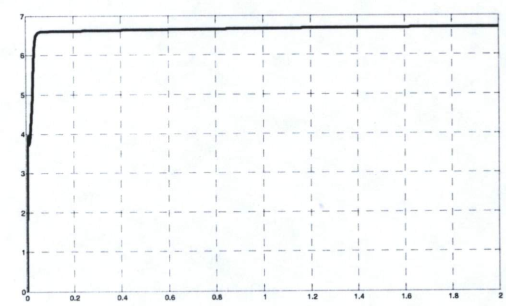

Fig. 8 current output load

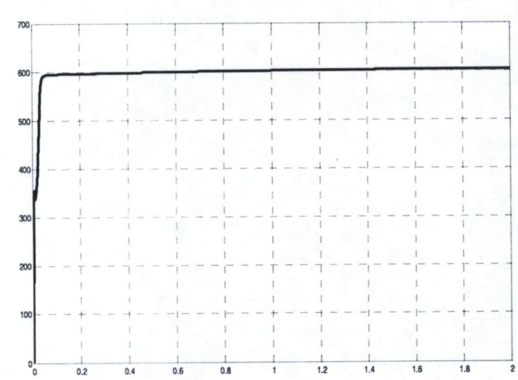

Fig. 9 Voltage output load.

Fig. 9 shows the output current of the interleaved boost converter that has been measured at load side.

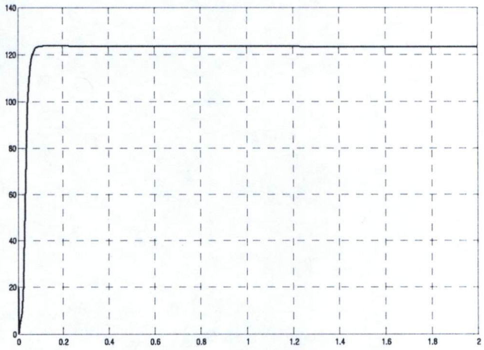

Fig.10 Current Inductor load.

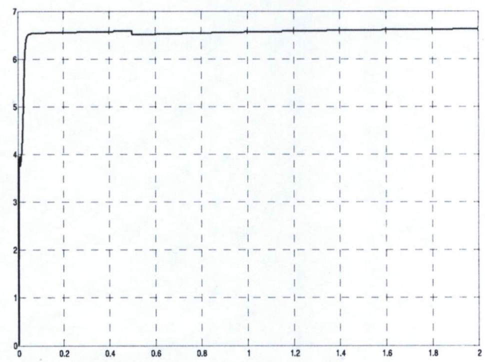

Fig11. Current load for 50% to 100%.

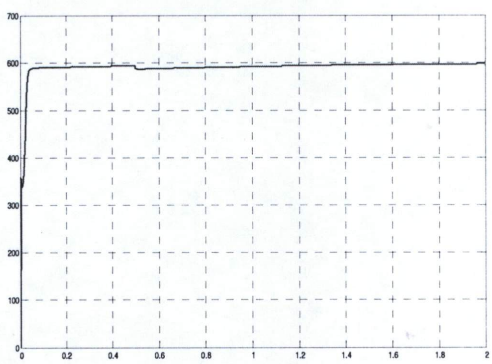

Fig.12 Voltage load for 50% to 100%.

Fig11 and Fig. 12 show the waveform when changed condition of operation for load from 50% to100% by using time simulation total 2 ms and using time for change load 0.5 ms.

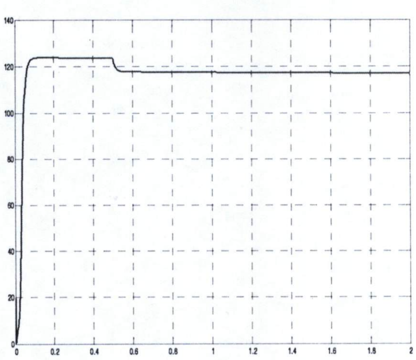

Fig 13 Current inductor for load 50% to 100%.

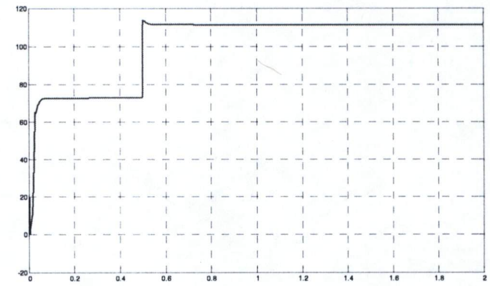

Fig 14 Current diode D1 for lod 50% to 100%.

Fig13 and Fig.14 show the waveform when changed condition of operation for load from 50% to100% by using time simulation total 2 ms and using time for change load 0.5 ms.

5. CONCLUSION

Design and analysis of dual boost converter for renewable application is expressed in this paper. The proposed methodology can be controlled the output voltage. The system has better efficient and is able to deliver the power to the load with stability operation. The evaluation by using mathematical model has been analyzed and shown that the output voltage signal that can be controlled.

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