A Solar Photovoltaic (PV) Energy Generating System with Paralleled DC Current Mode KY Converter

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Abstract— This paper presents, a low power stand-alone solar photovoltaic (PV) energy generating system with paralleled DC current mode along with FPGA. KY Boost Converter, a recent invention in the field of non-isolated DC-DC boost converter is identified for minimum voltage ripple. This KY boost converter is proposed by K.I.Hwu and Y.T.Yau. is a non-isolated DC-DC boost converter operating in CCM (Continuous Current Mode) with voltage conversion ratio of 1-plus D. The KY boost converter operates in CCM keeping the output current non-pulsating leading to reduced voltage stress across the output capacitor resulting low output voltage ripples in the order of few hundred mV. The use of KY converter is more efficient when compared to normal boost converter. Higher level of energy can be saved by using parallel operation. The parallel operation of power supply circuits, especially in applications with higher power demand, has several advantages. One of the most important aspects is to improve the system reliability and the operational redundancy by it. The design with these standard parallel converter modules influences the cost of development in a positive manner. The parallel operation of KY converter is designed using MATLAB.

Key words: Photovoltaic (PV) system, KY converter, Continuous Current Mode (CCM), Boost converter, Field Programmable Gate Array

I. INTRODUCTION

Solar energy is one of the most promising renewable energy resources. The photovoltaic (PV) systems are rapidly expanding and have increasing roles in electric power technologies, providing more secure power sources and pollution free electric supplies. A solar cell or photovoltaic cell is a device that converts solar energy into electricity by the photovoltaic effect. With the rapid increase in population and economic development, the problems of the energy crisis and global warming effects are today a cause for increasing concern. The utilization of renewable energy resources is the key solution to these problems. Solar energy is one of the primary sources of clean, abundant and inexhaustible energy that not only provides alternative energy resources, but also improves environmental pollution. The dual threats of energy depletion and global warming place the development of methods for harnessing renewable energy resources at the center of public interest.

In many 3C(Consumer, Communications, Computer) electronics, there are converters required to supply one boosted voltage or more under a given voltage, especially for portable communications systems, such as MPEG-3(MP3) players, blue-tooth devices, personal digital assistants, etc. For such applications, the output voltage ripple and noise should be taken into consideration seriously. As for the conventional non-isolated voltage-boosting converters, such as the boost converter and the buck-boost converter, their output currents are pulsating, thereby causing the output voltage ripple to tend to be large. As generally acknowledged, to overcome this problem, one way is to use the capacitor with low equivalent series resistance (ESR), another way is to add an inductance capacitance (LC) filter and the other way is to increase the switching frequency. Coupling inductors have been used in the boost/buck-boost converter. Regarding, the interleaved control scheme has been applied to the buck-boost converter. As for the voltage-lift technique has been utilized to boost output voltage along with small output voltage ripple considered. However, each of has one right-hand zero in the transfer function under the continuous current mode(CCM), thereby causing good performance of the transient load response not to be easy to achieve. Based on the mention above, a novel voltage-boosting converter KY converter is presented, which is always operated in CCM. Besides, the output current is non-pulsating, thereby causing the low output voltage ripple to occur. Most of all, its behavior is similar to that of the buck converter, and hence this converter possesses good transient load response.

FPGAs are going to rule in future because of their flexibility, increasingly better power efficiency and decreasing prices. Often a soft processor is added in the FPGA design to get microcontroller like functionality along-with other concurrent processing. FPGA are concurrent. While the microcontrollers are always sequential. This makes FPGAs better suited for real-time applications. FPGAs are flexible; we can add/subtract the functionality as required. This cannot be done in microcontroller. A Field Programmable Gate Array (FPGA) is an integrated circuit that could contain millions of logic gates that can be electrically configured to perform a certain task. The very basic nature of FPGAs allows it to be more flexible than most microcontrollers. FPGAs tend to operate at relatively modest clock rates measured in a few hundreds of megahertz, but they can perform thousands of calculation per clock cycle while operating in the low “tens of watts” range of power.

II. KY CONVERTER

A novel voltage-boosting converter, named as KY converter (i.e. one-plus-D converter) is presented. Unlike the traditional non-isolated boost converter, this converter possesses fast transient load responses, similar to the buck converter behavior. Besides, it possesses non-pulsating output current, thereby not only decreasing the current stress on the output capacitor but also reducing the output voltage ripple.

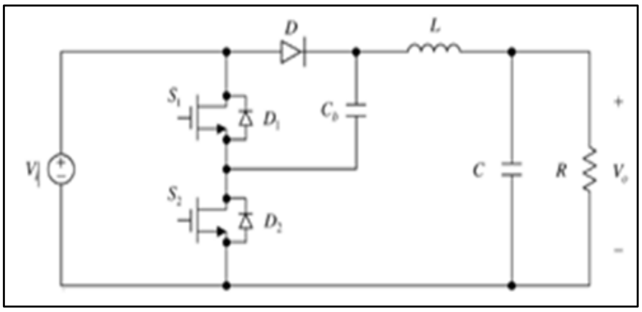

Fig. 1: KY Converter

As shown in Fig 1, the KY converter, which consists of two MOSFET switches S1 and S2 along with anti-diodes DI and D2 respectively, one diode D, one energy-transferring capacitor Cb which is large enough to keep the voltage across itself constant at the value of the input voltage, one output inductor L, and one output capacitor C.

It is assumed that the input voltage is vi, the voltage across the capacitor Cb is equal to vi, the output voltage is v0, the current flowing through L is i, as seen from Figs. 2 to 5. For the convenience of analysis, the dead time between two MOSFET switches and the voltage drop across switches and diodes are negligible. It is noted that this converter always operates in CCM. The following analysis contains the explanation of the power flow direction for each mode, the corresponding differential equations and the relationship between the DC input voltage and the DC output voltage. There are four possible operating modes generating three possible cases in this converter.

A. Case 1:

In this case, the power flowing through the output inductor L is assumed to be from the left side to the right side all the time, which usually happens at heavy loads.

1) Mode 1:

In Fig. 2, as soon as SI is turned on and S2 is turned off, the voltage across L is the input voltage vi plus the voltage vi across Cb minus the output voltage vo, thereby causing L to be magnetized. And hence, the corresponding differential equations are

$$L\frac{di}{dt} = 2vi - v \quad (2.1)$$

$$C\frac{dv0}{dt} = i - \frac{v0}{R} \quad (2.2)$$

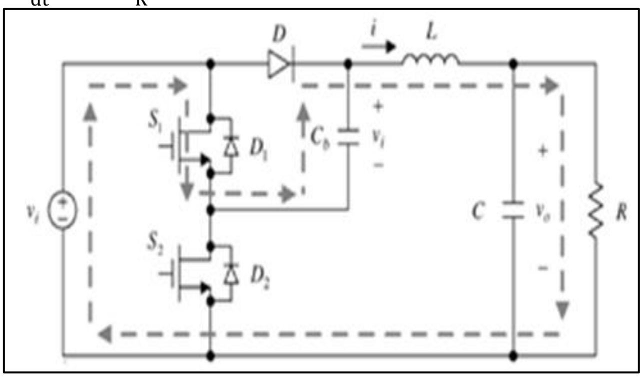

Fig. 2: Power Flow of KY Converter in Mode 1 of case 1

2) Mode 2:

In Fig. 3, as soon as S2 is turned on and SI is vi turned off, the voltage across L is the voltage vi across Cb minus the output voltage vo, thereby causing L to be demagnetized. And hence, the corresponding differential equations are

$$\frac{di}{dt} = vi - vo \quad (2.3)$$

$$C\frac{dvo}{dt} = i - \frac{Vo}{R} \quad (2.4)$$

By applying the voltage-second balance to (1) and (2), the relationship between DC input voltage vi and DC output voltage vo can be represented as

$$\frac{vo}{vi} = 1 + D \quad (2.5)$$

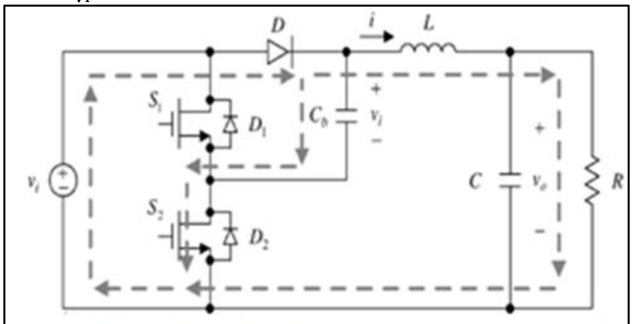

Fig 3 Power flow of KY converter in mode 2 of case 1

Fig. 3: Power Flow of KY Converter in Mode 2 of case 1

B. Case 2:

In this case, the power flowing through the output inductor L is assumed to be from the right side to the left side for any time, which does not exist in practice if the average power flow is from the source to the load.

1) Mode 1:

In Fig. 4, as soon as S1 is turned on and S2 is turned off, the voltage across L is the input voltage vi plus the (1) voltage vi across Cb minus the output voltage vo, thereby causing L to be magnetized in the opposite direction. And the corresponding differential equations are the same as those mentioned in mode 1 of case 1.

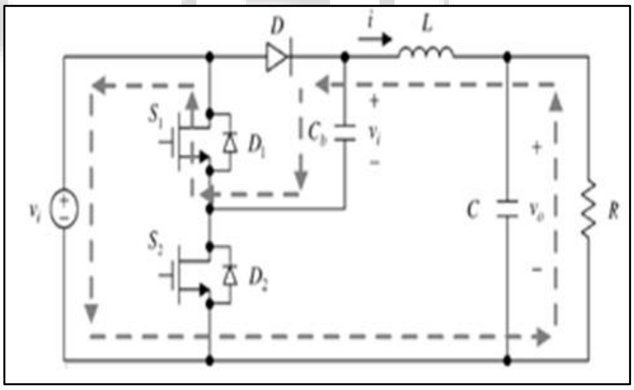

Fig. 4: Power Flow of KY Converter in Mode 1 of case 2

2) Mode 2:

In Fig. 5, as soon as S2 is turned on and S1 is turned off, the voltage across L is the voltage vi across Cb minus the output voltage vo, thereby causing L to be demagnetized in the opposite direction. And the corresponding differential equations are the same as those mentioned in mode 2 of case 1.

C. Case 3:

In this case, two cases mentioned above are combined, which usually occurs at light loads. And the corresponding differential equations are the same as those in case 1.

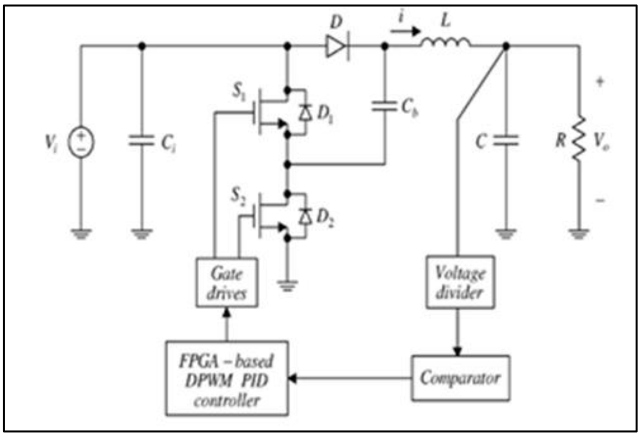

Fig. 5: System Configuration of KY Converter

III. CURRENT-MODE CONTROL OF DC-DC CONVERTERS

Compared with voltage-mode control, current-mode control provides an additional inner control loop control. The inductor current is sensed and used to control the duty cycle. An error signal is generated by comparing output voltage Vo with reference voltage Vref. Then this error signal is used to generate control signal ic. The inductor current is then sensed and compared with control signal ic to generate the duty cycle of the switch and drive the switch of the converter. If the feedback loop is closed, the inductor current becomes proportional with control signal ic and the output voltage becomes equal to reference voltage Vref.

IV. CONTINUOUS CONDUCTION MODE (CCM)

Continuous-conduction-mode (CCM) means that the current in the energy transfer inductor never goes to zero between switching cycles. In discontinuous-conduction-mode (DCM) the current goes to zero during part of the switching cycle. During steady-state operation when the switch is closed, the voltage across the capacitor causes the diode to become reverse-biased since the anode will be grounded. Thus, the voltage across the inductor, V_L is equal to the source voltage, V_S. Since the voltage across an inductor is equal to $L\frac{di_L}{dt}$. Hence the DC output-to-input transfer function yields:

$$\frac{V_O}{V_S} = \frac{1}{1+D} \quad (4.1)$$

V. PWM GENERATION AND PID CONTROLLER

Fig 6 depicts the PWM generator. The amplified error signal, is fed into the inverting terminal on the comparator and a voltage ramp operating at the switching frequency, is fed into the non-inverting terminal. When the error voltage matches the value of the input ramp, the comparator triggers high (causing the switch to open) which, with a varying error signal, will cause a modulation of the duty cycle in the output digital waveform. Modulation of this duty cycle is what controls the output voltage of the converter block.

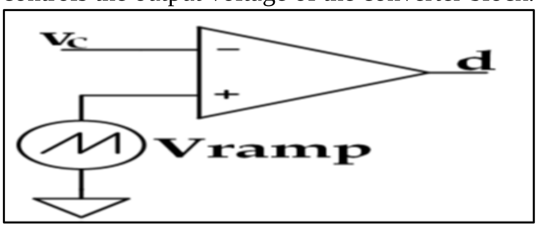

Fig. 6: PWM generator

The Characteristics of P, I, and D controllers

- A proportional controller (Kp) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error.
- An integral control (Ki) will have the effect of eliminating the steady-state error, but it may make the transient response worse.
- A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response.

VI. SYSTEM BLOCK DIAGRAM

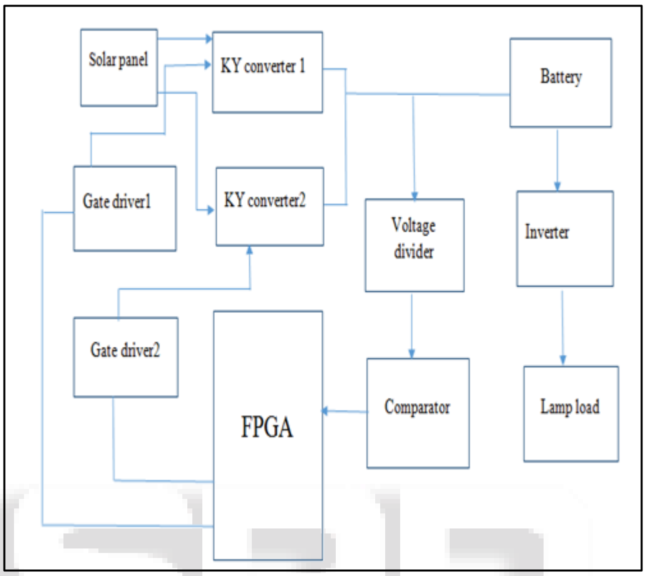

Fig. 7: Block diagram for proposed system

VII. SIMULATION RESULTS

The simulation tool used here is MATLAB/SIMULINK. The dc input voltage is given as 12v.

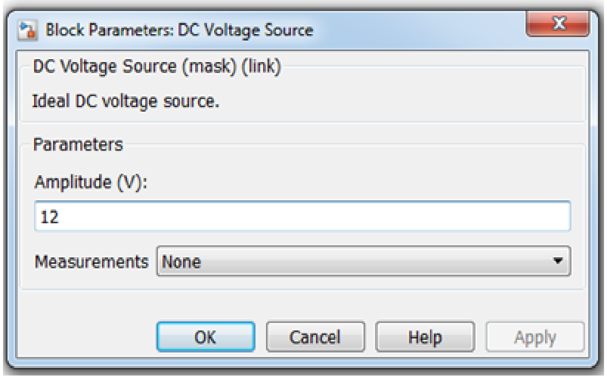

Fig. 8: DC input voltage

A. Proportional Control:

By only employing proportional control, a steady state error occurs.

B. Proportional and Integral Control:

The response becomes more oscillatory and needs longer to settle, the error disappears**.**

C. Proportional, Integral and Derivative Control:

All design specifications can be reached.

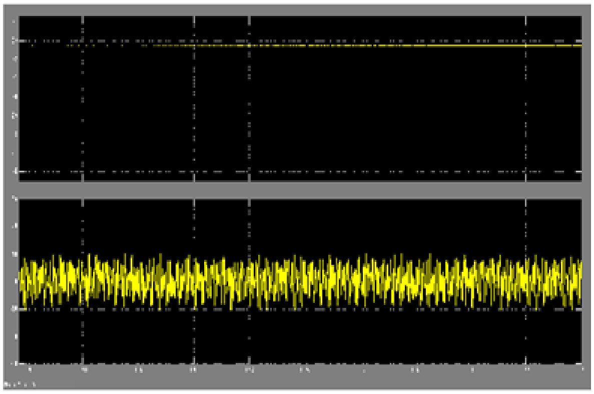

Fig. 9: Simulation result for KY converter

Fig 9 demonstrates the simulation result for single KY converter for which the given input voltage is 12v and the rated output voltage is measured as 30V and the output current is 1.5A. It has higher transient response when compared to normal boost converter.

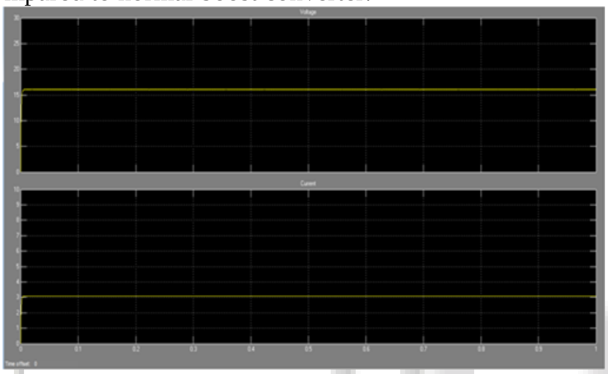

Fig. 10: Simulation result for parallel operation of KY converter

Fig 10 demonstrates the simulation result for parallel operation of KY converter for which the input voltage is given as 12V and the rated output voltage is 15V and the rated output current is 3A. This proposed model produces fast transient response when compared to other boost converters. It has minimum voltage ripple. Higher amount of energy can be saved since we go for parallel processing.

VIII. CONCLUSION

In recent years various DC-DC boost converter topologies were proposed whose output voltage ripple was large. To reduce output voltage ripple several methods such as usage of coupling inductor, interleaved control scheme in dual buck-boost converter and voltage lift technique had been proposed. All the methods have one-right half plane zero in CCM which is practically not feasible in all cases. But the KY converter works in CCM and produces a very low output ripple voltage with fast load transient response. FPGAs are an increasingly attractive solution path for demanding applications due to their ability to handle massively parallel processing. Higher level of energy can be saved by using parallel operation. The use of KY converter is more efficient when compared to normal boost converter. Sufficient power can be produced to all our home appliances through this system.

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