Research Article

Design and Implementation of Solar KY Converter using Sliding Mode Controller

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Abstract

The present work orient to design an implementation of solar KY converter using sliding mode controller with a view of regulate the output voltage and reduce a ripple over a wide range of operating loads. The philosophy modules results in generation of higher output current and low output voltage ripple and higher voltage boosting capability. The theory owes to derive the reference wave from the principle of the controller for generating the pulse width modulated (PWM) pulse to turn on the power switches in the converter, in accordance with the requirements of the change in the load, The advantage of using this circuit compare to the conventional boost converter is this long life because the input current ripple small and fast transient response. The MATLAB based simulation result project the suitability of the use of the controller for use in similar circuit and allow it to claim a place for it use in real world utilities.

Keywords: Solar PV system; KY converter; Pulse width modulation; Sliding mode controller.

Introduction

There arises a renewed focus on the power electronic converter interface for the dc energy sources, which offer low-voltage output and require series connection to provide enough output voltage. The dc-dc KY converter is generally used to boost the voltage to the required level. Various other boosters such as boost, buck-boost series resonant full bridge and push-pull converter are not recommended because they add objectionable ripples in the current flowing out of the sources [1]. Which is always operate in CCM and the output current is non- pulsating. The output voltage has less ripples. For many applications the output voltage gain ripples and gain is needed to take in to consideration. Regarding the traditional non-isolated voltage-boosting converters such as the traditional boost converter and buck-boost converter, their voltage gains are not high enough for some circuits. So KY converter can use instead of all other boost converters [2].

Consequently, the KY converter combined with the traditional synchronously rectified (SR) boost converter is presented herein to create a new voltage-boosting converter, named as KY boost converter, so as to enlarge the voltage ratio of the KY converter. Besides, this converter possesses a special feature that not only this converter always operates in CCM but also both its input and output sides have individual inductors, thereby, making the corresponding current ripples small [3]. Many conventional DC-DC converters are present, in which isolated converters are preferred because the non-isolated converters do not satisfy the requirements of galvanic isolation standards. In many DC-DC applications, multiple outputs are required and output isolation may need to be implemented depending on the application. In addition, input to output isolation may be required to meet safety specifications [4].

In the interleaved control scheme has been utilized. Both designs yield low output voltage ripples, but the presence of one right-half plane zero under the continuous current mode (CCM) makes it difficult to concurrently achieve fast transient load responses. To overcome this problem, a new voltage boosting converter, named KY converter has recently been developed [5]. Based on this converter, the inverse KY converter is presented herein, which can operate bidirectional and always works in the continuous conduction mode (CCM) inherently. In the boost mode, this converter

possesses the non-pulsating output current and the fast load transient response, whereas in the buck mode, this converter possesses the nonpulsating input current. If the battery is discharged to some extent, then this converter can charge the battery in the buck mode, whereas if the load requires the energy, then the battery is discharged via the same converter operating in the boost mode [6].

Several types of non-isolated voltage-bucking/boosting converters such as buck-boost converter, Cuk converter, SEPIC converter, Zeta converter, etc., operating in continuous conduction mode (CCM) and possess right–half plane, thereby causing the system stability to be low, load transient responses to be slow about several milliseconds and hence corresponding design for accelerating transient responses to be difficult. These problems can be rectified by the KY Converters [7]. The DC-DC switching converters suffer from high output voltage ripple. Therefore, a converter with low output voltage ripple is more appealing. The transfer function contains the parameters of input voltage, two energy-transferring capacitors, input and output inductors, duty cycle, output load, input and output currents, and switching frequency. Therefore, it is more practical to design the controller by using this transfer function [8].

Proposed strategy

Solar-PV cells produce electricity directly by converting the solar energy into electrical energy. The output voltage and current of the single PV cell is quite small to be used practically, thus these are used in series parallel combinations, called as PV array and modules to produce the significant level of voltage and current. It is also the most important of the non-conventional sources of energy because it is non-polluting. So the necessities of such converters which as low electricity intake, small and cheap system also increased. This is achieved by the way of boosting low voltage to excessive voltage. In the proposed module KY converter are used output current is non-pulsating. So it consists of small quantity of voltage ripple. The Fig. 1 shows the block diagram of KY converter.

A voltage boosting converter, named as KY converter is presented. Unlike the traditional non-isolated boost converter, this converter possesses fast transient load responses, similar to

the boost converter behaviour. 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.
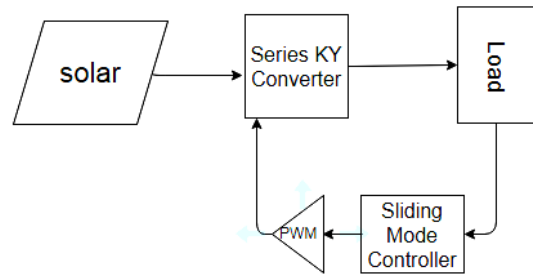

Fig. 1. Block diagram of KY converter

As shown in fig. 2, the KY converter, which consists of four MOSFET switches S_1, S_2, S_3 and S_4, diodes D and D_1 respectively, energy-transferring capacitor C_b and C_{b1}, which is large enough to keep the voltage across itself, solar gives the input voltage, output inductor L and L_1, output capacitor C and C_1. It is assumed that the input voltage is v_i, the voltage across the capacitor C_b is equal to Vi, the output voltage is Vo, the current flowing through L is i, as seen from Fig. 3 and 4. 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 in this converter. For the convenience of analysis, we take single KY converter to explain the mode of operation similar to the parallel KY converter.
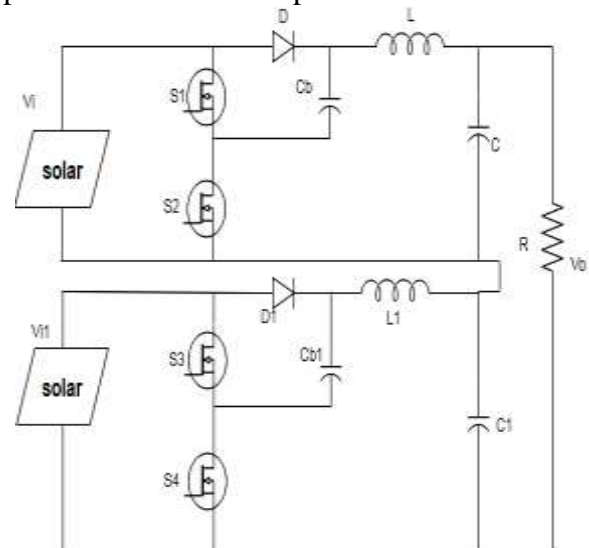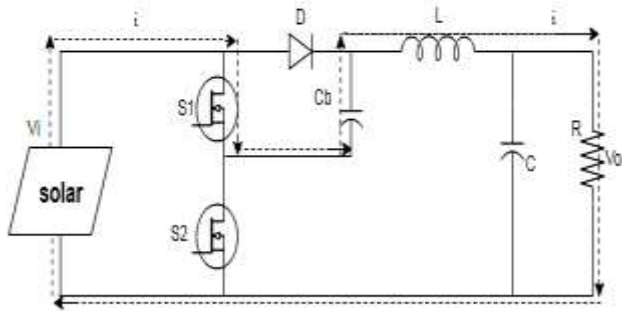

Fig. 2. Series KY converter

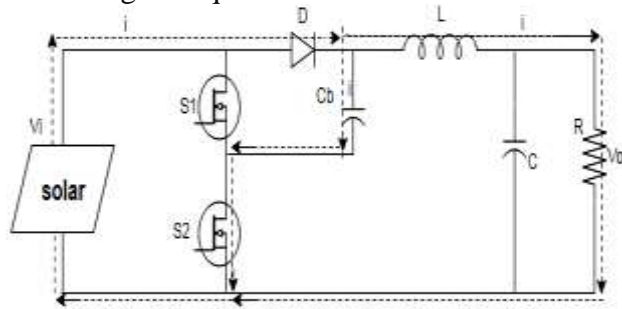Fig. 3. Equivalent circuit of mode 1

Fig. 4. Equivalent circuit of mode 2

Mode 1

The fig. 3 and 4 shows the equivalent circuit of mode 1where switch S1 is turned on. In both modes the load is supplied. S1 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. Also, the current flowing through C is equal to the current i flowing through L minus the current flowing through R. Besides, in this mode, Cb is discharged, and hence the corresponding differential eq. (1) and (2).

$$L\left(\frac{di}{dt}\right) = 2V_i - V_o \quad \text{---- (1)}$$

$$C\left(\frac{dV_o}{dt}\right) = i - \frac{V_o}{R} \quad \text{---- (2)}$$

Mode 2

As soon as S_1 is turned off and S_2 is turned on, the voltage across L is the input voltage V_i minus the output voltage V_o, thereby causing L to be demagnetized. Also current flowing through C is equal to the current i flowing through L minus the current flowing through R. Besides, in this mode, C_b is abruptly charged to V_i within a very short time, which is much less than T_s, and hence the corresponding differential eq. (3) and (4).

$$L\left(\frac{di}{dt}\right) = V_i - V_o \quad \text{---- (3)}$$

$$C\left(\frac{dV_o}{dt}\right) = i - \frac{V_o}{R} \quad \text{---- (4)}$$

Control algorithm

A control technique suitable for DC-DC converter must match with their nonlinearity and input voltage and load variations, ensuring stability in any operating condition. There are various control techniques such as, fuzzy logic controller, artificial neural network (ANN) controller, sliding mode controller (SMC), PI controller, PID controller. But here for DC-DC KY converter of sliding mode control method. Sliding mode control or SMC is a nonlinear method of control. It alters the dynamics of any nonlinear system by application of a discontinuous control signal. State feedback control law is a discontinuous function of time. Hence it switches from one continuous structure to another [9]. Hence sliding mode control is a variable structure control method. Discontinuous signal forces the system to slide along cross section of the system's normal behaviour. Sliding mode has been applied to current controller technology to KY converter. Fig. 5 represents the basic circuit diagram of the KY converter controlled by the sliding mode controller
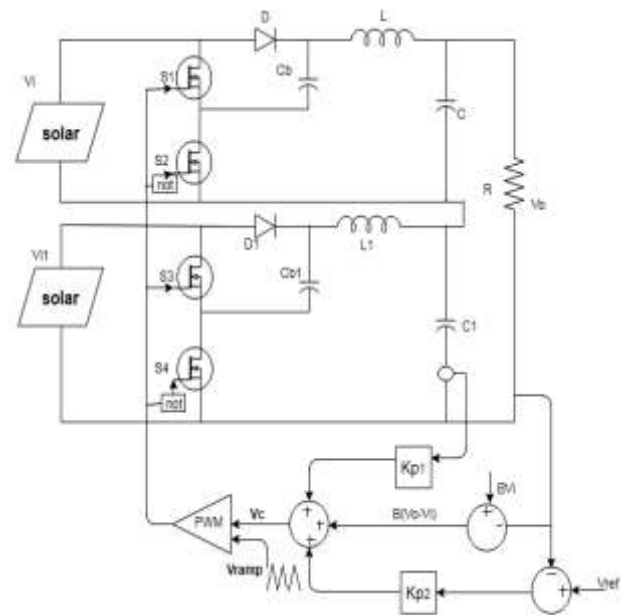

Fig. 5. System modelling of sliding mode controller

Let's consider, voltage error be X, rate of change of voltage error be Y & integral of voltage error be Z. Under continuous conduction mode, derived in [10] can be expressed as,

$$X = (V_{ref} - \beta V_o) \quad \text{---- (5)}$$

$$Y = \dot{X} = \frac{\beta}{c}\left[\frac{v_o}{RL} - \int 1 \frac{uv_i - v_o}{RL} dt\right] \quad \text{---- (6)}$$

$$Z = \int X_1 \, dt \quad \text{---- (7)}$$

$$X_{boost} = \begin{bmatrix} v_{ref} - \beta v_o \\ \frac{\beta}{c}\left[\frac{v_o}{RL} - \int 1\,\frac{uv_i - v_o}{RL}\,dt\right] \\ \int v_{ref} - \beta v_o \end{bmatrix} \text{---- (8)}$$

$$\dot{X}_{boost} = AX_{boost} + B\overline{u} \text{ ------ (9)}$$

Where

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & -1/R_L C & 0 \\ 1 & 0 & 0 \end{bmatrix} \text{------ (10)}$$

$$B = \begin{bmatrix} 0 \\ \frac{\beta v_o}{LC} - \frac{\beta v_i}{LC} \\ 0 \end{bmatrix} \text{---- (11)}$$

For this system, it is appropriate to have a general sliding mode control law that adopts a switching function such as,

u = 1 when S > 0
= 0 when S < 0 ---- (12)

$$u = \frac{1}{2(1+sign\,s)} \text{ ---- (13)}$$ Where S is the instantaneous state variable trajectory and is described as

$$S = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3) = J^T X \text{ --- (14)}$$

Where $J^T = [\alpha_1, \alpha_2, \alpha_3]$, α1,α2 and α3 are representing control parameter termed as sliding coefficients.

A sliding surface can be obtained by enforcing, S = 0. Finally, the mapping of the equivalent control function onto the duty ratio control d, where

$$0 < d = \frac{v_c}{v_{ramp}} < 1 \text{ ---- (15)}$$

gives the following relationship for the control signal V_c and ramp signal Vramp, where

$$V_c = U_{equ} = -\beta L\left[\left(\frac{\alpha_1}{\alpha_2}\right) - \left(\frac{1}{RC}\right)i_c + LC\left(\frac{\alpha_3}{\alpha_2}\right)(v_{ref} - \beta v_o) + \beta(v_o - v_i)\right]$$

$$\text{--- (16)}$$

$$V_c = K_{p1}i_c + K_{p2}\left(v_{ref} - \beta v_o\right) + \beta(v_o - v_i) \text{ ---- (17)}$$

$$K_{p1} = \left(\frac{\alpha_1}{\alpha_2}\right) - \left(\frac{1}{RC}\right) \text{ ----- (18)}$$

$$K_{p2} = LC\left(\frac{\alpha_3}{\alpha_2}\right) \text{ ----- (19)}$$

$$V_{ramp} = \beta(v_o - v_i) \text{ ------ (20)}$$

Using control voltage equation the sliding mode equation derived through the expression s(x)= 0.

Results and discussion

The Fig. 6 had shown the simulation diagram of series KY converter using SMC. This chapter gives a review of simulation circuit details of the proposed KY converter based on high performance capability. SM control method is applied to control the duty ratio of switches. The scheme is simulated KY converter parameters are chosen as L = 4 µH, C = 50 µF, switching frequency is 50 KHz and allowed to a load vary up to 1000 W. The two solar dc voltage of 72 V is applied to the parallel KY converter. The reference outputs are fixed at 120 V for KY converter. The output voltage and current corresponding to a load of 600W for KY modes of the converter are depicted in Fig. 7. In the series KY converter the voltage is constantly maintain and the current is divided with the converter. So the load current increases as seen in Fig. 8 and also shown in output power.

The output voltage obtained is as shown above. The output voltage of 120 V is obtained and the ripple content in the output voltage is very low. Proposed aim is fulfilled by achieving a high boosting voltage of 120 V from a 72 V input. However, the SMC controller is designed in such a way as to modify the duty cycle, in order to minimize the error generated because of the deviation of the output from its reference value and to maintain the desired output voltage The entries in table 1 compare the values of the load current, load voltage and load power, obtained using SMC in an attempt to validate the methodology and establish the supremacy of the SMC. It follows that the output voltage remains regulated through the operating range and the current sharing is equal for the load voltage.

Table 1. Performance Comparisons

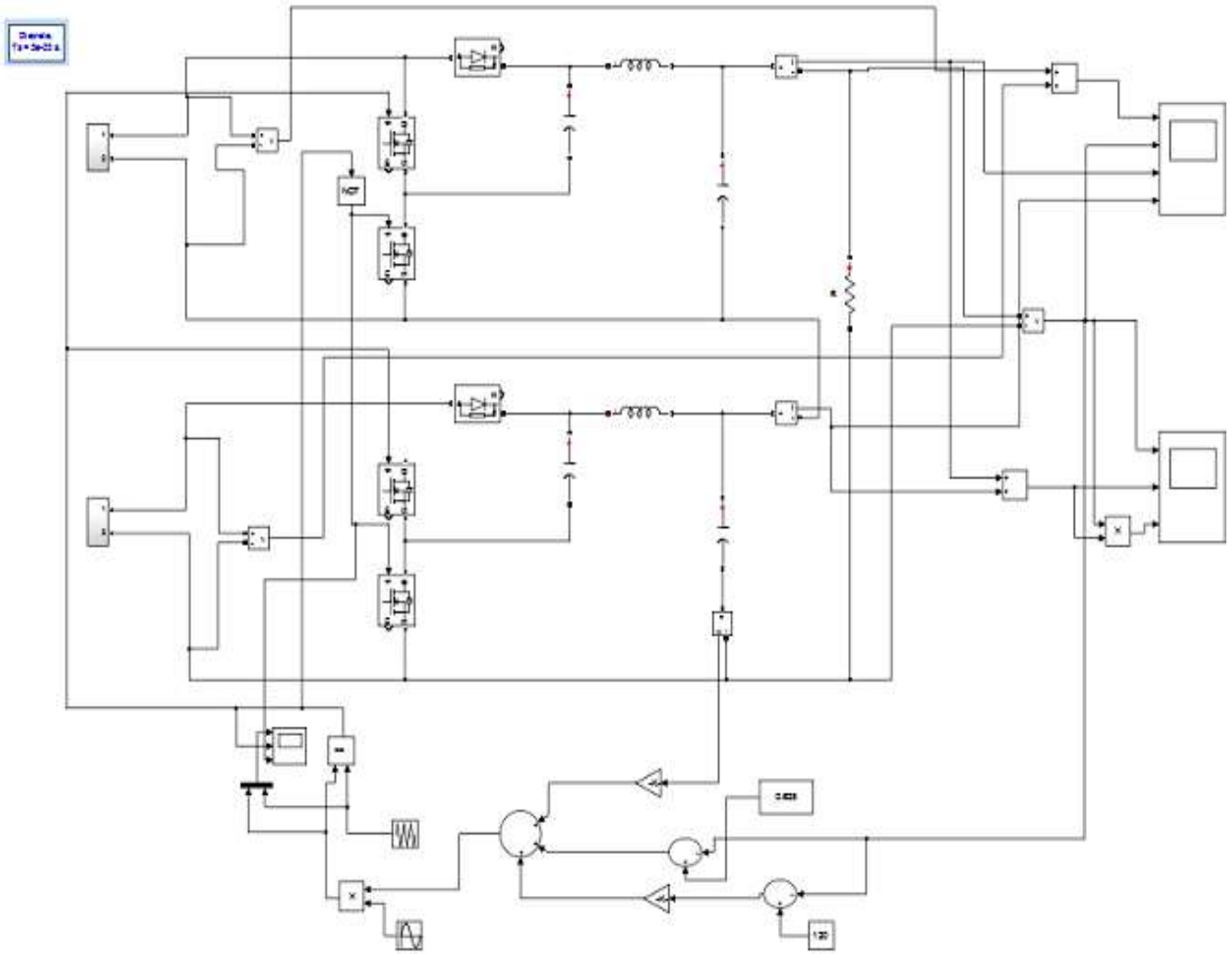| Solar Input (V)	"R" Value (W)	Output voltage (V)	Output Current (A)		Output Power (W)
			Con.1	Con. 2	
72	200	120	0.84	0.84	200.5
72	400	120	1.68	1.68	399.6
72	600	119.5	2.5	2.5	610.1
72	800	119.3	3.3	3.3	800.9
72	1000	119.1	4.15	4.15	1000.2

Fig. 6. Simulation diagram of solar KY Converter with sliding mode controller
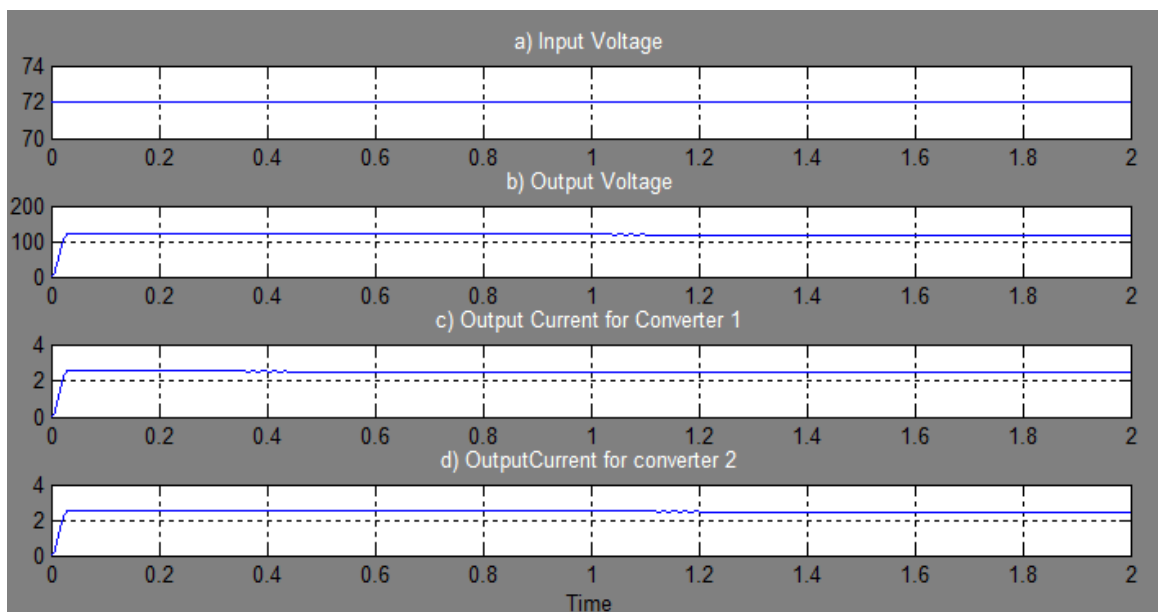

Fig. 7 Output voltage and current of solar KY converter using SMC controller
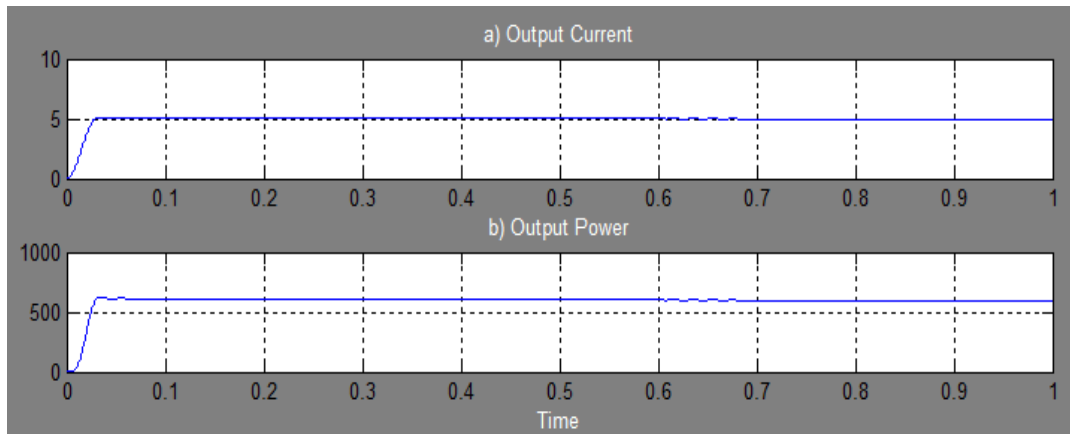
Fig. 8. Output current and power of solar KY converter using SMC controller

Conclusions

In the recent year 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. But the KY converter works a very low output ripple voltage with fast load transient response. Higher level of energy can be saved by using parallel operation. The closed loop performance of the proposed converter is done using the SMC controller and so the fast settling time and no overshoot of the converter is achieved. The converters need lesser components making it less weight, low cost and compact. 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.

Conflicts of Interest

Authors declare no conflict of interest

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