A Single Stage Three Port Converter for PV Pump Application


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Abstract—In this paper a new design of Single Stage Three Port Converter is proposed which is used for pv pump applications. The single stage three port converter has two converters namely boost and buck with buck-boost converter. The boost converter boosts the voltage level above the reference voltage and feeds the load. If supply from the PV panel is blocked, then an alternative source which has rating less than PV panel is connected to the load via converter. The buck with buck-boost converter boosts the less potential from battery and feeds the load. The same circuit is analysed mathematically and simulated in MATLAB simulink. The results were correlated with the hardware results.

Key words: PV panel, Three port converter, Single Stage Converter, Boost and Buck with Buck-Boost converter

I. INTRODUCTION

In many industrial applications, it is required to convert a fixed voltage DC source into a variable voltage DC source. A DC converter can be considered as DC equivalent to an AC transformer with a continuously variable turns ratio. Like a transformer, it can be used to step down or step up a DC voltage. DC converters are widely used for traction motor control in electric automobiles, trolley cars, and charge/discharge applications in UPS. They provide smooth acceleration control, high efficiency and fast dynamic response.

The battery voltage declines as its stored power is drained. Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing. A DC-DC converter is also known as a chopper. It converts a given constant DC voltage into a variable average DC voltage across the load by placing a static switch between the DC source and the load. The switch chops off the DC supply into ON and OFF periods. In recent years, the area of bidirectional DC-DC converters is improving the fuel cell economy automobile companies are developing alternative battery operated vehicles. In addition, a major change in the electrical system of the vehicles is on the horizon by going for a 40V DC from 12/24V DC systems.

The main reasons for switching over to 12V/24V to high voltages are to meet the increased electrical demands of cell vehicles, to lower the current drawn from the battery, and to implement additional safety and comfort features, also to reduce the mechanical and hydraulic components, and to improve the design flexibility of the vehicles. In hybrid/fuel cell vehicles, the main goals are to have a high efficient, small size, rugged and low cost bidirectional DC-DC converter. In hybrid/fuel cell vehicles, a power conditioning unit such as novel bidirectional DC-DC converter to match the fuel cell voltage with the battery pack may also required. In certain conditions, a fast response required to supply load, converter to give bidirectional power to that vehicle system without any disturbance. It is able to operate at adverse environmental conditions.

The power semiconductor devices MOSFET(Metal Oxide Semiconductor Field effect Transistor), IGBT(Insulated Gate Bipolar Transistor) and packaging of the individual units and the system integration play a major role in hybrid/fuel cell vehicles. The proposed converter system should be efficient to improve the range of performance of the battery operated vehicles. In addition to the power semiconductor devices, controllers, there are several other components such as inductors, capacitors, isolation transformer form a major portion of the proposed system. The soft switching converters have the advantage of lower switching losses and higher operating voltage. The proposed system with two integrated function is that DC/AC and AC/DC conversion, with low losses and with minimum use of capacitors need to be developed.

II. MATHEMATICAL MODELLING

A. Boost Converter

The schematic in Figure 1.1 shows the basic boost converter. This circuit is used when a higher output voltage than input is required.

![Boost Converter Circuit](image)

**Fig. 1.1: Boost Converter Circuit**

While the transistor is ON \( V_o = V_{in} \), and the OFF state the inductor current flows through the diode giving \( V_x = V_o \). For this analysis it is assumed that the inductor current always remains flowing (continuous conduction). The voltage across the inductor is shown in Figure 1.2 and the average must be zero for the average current to remain in steady state

\[
V_{in} t_{on} + (V_{in} - V_o) t_{off} = 0 \quad (1.1)
\]

\( V_{in} \) – Input Voltage
\( V_o \) – Output Voltage
\( t_{on} \) – On time
\( t_{off} \) – Off time
\( D \) - Duty Cycle

This can be rearranged as

\[
\frac{V_o}{V_{in}} = \frac{T}{t_{off}} = \frac{1}{1-D} \quad (1.2)
\]

and for a loss less circuit the power balance ensures...
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\[ \frac{I_o}{I_{in}} = (1-D) \] (1.3)

Fig. 1.2: Voltage and current waveforms of Boost Converter

Since the duty ratio "D" is between 0 and 1, the output voltage must always be higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage.

B. Buck Converter

In this circuit shown in Figure 1.3 the transistor turning ON will put voltage Vin on one end of the inductor. This voltage will tend to cause the inductor current to rise. When the transistor is OFF, the current will continue flowing through the inductor but now flowing through the diode. We initially assume that the current through the inductor does not reach zero, thus the voltage at Vx will now be only the voltage across the conducting diode during the full OFF time. The average voltage at Vx will depend on the average ON time of the transistor provided the inductor current is continuous.

\[ \text{Fig. 1.3: Circuit Diagram Buck Converter} \]

To analyse the voltages of this circuit let us consider the changes in the inductor current over one cycle as shown in Figure 1.4. From the relation

\[ V_x - V_o = L \frac{di}{dt} \] (1.4)

The change of current satisfies

\[ di = \int (V_x - V_o) \, dt + \int (V_o - V_{in}) \, dt \] (1.5)

For steady state operation the current at the start and end of a period T will not change. To get a simple relation between voltages we assume no voltage drop across transistor or diode while ON and ON and a perfect switch change. Thus during the ON time \( V_c = V_{in} \) and in the OFF \( V_c = 0 \). Thus

\[ 0 = \int (V_{in} - V_o) \, dt + \int (V_o - V_{in}) \, dt \] (1.6)

which simplifies to

\[ \frac{V_o}{V_{in}} = \frac{\text{ton}}{T} \] (1.7)

and defining "duty ratio" as

\[ D = \frac{\text{ton}}{T} \] (1.8)

the voltage relationship becomes \( V_o = D \cdot V_{in} \). Since the circuit is lossless and the input and output powers must match on the average, \( V_o \cdot I_o = V_{in} \cdot I_{in} \). Thus the average input and output current must satisfy \( I_{in} = D \cdot I_o \). These relations are based on the assumption that the inductor current does not reach zero.

C. Buck-Boost Converter

With continuous conduction for the Buck-Boost converter circuit as shown in Figure 1.5 \( V_x = V_{in} \) when the transistor is ON and \( V_x = V_o \) when the transistor is OFF. For zero net current change over a period the average voltage across the inductor is zero.

\[ V_{in} \cdot t_{ON} + V_o \cdot t_{OFF} = 0 \] (1.18)

which gives the voltage ratio

\[ \frac{V_o}{V_{in}} = - \frac{D}{(1-D)} \] (1.19)

and the corresponding current

\[ \frac{I_o}{I_{in}} = - \frac{D}{(1-D)} \] (1.20)

Since the duty ratio "D" is between 0 and 1, the output voltage can vary between lower or higher than the input voltage in magnitude. The negative sign indicates a
reversal of sense of the output voltage which is shown in Figure 1.6.

III. INTRODUCTION ABOUT BLOCK DIAGRAM

The power supply circuit consists of a step down transformer from which 230 V is stepdown to 12 V. With the help of rectifier AC is converted into DC which pass through voltage regulator and is regulated to 5 V. By using a capacitor the ripple and fluctuations are reduced. The output from the power supply circuit is fed into the control circuit which consists of a 40 pin base ic which is capable of withstanding 5V, by the help of the crystal oscillator the execution time is reduced for quick response. The output from the control circuit is fed into the drive circuit as an input which consists of a driver ic 7667 capable of withstanding 15V which drives the three port converter. The supply from the pv panel drives the three port converter which consists of boost and buck with buck-boost converter thereby increasing the voltage level than the reference voltage with the help of the boost converter and maintains the same voltage level with the help of buck with buck-boost converter when there is absence of the supply from the pv panel and supplies the load.

IV. SIMULATION OF THREE PORT CONVERTER

The simulation is done in the matlab and simulink software. Input voltage before feeding to the load is given to the converter in order to add or subtract the voltage as per the requirements of the load. This correction is done by taking a feedback from the output of the converter, this output is compared in the summer with a voltage reference value. Output of the summer is considered as the error signal “e” in fig (matlab) based on the error whether it is high or low the delay block produces the delay signal, zero-holder (that holds the waveform where it meets zero) delays the signal by holding it. This is fed to the quantizer. The quantizer is used to map where the waveform is present. The sensed signal is given to A/D limiter and is processed using the formula Discrete-time Integral Compensator which is designed using mathematical equations. This is given to the PULSE WIDTH MODULATOR which controls the converter to generate and stop the addition potentials for proper output. The output of this simulink scope is viewed in DSO hardware.

DC output voltage waveform for converter observed from MATLAB Scope.
V. CONCLUSION

From the simulation results it is evident that the three port converter maintains the voltage level constant with the use of boost and buck with buck-boost converter. Thus the single stage three port converter for pv pump applications is verified and experimented successfully. This module can be used in various applications such as lap charging, pv pump applications.

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