Implementation of Constant Frequency Parallel Tuned Resonant DC-DC Converter Design for Solar Energy

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Abstract

The constructed DC-DC converter are power electronic circuit that converts a dc voltage to a different dc voltage level, often providing a regulated output voltage. Buck-boost converters make it possible to efficiently convert a dc voltage to either a lower or higher voltage. Buck-boost converter are especially useful for PV maximum power tracking purpose, where the objective is to draw maximum possible power from solar panels at all time, regardless of the load. This paper analyzes and describes step by step the process of designing and construction of high efficiency low ripple voltage buck-boost DC-DC converter for solar energy. The input voltage (5V-20V) can be changed a regulated voltage (12V). ISIS simulation results provided strong evidences about the high efficiency, minimum ripple voltage, high accuracy, and the usefulness of the system.

Keywords: Photovoltaic Solar System, DC-DC Converter, Design of Buck-Boost Converter, ISIS Software.

I. Introduction

There are many renewable energy sources, such as biomass energy, wind energy, geothermal, solar thermal and solar photovoltaic. Among these sources, solar energy is more popular than other renewable energies to take over the scarcity of hydrocarbon in future. Solar energy is transmitted from the sun through space to the earth by electromagnetic radiation. Solar energy is the most abundant and constant stream of energy. Among any other of renewable energy sources, solar energy was chosen as the topic of the paper.

Photovoltaic PV power systems are one of today's fastest growing renewable energy technologies. Solar power is produced by photovoltaic. The word "photovoltaic'' is a marriage of two words "photo'' meaning light and "voltaic'' meaning electricity. So photovoltaic technology, the scientific term used to describe solar energy, involves the generation of electricity from light.

Photovoltaic system has no fuel requirements, long life and easy to maintain. Photovoltaic system can be used to improve quality of life and provide national economic benefits. Solar cells, which are the foundation of PV system, convert the energy in sunlight directly into electricity. A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Several solar cells are connected in series, parallel to get desired voltage, current and power. Several solar cells are connected in series to form a string. Several strings are connected in parallel to form a module. Modules are designed to supply electricity at a certain voltage, such as common (12V) system.

A solar PV panel delivers certain DC current at certain DC voltage for certain intensity of incident solar energy. The DC output power depends upon total number of cells and power per cell. [6]

DC-DC voltage conversion is more widely used in power supply circuits because every piece of equipment that has an electronic board in it requires a wide variety of DC voltage supplies. Each voltage must be supplied from a power supply.

This means that computers, PLCs, and all other electronic equipment required a DC power supply. Today converter circuits are often found in switch-mode power supplies (SMPS). The DC-DC converter converts a DC input voltage, to a DC output voltage, with a magnitude lower or higher than the input voltage. A DC-AC inverter requires its own small amount of electricity to operate to AC load. Figure 1 and Figure 2 show the basic block diagram of solar energy conversion system for AC load and DC load.

The DC-DC converters are converting the unregulated DC input to a controlled DC output voltage with a desired voltage level. The DC-DC converters are widely used in regulated switched-mode DC power supplies and DC motor drive applications. The input of these converters is often an unregulated DC voltage, which is obtained by renewable energy or rectifying the line voltage, therefore it will fluctuate due to changes in the line voltage magnitude.

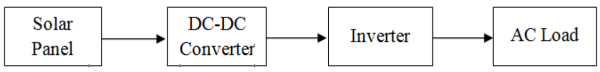


Fig 1.The basic block diagram of the solar energy conversion system for ac load

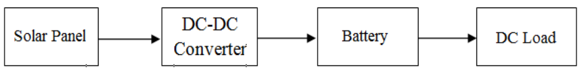


Fig 2.The Basic block diagram of the solar energy conversion system for dc load

High efficiency is invariably required, since cooling of inefficient power converters is difficult and expensive. The ideal DC-DC converter exhibits 100% efficiency; in practice, efficiencies of 70% to 95% are typically obtained. This is achieved using switched-mode circuits whose elements dissipate negligible power. The pulse-width modulation (PWM) allows control and regulation of the total output voltage.

A basic DC-DC converter is as shown in Figure 3.

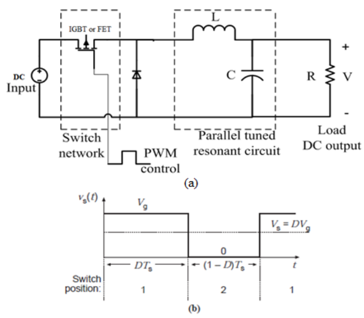


Fig 3.The basic dc-dc converter: (a) schematic (b) switch voltage waveform

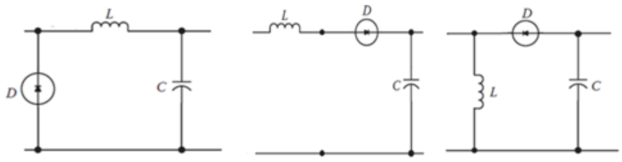
A single-pole double-throw (SPDT) switch is connected to the DC input voltage V_g. The switch output voltage $v_s(t)$ is equal to V_g when the switch is position 1, and is equal to zero when the switch is in position 2. The switch position varies periodically, such that $v_s(t)$ is a rectangular waveform having period T_s and duty cycle D. The duty cycle is equal to the fraction of time that the switch is connected in position1, and hence $0 \leq D \leq 1$. The switching frequency f_s is equal to $1/T_s$. In practice, the SPDT switch is realized using semiconductor devices such as diodes, power MOSFETs, IGBTs, BJTs, or thyristors. Typical switching frequencies lie in the range 1 kHz to 1 MHz, depending on the speed of the semiconductor devices. [1]

II. Constant Frequency Parallel Tuned Resonant Circuit for Dc-Dc Converter

The desired DC voltage component V_s, the switch waveform $v_s(t)$ also contains undesired harmonics of the switching frequency. In most application, these harmonics must be removed, such that the converter output voltage v(t) is essentially equal to the dc component $V=V_s$. A constant frequency parallel tuned resonant, low-pass filter is employed for this purpose. The converter contains a single- section parallel tuned resonant L-C low-pass filter. The filter has resonant frequency f_r is given by:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \qquad (1)$$

The resonant frequency f_r is chosen to be sufficiently less than the switching frequency f_s, so that the filter essentially passes only the dc component of $v_s(t)$. To the extent that the inductor and capacitor are ideal, the filter removes the switching harmonics without dissipation of power. Figure 4 is shown the parallel tuned resonant circuit for buck converter, boost converter and buck-boost converter. [1]



(a) (b) (c)

Fig 4. Parallel tuned resonant circuit for (a) buck converter (b) boost converter (c) buck-boost converter

III. Analysis of the Dc-Dc Buck-Boost Converter

The buck-boost converter is also a member of the DC-DC converter family used extensively for advanced switching power supplies. The buck-boost converter has an output voltage magnitude that is either greater than or less than the input voltage magnitude. The output voltage is adjustable based on the duty cycle (D) of the switching transistor. The polarity of the output voltage is opposite the input voltage. The power stage of the topology is shown in Figure 5.

When the switch is on, the diode is reverse-biased and the input is connected across the inductor, which stores energy. At turn-off, the inductor voltage reverses and the stored energy is then passed to the capacitor and load through the forward biased rectifier diode. There is a polarity inversion; the output voltage generated is negative with respect to input. The continuous mode DC equation is below:

$$\frac{V_o}{V_d} = \frac{D}{1-D} \qquad (2)$$

The duty cycle (D) can be selected such that the output voltage can either be higher or lower than the input voltage. This gives the converter the flexibility to either step up or step down the supply. Since both input and output currents are pulsating, low ripple levels are very difficult to achieve using the buck-boost. Very large output filter capacitors are needed, typically up to eight times that a buck converter.

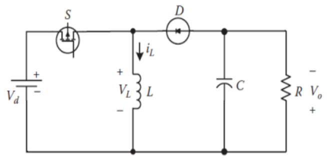


Fig 5. Buck-boost converter

As the converter is assumed to be operating in continuous conduction mode, the inductor current has some definite minimum value before time t=0, before the switch is on. As soon as the switch is on, the first sub-interval of the switching period starts. The inductor current starts increasing from its minimum value. The diode is reverse biased and thus off. The output capacitor supplies the load in this sub-interval and therefore it is discharge, too. The power stage appears as shown in Figure 6. The decrease in capacitor voltage is also linear. The first sub-interval, from switch on to switch off can be written as,

$$0 < t < DT$$

$$V_L = V_d \qquad (3)$$

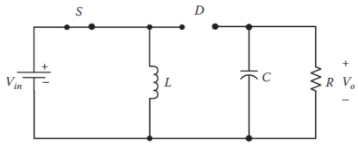


Fig 6. Buck-boost converter when switch is on

The inductor current keeps on increasing until the switch is made off. The off command can be from pulse-width modulation (PWM), pulse-frequency modulation (PFM), or other kind of controller. Once the switch is made off the first sub-interval ends and the second one starts. In the second sub-interval, the inductor depletes the energy partly through the output capacitor and partly through the load. Thus, the inductor current decreases linearly in this sub-interval and the capacitor charge increases linearly. The diode is on in this interval and allows the inductor current to flow through it. The power stage circuit for this sub-interval is shown in Figure 7.[13]

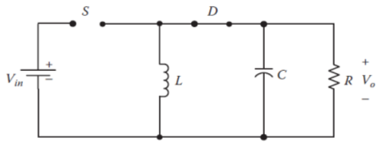


Fig 7. Buck-boost converter when switch is off and diode is on

For the second sub-interval,

$$DT < t < T$$

$$V_L = -V_o \qquad (4)$$

IV. Design of The 12V Regulated Dc-Dc Buck Boost Converter

The operating requirements for the buck-boost converter are chosen as follows:

Output Power, $P_{out(max)} = 100W$

Range of input voltage, V_{in} range = 5-20V_{dc}

Switching fixed frequency, f = 28 kHz

Output voltage, Vo= 12V_{dc}

Output current, $I_o = 8.34A$

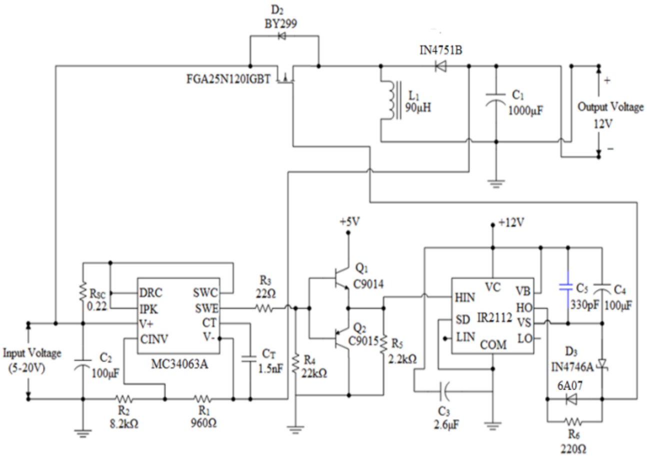


Fig 8. Overall circuit diagram of 12V regulated dc-dc buck-boost converter

The switching frequency must be high enough to minimize the size of power circuit and reduce distortion. On the other hand, it should be less for greater efficiency. The switching frequency of high efficiency buck-boost converters applicable in solar system will be between (20kHz - 100kHz). To find the switching frequency (f) for which the output current (I_o) values, the time period (T), and the duty ratio (D) must know, because the value of inductor (L_{cr}) is dependent upon them. To determine the output current (I_o), the uses of analytical equations are possible. For a typical output voltage (12V) and output power (100W), the output current of the converter will be (8.34A). Then the calculated results of duty ratio (D) and inductor current are shown in table 1.

$$I_L = \frac{I_o}{1 - D} \quad (5)$$

TABLE 1 Calculated Duty Ratio and Inductor Current for Different Vd

V_d (V)	V_o (V)	D (%)	I_L (A)	V_d (V)	V_o (V)	D (%)	I_L (A)
5	12	70.58	28.32	13	12	48.00	16.02
6	12	66.66	24.99	14	12	46.15	15.47
7	12	63.15	22.61	15	12	44.44	15.00
8	12	60.00	20.83	16	12	42.85	14.58
9	12	57.14	19.44	17	12	41.37	14.21
10	12	54.54	18.33	18	12	40.00	13.89
11	12	52.17	17.42	19	12	38.70	13.59
12	12	50.00	16.66	20	12	37.50	13.33

A. Inductor Selection

There are different ways to calculate the required inductance. The best method is to choose the inductor ripple current (Δi_L) between (20% -30%) of the average value of (I_L). To make the regulator operate in continuous mode, the design will have a good load transient response with an acceptable output ripple voltage and according to the simulation results, it is selected to be 22% of the peak inductor current.

$$\Delta i_L = 0.22 I_L \quad (6)$$

The required inductor will be,

$$L = \frac{V_d \times D}{f \times \Delta i_L} \qquad (7)$$

TABLE 2 INDUCTOR SELECTION TABLE

Switching Frequency	f=20kHz		f=100kHz	
Input Volt	V_{in}=5 V	V_{in}=20 V	V_{in}=5 V	V_{in}=20 V
L(μH)	28.32	127.8	5.66	25.57

For any value of critical inductor value (127.8μH >L_{cr}> 5.66μH), so, choosing the inductor (L=90μH).

B. Capacitor Selection

The critical value of the capacitor (C_{cr}) operating on the frequency (28 kHz) and minimum or maximum input voltages (5-20V) regarding the output ripple voltage (ΔV_o< 50 mV), using (ΔV_o =40 mV) is calculated as shown in table 3.

$$C_{cr} = \frac{\Delta i_L \times D}{f \times \Delta V_o} \qquad (8)$$

TABLE 3 CAPACITOR SELECTION TABLE

Input Voltage	V_d=5V	V_d=20V
C (μF)	3926	982

The possible capacitance value (C >C_{cr}), so, choosing the capacitor, C = 1000μF.

C. PWM Switching Control Circuits (MC34063)

The reference voltage is set at 1.25V and is used to set the output voltage of the converter.

$$V_{out} = 1.25(\frac{R_2}{R_1} + 1) \qquad (9)$$

Output Voltage, V_o= 12V

Assume R_1 = 960 Ω

Therefore, R_2=8.256kΩ

The oscillator frequency (f) is composed of a current source and a current sink that charge and discharge the external timing capacitor (C_T) between an upper and lower preset threshold.

$$f = \frac{1}{2\pi\sqrt{LC_T}} \qquad (10)$$

Calculate the C_T, to give the desired switching frequency (f =28 kHz) and inductance (L= 22 mH).

$$C_T = \left[\frac{1}{2\pi \times 28k}\right]^2 \times \frac{1}{22mH} = 1.468\ nF$$

Therefore, choosing the timing capacitor, C_T =1.5 nF.

The current limit is accomplished by monitoring the voltage drop across an external sense resistor located in series with V_{CC} and the output switch.

$$I_{pk} = \frac{330mV}{R_{sense}} \quad (11)$$

The maximum peak current for MC34063A is 1.5A.

Therefore, $R_{sense} = \frac{330mV}{1.5} = 0.22\,\Omega$

D. IGBT Gate Driver (IR2112)

The dc power supply of IR2112IC is +12V, therefore, it is connected to pin 9 of V_{DD} supply and the capacitor filter is used for IR2112IC. Therefore, the capacitance value is:

$$C = \frac{I_{dc} \times 10^4}{0.48 \times V_{dc}}\,\mu F \quad (12)$$

I_{dc}=1.5mA and V_{dc}= 12V

Therefore, C_3 = 2.6μF

The gate voltage of IGBT depends on the IN4746A zener diode. The diode ratings of IN4746A zener diode are 1W and 18V. Therefore, zener current is calculated as follow:

$$I_Z = \frac{P_Z}{V_Z} = \frac{1W}{18V} = 55.56mA \quad (13)$$

$$C = \frac{55.56 \times 10^4}{0.48 \times 12}\,\mu F = 96.46\ \mu F$$

Therefore, 100μF capacitor is selected for the bootstrap operation. [11]

V. Test and Result

The test and result is firstly mentioned by ISIS simulation. The operation of the DC-DC buck-boost converter is converted unregulated DC voltage (5-20V) to regulated DC voltage (12V).

A. Software Simulation for Buck-Boost Converter

The designed program and hardware is tested by Proteus circuit simulation software. Proteus VSM (Virtual System Modeling), has been used to create the circuit diagrams and test the designs in this paper.

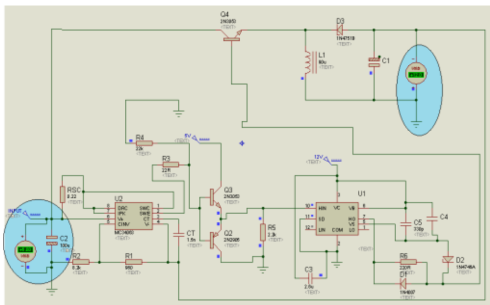


Fig 9. Circuit simulation in ISIS software (when the input voltage is 6V and output voltage is 12V)

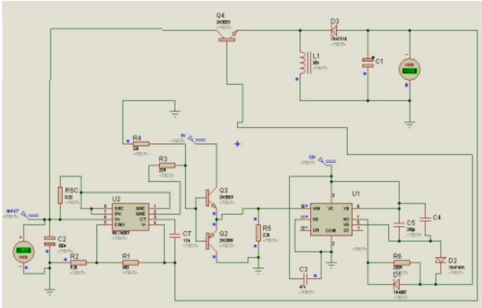


Fig 10. Circuit simulation in ISIS software (when the input voltage is 20V and output voltage is 12V)

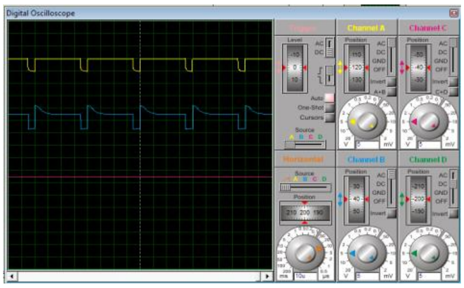


Fig 11.Circuit simulation in ISIS software (PWM output waveform of MC34063A and IR2112)

B. Testing for Buck-Boost Converter

In this circuit, PWM control circuit is constructed with MC34063A, push-pull output driver amplifier circuit is constructed with NPN transistor C9014 and PNP transistor C9015, IGBT (switch) gate driver is constructed with IR2112IC and constant frequency parallel tuned resonant circuit with inductor (90µH) and capacitor (1000µF). The constructed 12V regulated DC-DC buck-boost converter is converted the input voltage (5V to 12V) to regulate voltage (12V). Thus, the 12V regulated buck-boost converter is used to maintain regulated output voltage from solar array when the solar power is rising and falling.

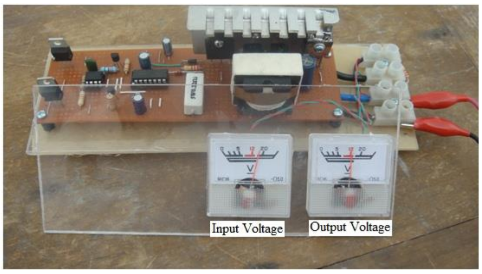


Fig 12. Photo of 12V regulated buck-boost converter testing

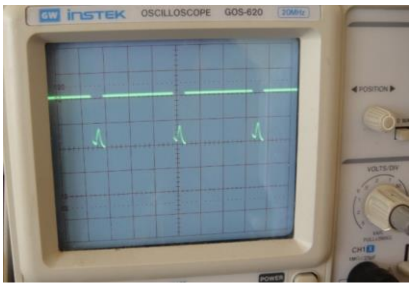


Fig 13. Photo of 12V regulated buck-boost converter testing (PWM output waveform)

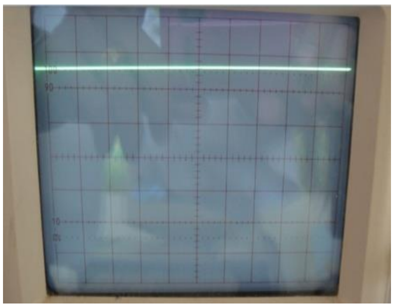


Fig 14. Photo of 12V regulated buck-boost converter testing (12V DC output waveform)

VI. CONCLUSION

This paper presents a complete construction and design of the DC-DC Buck-Boost switching converter and architecture for (100W) home appliances to meet the requirements of high efficiency, minimum ripple voltage and constant (12V) output voltage. The converter and controller architecture for the designed parameters are simulated using ISIS software. The simulations have demonstrated that, the design can achieve the input voltage (5-20V), all at (28kHz) switching frequency. In the power converter design, the application of PWM in close loop control is common. In this paper, the MC34063A controller is designed for DC/DC PWM converter. The parallel tuned resonant filter design calculation and selection of switching devices are also described in detail. The voltage regulator is used to get regulated voltage from the solar panel array to the battery to provide optimum current control during charge. Thus, it is used to get the long life of batter.

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