ISSN 2321 – 2004
ISSN 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 1, Issue 6, September 2013

A single-stage full-bridge series-resonant buck-boost inverter (Full-bridge topology)

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Abstract - This Paper is to extract the underlying A single-stage full-bridge series-resonant buck-boost inverter (FB-SRBBI) is proposed in this paper. The proposed inverter only includes a full-bridge topology and a LC resonant tank without auxiliary switches. The output voltage of the proposed inverter can be larger or lower than the dc input voltage, depending on the instantaneous duty-cycle. This property is not found in the classical voltage source inverter, which produces an ac output instantaneous voltage always lower than the dc input voltage.The proposed inverter circuit topology provides the main switch for turn-on at ZCS by a resonant tank. The nonlinear control strategy is designed against the input dc perturbation and achieves well dynamic regulation. An average approach is employed to analyze the system. A design example of dc/ac inverter is examined to assess the inverter performance and it provides high power efficiency above 80% under the rated power.
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Keywords: High-Voltage Direct Current (Hvdc) Power Transmission, Three phase inverter,buck boost inverter, Transformer, Eight level deep hardware stack

I.INTRODUCTION

An inverter is an electronic circuit that converts direct current (DC) to alternating current (AC). Inverters are used in a wide range of applications, from small switching power supplies in computers, to large electric utility applications that transport bulk power. The inverter is so named because it performs the opposite function of a rectifier.

1.1) Dc Power Source Utilization

Inverter designed to provide 115 VAC from the 12 VDC source provided in an automobile. An inverter converts the DC electricity from sources such as batteries, solar panels, or fuel cells to AC electricity. The electricity can then be used to operate AC equipment such as those that are plugged in to most house hold electrical outlets.

1.2) Uninterruptible Power Supplies

One type of uninterruptible power supply uses batteries to store power and an inverter to supply AC power from the batteries when main power is not available. When main power is restored, a rectifier is used to supply DC power to recharge the batteries. A UPS is a device which supplies the stored electrical power to the load in case of raw power cut-off or Blackout.

1.3) Induction Heating

Inverters convert low frequency main AC power to a higher frequency for use in induction heating. To do this, AC power is first rectified to provide DC power. The inverter then changes the DC power to high frequency AC power.

With HVDC power transmission, AC power is rectified and high voltage DC power is transmitted to another location. At the receiving location, an inverter in a static inverter plant converts the power back to AC.

1.4)Variable-Frequency Drives

A variable-frequency drive controls the operating speed of an AC motor by controlling the frequency and voltage of the power supplied to the motor. An inverter provides the controlled power. In most cases, the variable-frequency drive includes a rectifier so that DC power for the inverter can be provided from main AC power. Since an inverter is the key component, variable-frequency drives are sometimes called inverter drives or just inverters.

1.5) Electric Vehicle Drives

Adjustable speed motor control inverters are currently used to power the traction motor in some electric locomotives and diesel-electric locomotives as well as some battery electric vehicles and hybrid electric highway vehicles such as the Toyota Prius. Various improvements in inverter technology are being developed specifically for electric vehicle applications. In vehicles with regenerative braking, the inverter also takes power from the motor (now acting as a generator) and stores it in the batteries.

1.6) Inverter Circuit Description

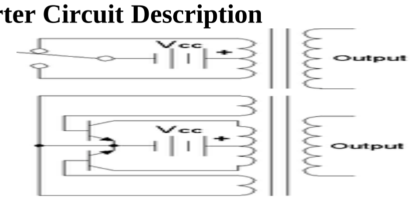

Fig: 1.1 Simple inverter circuit shown with an electromechanical switch and with a transistor switch

1.7) Basic Inverter Designs

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ISSN 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 1, Issue 6, September 2013

In one simple inverter circuit, DC power is connected to a transformer through the centre tap of the primary winding. A switch is rapidly switched back and forth to allow current to flow back to the DC source following two alternate paths through one end of the primary winding and then the other. The alternation of the direction of current in the primary winding of the transformer produces alternating current (AC) in the secondary circuit.

The electromechanical version of the switching device includes two stationary contacts and a spring supported moving contact. The spring holds the movable contact against one of the stationary contacts and an electromagnet pulls the movable contact to the opposite stationary contact. The current in the electromagnet is interrupted by the action of the switch so that the switch continually switches rapidly back and forth. This type of electromechanical inverter switch, called a vibrator or buzzer, was once used in vacuum tube automobile radios. A similar mechanism has been used in door bells, buzzers and tattoo guns.

II.SYSTEM OVERVIEW

The switch in the simple inverter described above produces a square voltage waveform as opposed to the sinusoidal waveform that is the usual waveform of an AC power supply. Using Fourier analysis, periodic waveforms are represented as the sum of an infinite series of sine waves. The sine wave that has the same frequency as the original waveform is called the fundamental component. The other sine waves, called harmonics that are included in the series have frequencies that are integral multiples of the fundamental frequency.

The quality of the inverter output waveform can be expressed by using the Fourier analysis data to calculate the total harmonic distortion (THD). The total harmonic distortion is the square root of the sum of the squares of the harmonic voltages divided by the fundamental voltage:

$$\mathrm{THD} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2}}{V_1}$$

The quality of output waveform that is needed from an inverter depends on the characteristics of the connected load. Some loads need a nearly perfect sine wave voltage supply in order to work properly. Other loads may work quite well with a square wave voltage.

2.1) More Advanced Inverter Designs

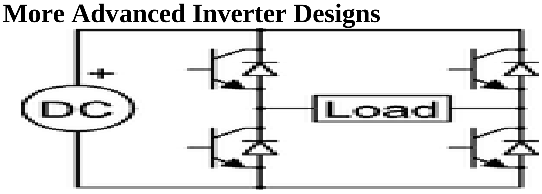

Fig: 2.1 H-bridge inverter circuit with transistor switches and anti-parallel diodes

There are many different power circuit topologies and control strategies used in inverter designs. Different design approaches address various issues that may be more or less important depending on the way that the inverter is intended to be used.

The issue of waveform quality can be addressed in many ways. Capacitors and inductors can be used to filter the waveform. If the design includes a transformer, filtering can be applied to the primary or the secondary side of the transformer or to both sides. Low-pass filters are applied to allow the fundamental component of the waveform to pass to the output while limiting the passage of the harmonic components. If the inverter is designed to provide power at a fixed frequency, a resonant filter can be used. For an adjustable frequency inverter, the filter must be tuned to a frequency that is above the maximum fundamental frequency.

Since most loads contain inductance, feedback rectifiers or anti parallel diodes are often connected across each semiconductor switch to provide a path for the peak inductive load current when the switch is turned off. The anti parallel diodes are somewhat similar to the freewheeling diodes used in AC/DC converter circuits.

Fourier analysis reveals that a waveform, like a square wave, that is anti symmetrical about the 180 degree point contains only odd harmonics, the 3rd, 5th, 7th etc. Waveforms that have steps of certain widths and heights eliminate or “cancel” additional harmonics. For example, by inserting a zero-voltage step between the positive and negative sections of the square-wave, all of the harmonics that are divisible by three can be eliminated. That leaves only the 5th, 7th, 11th, 13th etc. The required width of the steps is one third of the period for each of the positive and negative voltage steps and one sixth of the period for each of the zero-voltage steps.

Changing the square wave as described above is an example of pulse-width modulation (PWM). Modulating, or regulating the width of a square-wave pulse is often used as a method of regulating or adjusting an inverter's output voltage. When voltage control is not required, a fixed pulse width can be selected to reduce or eliminate selected harmonics. Harmonic elimination techniques are generally applied to the lowest harmonics because filtering is more effective at high frequencies than at low frequencies. Multiple pulse-width or carrier based PWM control schemes produce waveforms that are composed of many narrow pulses. The frequency represented by the number of narrow pulses per second is called the switching frequency or carrier frequency. These control schemes are often used in variable-frequency motor control inverters because they allow a wide range of output voltage and frequency adjustment while also improving the quality of the waveform.

Multilevel inverters provide another approach to harmonic cancellation. Multilevel inverters provide an output waveform that exhibits multiple steps at several voltage levels. For example, it is possible to produce a more sinusoidal wave by having split-rail direct current inputs at two voltages, or positive and negative inputs with a central ground. By connecting the inverter output terminals in

ISSN 2321 – 2004
ISSN 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
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sequence between the positive rail and ground, the positive rail and the negative rail, the ground rail and the negative rail, then both to the ground rail, a stepped waveform is generated at the inverter output. This is an example of a three level inverter: the two voltages and ground.

Three Phase Inverters

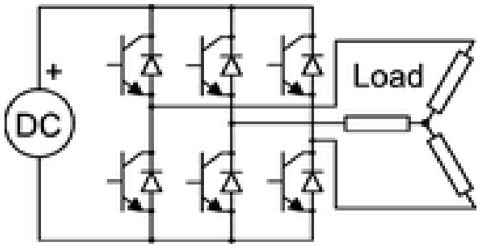

Fig:2.2 Three phase inverter with Y- connected load

Three-phase inverters are used for variable-frequency drive applications and for high power applications such as HVDC power transmission. A basic three-phase inverter consists of three single-phase inverter switches each connected to one of the three load terminals. For the most basic control scheme, the operation of the three switches is coordinated so that one switch operates at each 60 degree point of the fundamental output waveform. This creates a line-to-line output waveform that has six steps. The six-step waveform has a zero-voltage step between the positive and negative sections of the square-wave such that the harmonics that are multiples of three are eliminated as described above. When carrier-based PWM techniques are applied to six-step waveforms, the basic overall shape, or envelope, of the waveform is retained so that the 3rd harmonic and its multiples are cancelled.

III.THE WORKING PRINCIPLE

BASIC PRINCIPLE OF BUCK-BOOST INVERTER:

The buck-boost is a popular non-isolated inverting power stage topology, sometimes called a step-up/down power stage. Power supply designers choose the buck-boost power stage because the required output is inverted from the input voltage, and the output voltage can be either higher or lower than the input voltage.

The input current for a buck-boost power stage is discontinuous, or pulsating, because the power switch (Q1) current that pulses from zero to IL every switching cycle. The output current for a buck-boost power stage is also discontinuous or pulsating because the output diode only conducts during a portion of the switching cycle. Figure 1 shows a simplified schematic of the buck-boost power stage. Inductor L and capacitor C make up the effective output filter. The capacitor equivalent series resistance (ESR), RC, and the inductor dc resistance, RL, are included in the analysis. Resistor R represents the load seen by the power supply output. The diode D1 is usually called the catch diode, or freewheeling diode.

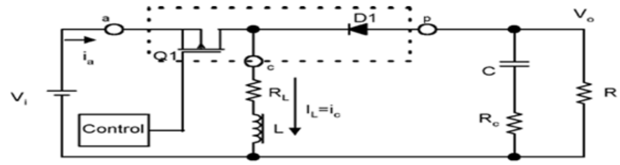

Fig:3.1 Buck Power Stage Schematic

During normal operation of the buck-boost power stage, Q1 is repeatedly switched on and off with the on- and off-times governed by the control circuit. This switching action gives rise to a train of pulses at the junction of Q1, D1, and L. Although the inductor, L, is connected to the output capacitor, C, only when D1 conducts, an effective L/C output filter is formed. It filters the train of pulses to produce a DC output voltage.

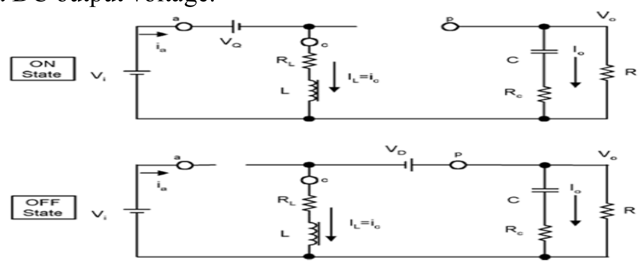

Fig: 3.2 Buck power stage states

The inductor current increses during the ON state is given by

$$\Delta I_L(+) = \frac{V_i - (V_Q + I_L * R_L)}{L} * T_{on} \quad (1)$$

The is the inductor ripple current

The inductor current increses during the OFF state is given by

$$\Delta I_L(-) = \frac{-(V_0 - V_D - I_L * R_L)}{L} * T_{OFF} \quad (2)$$

The is the inductor ripple current.

In steady state conditions, the current increase and the current decrese must be equal, solving for

$$V_0 = -\left[(V_i - V_Q) * \frac{T_{ON}}{T_{OFF}} - V_D - I_L * R_L * \frac{(T_{ON} + T_{OFF})}{T_{OFF}}\right]$$

$$= -\left[(V_i - V_Q) * \frac{D}{1-D} - V_D - \frac{I_L * R_L}{(1-D)}\right] \quad (3)$$

A common simplification is to assume VQ, Vd, and RL are small enough to ignore.

Setting VQ, Vd, and RL to zero, the above equation simplifies considerably to:

$$V_0 = -[(V_i) * \quad (4)$$

Unlike the buck power stage, the average of the inductor current is not equal to the output current. To relate the inductor current to the output current, referring to Figures 2

ISSN 2321 – 2004
ISSN 2321 – 5526
INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
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and 3, note that the inductor delivers current to the output only during the off state of the power stage. This current averaged over a complete switching cycle is equal to the output current because the average current in the output capacitor must be equal to zero

PULSE WIDTH MODULATION

Usually, the on- and off-states of the power switches in one inverter leg are always opposite. Therefore, the inverter circuit can be simplified into three 2-position switches. Either the positive or the negative dc bus voltage is applied to one of the motor phases for a short time. Pulse width modulation (PWM) is a method whereby the switched voltage pulses are produced for different output frequencies and voltages. A typical modulator produces an average voltage value, equal to the reference voltage within each PWM period. Considering a very short PWM period, the reference voltage is reflected by the fundamental of the switched pulse pattern.

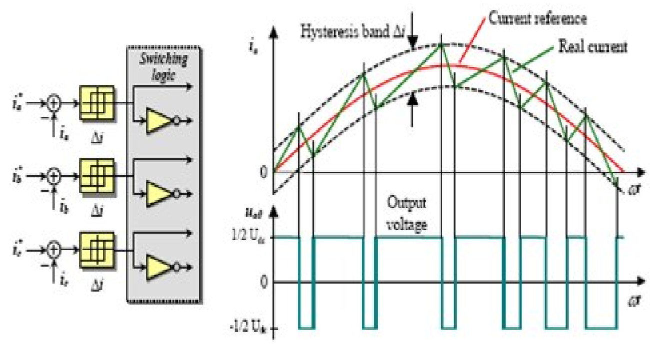
Apart from the fundamental wave, the voltage spectrum at the motor terminals consists of many higher harmonics. The interaction between the fundamental motor flux wave and the 5^{th} and 7^{th} harmonic currents produces a pulsating torque at six times of the fundamental supply frequency. Similarly, 11^{th} and 13^{th} harmonics produce a pulsating torque at twelve times the fundamental supply frequency [Dub 89]. Furthermore, harmonic currents and skin effect increase copper losses leading to motor derating. However, the motor reactance acts as a low-pass filter and substantially reduces high-frequency current harmonics. Therefore, the motor flux (IM & PMSM) is in good approximation sinusoidal and the contribution of harmonics to the developed torque is negligible. To minimize the effect of harmonics on the motor performance, the PWM frequency should be as high as possible. However, the PWM frequency is restricted by the control unit (resolution) and the switching device capabilities, e.g. due to switching losses and dead time distorting the output voltage.

There are various PWM schemes. Well-known among these are sinusoidal PWM, hysteresis PWM, space vector modulation (SVM) and "optimal" PWM techniques based on the optimization of certain performance criteria, e.g. selective harmonic elimination, increasing efficiency, and minimization of torque pulsation [Jen 95]. While the sinusoidal pulse-width modulation and the hysteresis PWM can be implemented using analog techniques, the remaining PWM techniques require the use of a microprocessor.

A modulation scheme especially developed for drives is the direct flux and torque control (DTC). A two-level hysteresis controller is used to define the error of the stator flux. The torque is compared to its reference value and is fed into a three-level hysteresis comparator. The phase angle of the instantaneous stator flux linkage space phasor together with the torque and flux error state is used in a switching table for the selection of an appropriate voltage state applied to the motor [Dam 97], [Vas 97]. Usually, there is no fixed pattern modulation in process or fixed voltage to frequency relation in the DTC. The DTC approach is similar to the FOC with hysteresis PWM. However, it takes the interaction between the three phases into account. In the following subsections, hysteresis PWM, sinusoidal PWM and SVM are discussed in more detail.

Hysteresis PWM Current Control :

Hysteresis current control is a PWM technique, very simple to implement and taking care directly for the current control. The switching logic is realized by three hysteresis controllers, one for each phase (figure 1.4). The hysteresis PWM current control, also known as bang-bang control, is done in the three phases separately. Each controller determines the switching-state of one inverter half-bridge in such a way that the corresponding current is maintained within a hysteresis band Δi.



Hysterisis PWM, current control and switching logic

Dc bus voltage until the upper band-range is reached. Then, the negative dc bus voltage -½ U_{dc} applied as long as the lower limit is reached &c. More complicated hysteresis PWM current control techniques also exist in practice, e.g. adaptive hysteresis current vector control is based on controlling the current phasor in a α/β-reference frame. These modified techniques take care especially for the interaction of the three phases.

Obviously, the dynamic performance of such an approach is excellent since the maximum voltage is applied until the current error is within predetermined boundaries (bang-bang control). Due to the elimination of an additional current controller, the motor parameter dependence is vastly reduced. However, there are some inherent drawbacks .

• No fixed PWM frequency: The hysteresis controller generates involuntary lower sub harmonics.

• The current error is not strictly limited. The signal may leave the hysteresis band caused by the voltage of the other two phases.

• Usually, there is no interaction between the three phases: No strategy to generate zero-voltage phasors.

• Increased switching frequency (losses) especially at lowermodulation or motor speed.

HARDWARE DETAILS

All electronic circuits works only in low DC voltage, so we need a power supply unit to provide the appropriate voltage

ISSN 2321 – 2004
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INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
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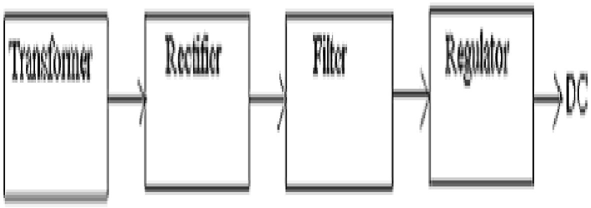
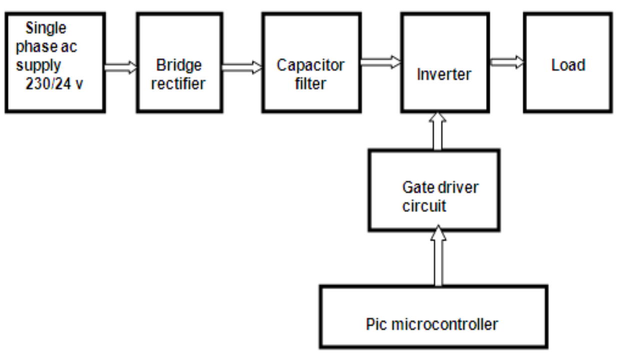
supply for their proper functioning .This unit consists transformer, rectifier, filter & regulator. AC voltage of typica 230v rms is connected to a transformer voltage down to level to the desired ac voltage. A diode rectifier that provi the full wave rectified voltage that is initially filtered by simple capacitor filter to produce a dc voltage. This result dc voltage usually has some ripple or ac voltage variatic A regulator circuit can use this dc input to provide dc volt that not only has much less ripple voltage but also remains same dc value even the dc voltage varies some what, or



load connected to the output dc voltages changes.

Fig 3.3.General Block of Power Supply Unit



Block Diagram:

Overall Block Diagram:

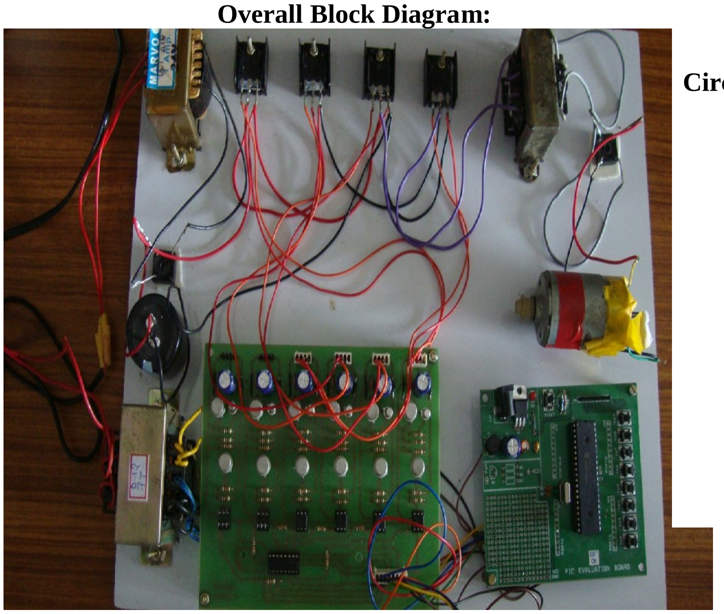


Fig 3.4 Block Diagram of Power Supply Unit

POWER SUPPLY UNIT

Transformer:

A transformer is a static piece of which electric power in one circuit is transformed into electric power of same frequency in another circuit. It can raise or lower the voltage in the circuit, but with a corresponding decrease or increase in current. It works with the principle of mutual induction. In our project we are using a step down transformer to providing a necessary supply for the electronic circuits. Here we step down a 230v ac into 12v ac.

Rectifier:

A dc level obtained from a sinusoidal input can be improved 100% using a process called full wave rectification. Here in our project for full wave rectification we use bridge rectifier. From the basic bridge configuration we see that two diodes (say D2 & D3) are conducting while the other two diodes (D1 & D4) are in off state during the period t = 0 to T/2.Accordingly for the negative cycle of the input the conducting diodes are D1 & D4 .Thus the polarity across the load is the same. In the bridge rectifier the diodes may be of variable types like 1N4001, 1N4003, 1N4004, 1N4005, IN4007 etc… can be used . But here we use 1N4007, because it can withstand up to 1000v.

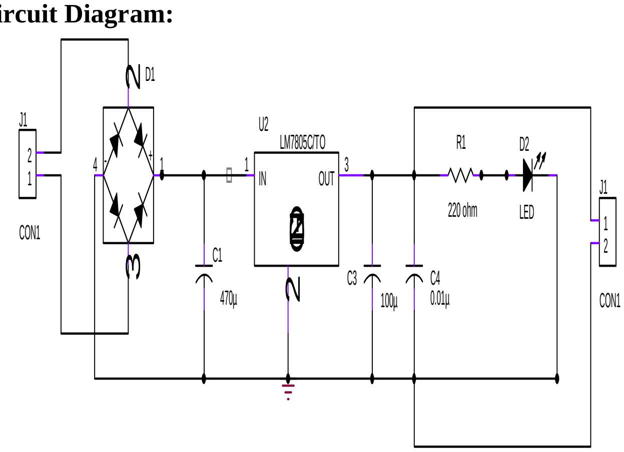
Filters:

In order to obtain a dc voltage of 0 Hz ,we have to use a low pass filter. so that a capacitive filter circuit is used where a capacitor is connected at the rectifier output& a dc is obtained across it. The filtered waveform is essentially a dc voltage with negligible ripples & it is ultimately fed to the load.

Regulators:

The output voltage from the capacitor is more filtered & finally regulated. The voltage regulator is a device, which maintains the output voltage constant irrespective of the change in supply variations, load variations & temperature changes. Here we use fixed voltage regulator namely LM7805.The IC LM7805 is a +5v regulator which is used for microcontroller.

Circuit Diagram:



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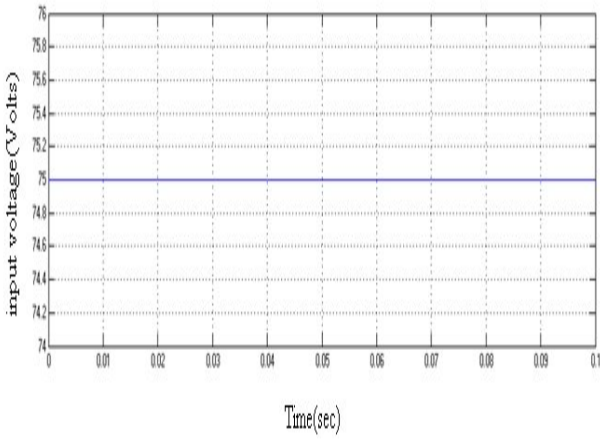
IV.IMPLEMENTATION OF SYSTEM SIMULATION AND HARDWARE RESULTS:

The DC input voltage of the buck inverter is 75 V at the duty cycle of the 50% and the fundamental frequency is in the 50 Hz.The input is shown below



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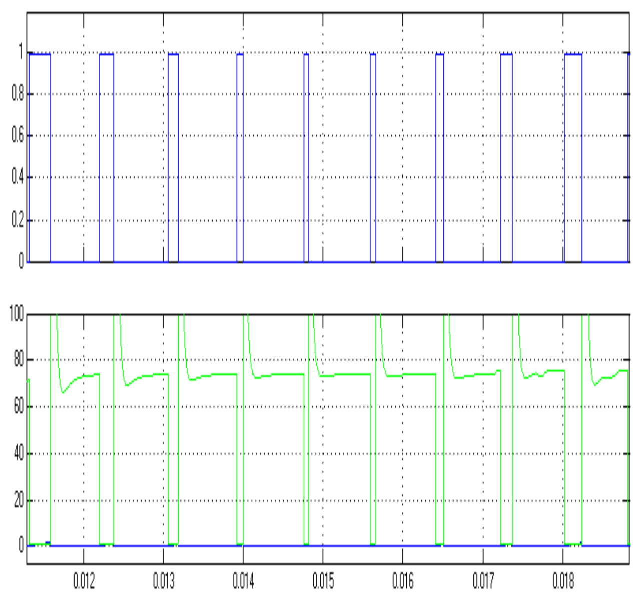
g 4.1 Input DC Voltage

The switches in the circuit are turn-on and turn-off at the zero current. The circuit consists of a switch and inductor is connected to in series of the power switch. The advantage of ZCS is reduce the switching losses and increases the system stability



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ig 4.2 Zero Current Switching

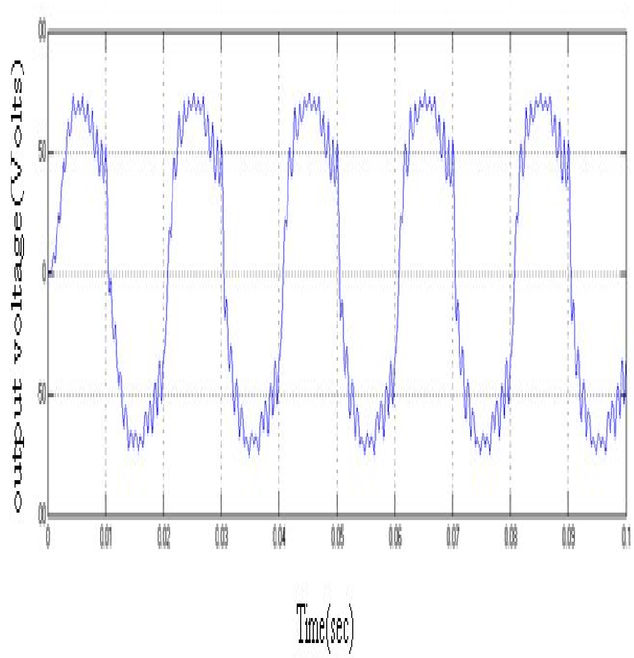

Fig 4.3 output voltage for the Buck inverter

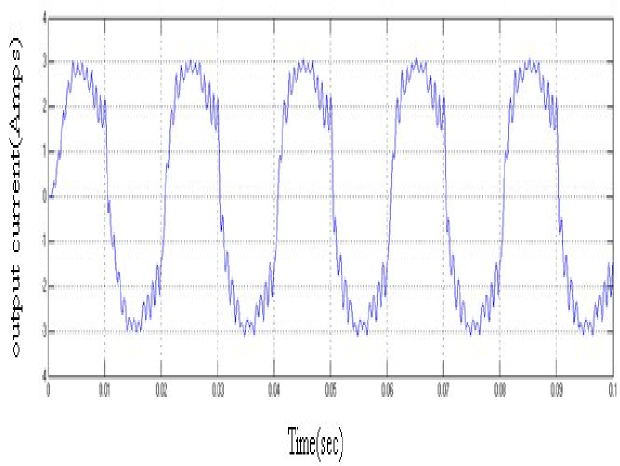

Fig 4.4 output current for the Buck inverter

- During one resonant period, there are three dynamic states including

1. linear-charging state
2. resonant state, and
3. Linear-discharging states.

These states are represented in below figure.

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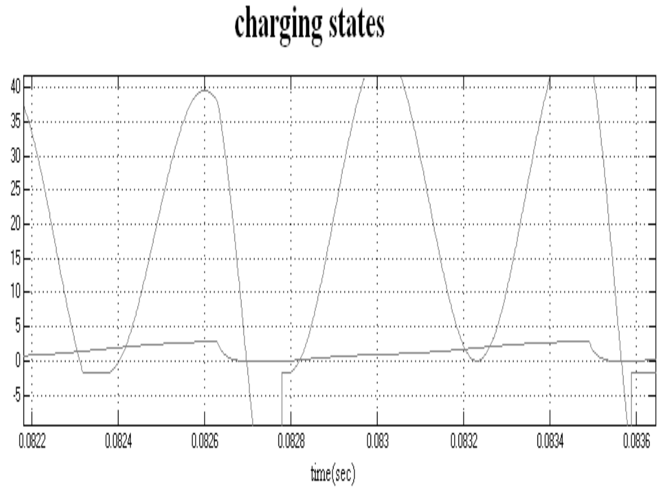
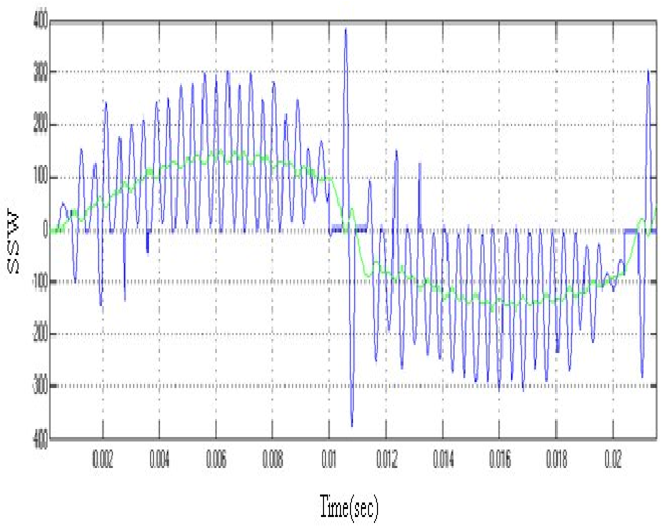


Synthesized Sinusoidal Waveform (SSW) of FB-BBI:

• The fig. Referred as the QSP, and is an element of the SSW.The desired SSW consists of a series of QSP's which are equally spread in each switching period Ts.The presented inverter also uses an LC resonant tank to produce a series of quasi-sinusoidal-pulses(QSP's).Thus the low switching loss, conduction loss, electromagnetic interference is achieved.



OUTPUT VOLTAGE WITHOUT FILTER:

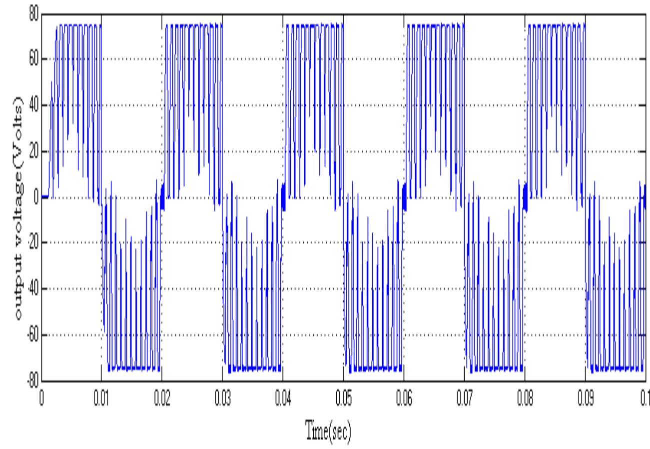


Fig 4.5 output voltage for the inverter without filter

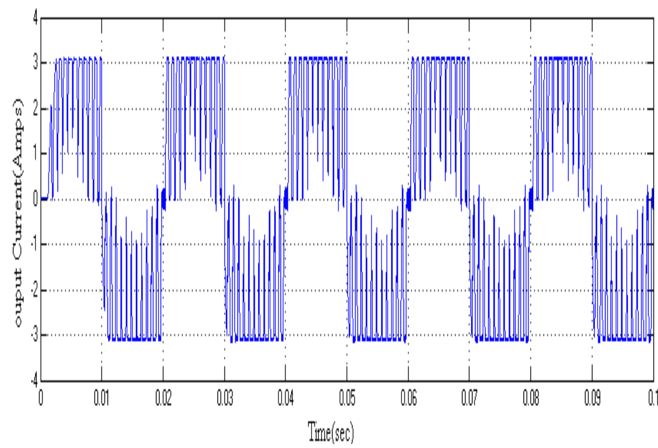


Fig 4.6 output current for the inverter without filter

BOOST MODE:

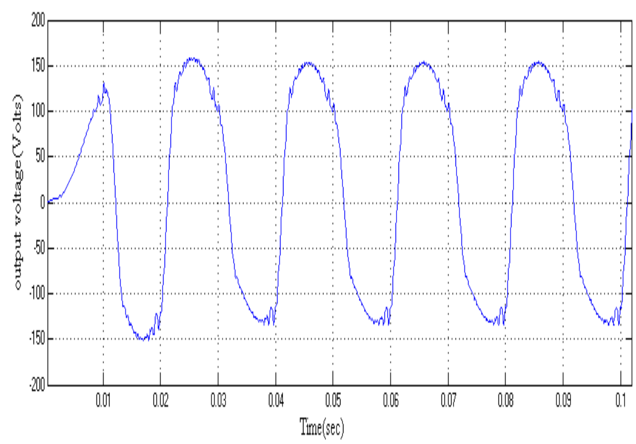


Fig 4.7 output voltage for the boost inverter

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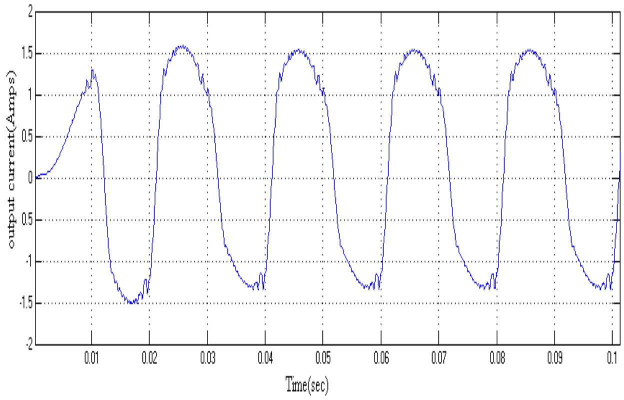

Fig 4.8 output current for the boost inverter

VI.CONCLUSION

In this project Single-Stage Full Bridge-Series Resonant Buck Boost Inverter is presented with simple and compact configuration. The proposed inverter is applicable in UPS design, whenever an ac output voltage larger than the dc link voltage in needed, with no need of a second power conversion stage. The active switches are operated at a fixed frequency with the pulse width modulation technique. A resonant cell is built in the power stage to build ZCS for turning on the power switches.The state space averaging approach is used to estimate the system performance. The design procedure and example of the new FB-SRBBI is described. Some of simulated results prove the truth of the theoretical prediction.

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