International Journal of Technology and Engineering System (IJTES)
Vol 6. No.2 – Jan-March 2014 Pp. 119-127
©gopalax Journals, Singapore
available at : www.ijcns.com
ISSN: 0976-1345

AN ANALOGY OF VARIOUS HIGH EFFICIENCY POWER CONVERTER CONFIGURATIONS FOR INDUSTRIAL DRIVES

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ABSTRACT

A DC-DC converter consisting of resonant boost converter followed by an LCL type Series Resonant Converter (SRC) with isolation transformer and capacitive output filter can provide ZVS (Zero Voltage Switching) and hence high efficiency for all load conditions. The load current in industrial drives will vary from light load to full load. Usually the efficiency of the drives will be maximum at full load. It will be economical if the drive is designed to work with high efficiency at all load conditions. The LCL type series resonant converter consists of a bridge inverter, LC resonant circuit, high frequency isolation transformer and a diode bridge rectifier. The inverter is switched to generate alternating current pulses in primary, which will induce emf in secondary and the emf is rectified and filtered to get constant dc for the drive motor. Here another separate closed loop control is employed by using PID control logic.

Keywords: Dc to Dc converter, LCL type series resonant converter ,zero voltage switching

I. INTRODUCTION

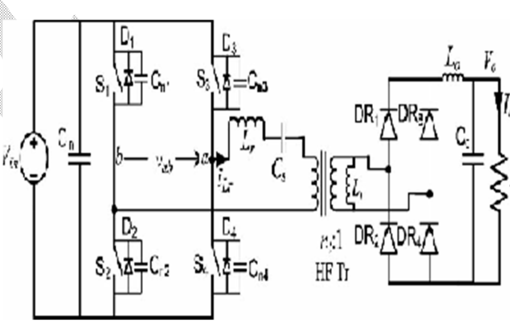
Power electronics is the field of electrical engineering related to the use of semiconductor devices to convert power from the form available from a source to that required by a load. The load may be AC or DC, single-phase or three-phase, and may or may not need isolation from the power source. The power source can be a DC source or an AC source (single-phase or three-phase with line frequency of 50 or 60 Hz), an electric battery, a solar panel, an electric generator or a commercial power supply. A power converter takes the power provided by the source and converts it to the form required by the load. The power converter can be an AC-DC converter, a DC-DC converter, a DC-AC inverter or an AC-AC converter depending on the application

II COMPARISON OF VARIOUS DC –DC CONVERTER CONFIGURATIONS

1) fixed-frequency *LCL* SRC with an inductive output filter
2) fixed frequency phase shifted ZVS PWM full bridge converter
3) fixed-frequency *LCL* SRC with an capacitive output filter

A) Fixed Frequency LCL SRC with an inductive output filter:

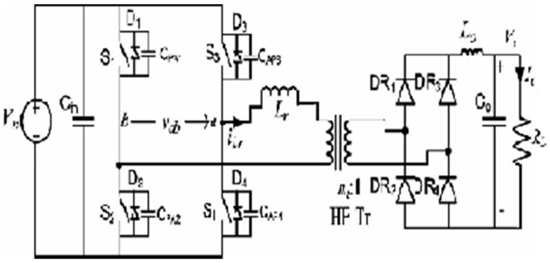
This converter operates in lagging Power factor mode for a very wide change in load and the supply voltage variations.
Thus facilitates ZVS for all the primary switches. The peak current through the switches decreases with load current and is approximately clamped to the load current



B) Fixed frequency phase shifted ZVS PWM full bridge converter

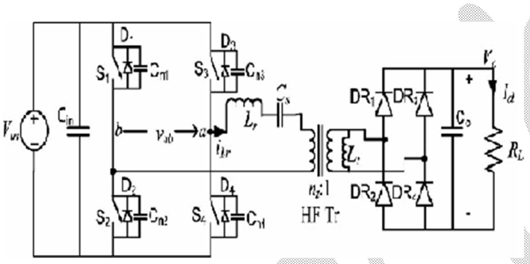
This converter has reduced peak current stresses compared to a resonant converter. The ZVS for the switches is realized by using the leakage inductance of the transformer (together with an external inductor) and the output capacitance of the switch.
Although various improvements have been suggested for this converter , all of them use the increased number of components and suffer from one or another disadvantage (limited ZVS range or high

voltage ringing on the secondary-side rectifier diodes or loss of duty cycle).



C) Fixed Frequency LCL SRC with capacitive output filter

The converter operates in lagging power factor mode for a very wide change in load and the supply voltage variations, thus ensuring ZVS for all the primary switches. The peak current through the switches decreases with load current.



In the case of first two configurations, a snubber circuit is needed across the output rectifier to clamp the voltage ringing due to diode junction capacitance with the leakage inductance of the transformer

ADVANTAGES

1)This (scheme) has the highest efficiency among the three converters.

2) There is no duty cycle loss. Duty cycle loss occurs with inductive output filter converters due to the overlap time during which all the output rectifier diodes conduct. This causes a decrease in the output voltage and increases the primary peak current for the same power output.

3) The transformer turns ratio (= $1/nt = Ns/Np$) is less compared to other two configurations and this is possible since there is no duty cycle loss as mentioned previously.

4) This configuration does not have the ringing problem of the rectifier; therefore, this scheme does not need lossy snubber at the output. The current through the rectifier diodes are sinusoidal, and therefore, the rectifier switches smoothly, and they do not suffer from *di*/*dt* and reverse recovery problems. The rectifier diode voltages are clamped to the output voltage. Therefore, 100-V Schottky diodes can be used with low forward voltage drops.

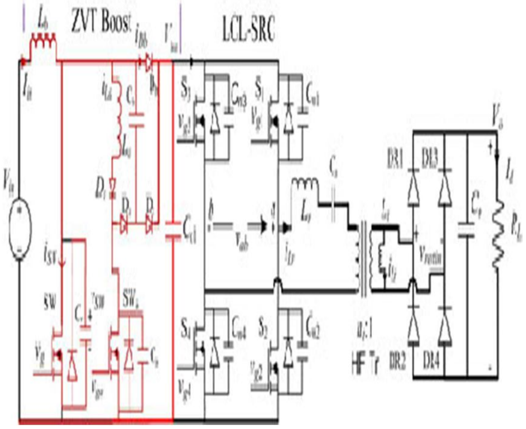
5) This scheme has a wide ZVS range for the MOSFETs. Also the current in the tank circuit reduces with load current; therefore, this scheme has very good part load efficiency.

6) The variation in duty cycle required is narrow for a wide range in power control.

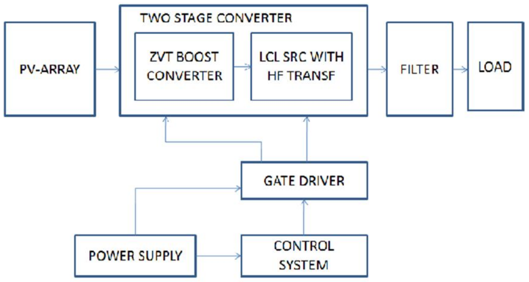
7) A capacitive output filter is used which carries a ripple current equal to 44% of the dc output current. The capacitor has to filter out mainly 200-kHz component of the rectifier output current.

III TWO STAGE APPROACH

LCL SRC with capacitive output filter has better performance compared to other configurations, this converter cannot also maintain ZVS for wide change in input voltage and requires small *Lr* , which is very difficult to realize in practice. Therefore, the proposed solution is to boost the input voltage and then use the *LCL* SRC with capacitive output filter as a second stage. When this converter is operated with almost fixed input voltage, duty cycle variation required is the least among all the three converters. Thus, in this two-stage approach, a ZVT boost converter generates approximately 100V as the input (*V*bus) to the resonant converter for the specified input voltage (40–60 V) while delivering the output voltage of *Vo* =60V. This approach not only achieves ZVS for all the switches but also simplifies the design of *Lr* and *Cs* resonant components.



IV BLOCK DIAGRAM



The output voltage from the PV panel is given to the ZVT boost converter. The stepped up voltage is then given to the LCL series resonant converter. The resonant tank in the LCL series resonant converter is series with the load and act as a voltage divider. By changing the frequency of the input voltage, the impedance of the resonant tank will change. This impedance will divide the input voltage with load. At resonant frequency maximum gain obtained. The stepped up voltage is given to the capacitive output filter and to the load.

V DC - DC CONVERTER

DC-DC converters are electronic devices used whenever to change DC electrical power efficiently from one voltage level to another. They are needed because unlike AC, DC cannot simply be stepped up or down using a transformer. In many ways, a DC-DC converter is the DC equivalent of a transformer.

Typical applications of DC-DC converters are where 24V DC from a truck battery must be stepped down to 12V DC to operate a car radio, CB transceiver or mobile phone; where 12V DC from a car battery must be stepped down to 3V DC, to run a personal CD player; where 5V DC on a personal computer motherboard must be stepped down to 3V, 2V or less for one of the latest CPU chips; where the 340V DC obtained by rectifying 240V AC power must be stepped down to 5V, 12V and other DC voltages as part of a PC power supply; where 1.5V from a single cell must be stepped up to 5V or more, to operate electronic circuitry; where 6V or 9V DC must be stepped up to 500V DC or more, to provide an insulation testing voltage; where 12V DC must be stepped up to +/-40V or so, to run a car hifi amplifier's circuitry; or where 12V DC must be stepped up to 650V DC or so, as part of a DC-AC sine-wave inverter.

In all of these applications, there is a need to change the DC energy from one voltage level to another, while wasting as little as possible in the process. In other words, we want to perform the conversion with the highest possible efficiency.

An important point to remember about all DC-DC converters is that like a transformer, they essentially just change the input energy into a different impedance level. So whatever the output voltage level, the output power all comes from the input; there's no energy manufactured inside the converter.

Quite the contrary, in fact some of this are inevitably used up by the converter circuitry and components, in doing their job. Therefore represent the basic power flow in a converter with this equation:

$$P_{in} = P_{out} + P_{losses}$$

Where Pin is the power fed into the converter, Pout is the output power and Plosses is the power wasted inside the converter.

Of course if there is a perfect converter, it would behave in the same way as a perfect transformer. There would be no losses, and Pout would be exactly the same as Pin.then say that:

$$V_{in}.\ I_{in} = V_{out}.\ I_{out}$$

Or by re-arranging, we get:

$$V_{out}/V_{in} = I_{in}/I_{out}$$

In other words, if we step up the voltage we step down the current, and vice-versa.Of course there's no such thing as a perfect DC-DC converter, just as there are no perfect transformers. So we need the concept of efficiency, where:

$$Efficiency\ (\%) = P_{out}/P_{in}$$

Nowadays some types of converter achieve an efficiency of over 90%, using the latest components and circuit techniques. Most others achieve at least 80-85%, which as you can see compares very well with the efficiency of most standard AC transformers.

A.DIFFERENT TYPES OF DC - DC CONVERTERS

There are many different types of DC-DC converter, each of which tends to be more suitable for some types of application than for others. For

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convenience they can be classified into various groups, however. For example some converters are only suitable for stepping down the voltage, while others are only suitable for stepping it up; a third group can be used for either. Another important distinction is between converters which offer full dielectric isolation between their input and output circuits, and those which don't. Needless to say this can be very important for some applications, although it may not be important in many others.

B. NON-ISOLATING CONVERTERS

The non-isolating type of converter is generally used where the voltage needs to be stepped up or down by a relatively small ratio (say less than 4:1), and there is no problem with the output and input having no dielectric isolation. Examples are 24V/12V voltage reducers, 5V/3V reducers and 1.5V/5V step-up converters.

There are five main types of converter in this non-isolating group, usually called the buck, boost, buck-boost, and Cuk and charge-pump converters. The buck converter is used for voltage step-down/reduction, while the boost converter is used for voltage step-up. The buck-boost and Cuk converters can be used for either step-down or step-up, but are essentially voltage polarity reversers or 'inverters' as well. (The Cuk converter is named after its originator, Slobodan Cuk of Cal Tech University in California.) The charge-pump converter is used for either voltage step-up or voltage inversion, but only in relatively low power applications.

C.BOOST (STEP-UP) CONVERTER

The boost converter converts an input voltage to a higher output voltage. The boost converter is also called a step-up converter. Boost converters are used in battery powered devices, where the electronic circuit requires a higher operating voltage than the battery can supply, e.g. notebooks, mobile phones and camera-flashes.

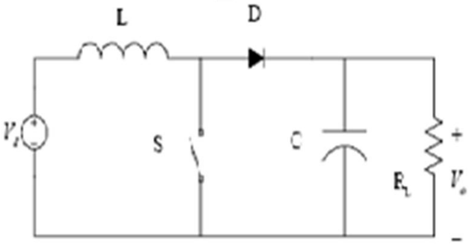


Fig: Boost Converter

Figure 4.1.3(a) shows the basic circuit diagram of the boost converter. The switch S, is turned on and off by a pulse-width-modulated control voltage Vcont.

When switch S is closed, diode is reversed. Thus output is isolated. The input supplies energy to the inductor i.e., the voltage across L is equal to Vin and the current I_L increases linearly.

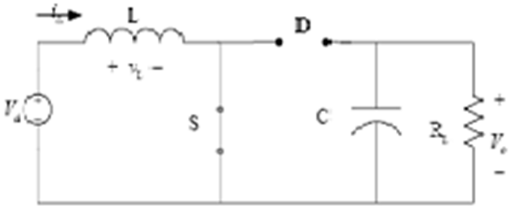


Fig switch s closed

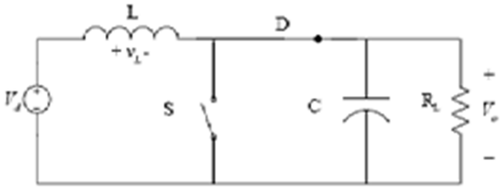


Fig switch s open

When switch S is opened, the current I_L flows through the diode and charges the output capacitor C. Thus the output stage receives energy from the input as well as from the inductor. Hence the output across the load is large.

The function of the boost converter can also be described in terms of energy balance. During the on-time of the switch the inductance is charged with energy and during the off-time of the switch this energy is transferred from the inductor through the diode to the output capacitor. Output voltage is maintained constant by virtue of large C.

D. LCL Type Series Resonant Converter

There are two types of high frequency resonant convertors; series resonant and parallel resonant. While a series resonant convertor has a problem on voltage regulation, parallel resonant convertors have lower efficiency due to reduced circulating currents. The main advantages of resonant convertor operating in the above resonance (lagging power factor) is that the circuit will not require lossy snubber and di/dt limiting inductors. A dc/dc high-frequency link LCL-type series resonant converter suitable for operation above resonance. Below, the half bridge version is shown.

The LCL resonant converter will create a smooth sinusoidal wave from the choppy square wave output from the switching circuit. The “LCL” term refers to an arrangement of electrical inductors and capacitors (wire coils and charged plates) which filter and define the shape of the signal.

E. HIGH FREQUENCY TRANSFORMER

High-frequency (HF) transformer isolated, HF switching dc-to- dc converters are suitable for this application due to their small size, light weight, and reduced cost. To increase their efficiency and to further increase the switching frequency while reducing the size, cost, and electromagnetic interference problems, soft-switching techniques will be used in this paper. Due to the high power requirement, an interleaved multi cell configuration that uses three cells in parallel with each cell being phase shifted by 120°. Each cell shares equal power and the thermal losses are distributed uniformly among the cells. Also, the input/output ripple frequency of three-cell configuration becomes three times the input/output ripple frequency of each cell.

There are three major types of HF transformer isolated soft switching converter configurations possible: 1) voltage fed resonant converters 2) current fed resonant converters and 3) fixed-frequency resonant transition zero-voltage switching (ZVS) pulse width modulation (PWM) bridge converters. Our studies show that current fed resonant converters require HF switches rated at 5–6 times the input voltage (reducing the efficiency) in the present application, and therefore, they are not considered further. Voltage fed resonant converters can be operated either in variable-frequency mode or fixed-frequency mode. But the operation in variable frequency mode suffers from several disadvantages: wide variation in switching frequency making the design of filters and control circuit difficult. Here it is proposed to develop a high efficiency power converter for industrial drives with improved efficiency.

F. ENERGY EFFICIENCY

Energy consumption can be reduced if energy efficiency is increased. In the end energy saved is the cheapest energy. In turn, drive technology can help to improve the energy efficiency of many production lines, as the energy for nearly all process of production and materials transport is provided by electrical drives. Also in the case of hydraulically and pneumatically operated drives, the basic energy source is an electric motor that powers the hydraulic pump or the air compressor. Futher more there are many ancillary processes in the infrastructure of a plant that are also equipped with electrical drives.

In order to obtain drives with a high energy efficiency, there are no quick solutions such as those available when buying a fridge. This is because drives convert energy and thus always perform their task in combination with a mechanical process. The components of the drive system can only reduce their losses. However, they usually do not account for the largest proportion of the electrical energy consumed.

The total potential for increasing the energy efficiency in industrial drive technology can only be exploited if the individual applications are closely examined with regard to the kind of energy they require and the way the energy is provided by the drive. All in all the measures for saving energy can be summarized under the following three items:

Energy is to be provided as intelligently as possible, so that the lowest amount necessary is used. This includes the dimensioning and control of drives in line with the requirements.
Within the drive train, the energy is to be converted as efficiently as possible.If the mechanical process recovers braking energy to a considerable extent, it is used further.

From the three pillars. The first one is the most important, with the intelligent provision of energy; four to five times more energy can be saved than by reducing the power loss. With regard to the typical application mix within plants, the use of braking energy has a smaller effect than the optimization of efficiency. By implementing measures to increase energy efficiency, an overall energy saving of 20 to 30can usually be obtained. For individual applications, it can be much more. Payback periods of two to three years are the normal case, so that such capital investment expenditures even meet the requirements of any serious profitability calculation.

Here variable speed drives allow adjusting the flow to the needs of the process. Compared to classic methods of flow control like throttling and bypassing, electronic speed control significantly increases the overall efficiency. Furthermore the use of an inverter enables the application of more efficient motor technology like permanent magnet synchronous motors and reluctance motors. Today such kind of drives can be implemented in a power range from Watts up to Megawatts.

Nearly all static converters for electrical drives used today employ a combination of Input rectifier, DC-link and Output inverter. If no regeneration system is required for the electrical drive, the most competitive semiconductor components for the input rectifier are bipolar thyristors and/or diodes offered in various topologies, such as complete six pack modules, half bridge modules or single modules.

VI SOFT SWITCHING TECHNIQUES

There are two types of resonant soft switching depending on whether the voltage across switch or the current through switch is made zero.

A.Zero-Current Switching (ZCS)

A switch that operates with ZCS has an inductor in series with it and a series blocking diode if the switch is bi-directional. The switch is turned on with ZCS as the series inductor slows down the rate of rise of current after voltage across switch goes to zero. If a negative voltage from a resonant circuit is made to appear across the switch-inductor combination, then the current through switch will naturally reduce to zero and switch is turned off with ZCS.

B. Zero-Voltage Switching (ZVS)

A switch that operates with ZVS has an anti-parallel diode and a capacitor across it. If negative current is forced to flow through the antiparalle1 diode then voltage across switch reduces to zero and then the switch is turned on with ZVS. During turn-off the capacitor across switch reduces the rate of rise of voltage across device as current reduces to zero

ZVS is preferred over ZCS because with ZVS the parasitic switch capacitance dissipates its energy into the load. If there were no ZVS this parasitic capacitance would dissipate as heat in the switch which lowers the efficiency of the system.

In this project, the converter employs another LC resonant circuit designed to resonate at switching frequency so that ZVS condition is achieved during both buck and boost operating modes.

VII MODES OF OPERATION

The demand for a high energy conversion efficiency and performance. The growing electronic product market has increased the demand for high energy conversion efficiency and high power density of dc-to-dc energy power converters. The soft-switching scheme is the most attractive dc-to-dc energy con-version topology in recent years. The soft-switching method can reduce switching losses and EMI of the switch-mode converter. Figure shows the proposed loaded-resonant converter for application of the dc-to-dc energy conversion system.The two capacitors, C1 and C2, on the input are large and split the voltage of the input dc source. The elements Lr1, Lr2, and Cr form the resonant tank. The load resistance R is connected across a bridge rectifier via a low pass filter capacitor Co.

A. Mode 1(Between ωot0 and ωot1)

Periodic switching of the resonant energy tank voltage between +Vs/2 and −Vs/2 generates a square-wave voltage across the input terminal. Since the output voltage is assumed to be a constant voltage Vo, the input voltage to the full-bridge rectifier is Vo when iLr2 (t) is positive and is −Vo when iLr2 (t) is negative.

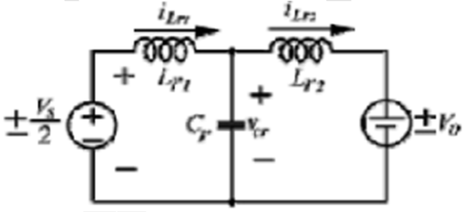


Fig. Equivalent circuit of Mode I

In this mode, the power switches are turned on naturally at zero voltage and at zero current. Therefore, the current through the active power switch is negative after turning on and positive before turning off. Although the current in the switches is turned on at zero voltage and zero current to eliminate turn-on losses, the switches are forced to turn off a finite current, thus allowing turn-off losses exit. Fortunately, small Capacitors can be placed across the switches to function as snubber in order to eliminate turn-off losses.

B. Mode 2 (Between ωot1 and ωot2):

The cycle starts at ωot1 when the current iLr1 resonant tank resonates from negative values to zero. At ωot2, before the half-cycle of resonant current iLr1 oscillation ends, switch S1 is forced to turn off, forcing the positive current to flow through bottom freewheeling diode D2.

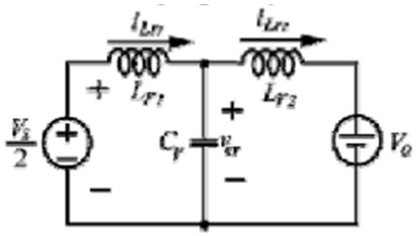


Fig.Equivalent circuit of Mode 2

Figure shows the equivalent circuit. The positive dc input voltage applied across the resonant tank causes the resonant current that flows through the power switch to go quickly to zero.

C. Mode 3 (Between ωot3 and ωot4)

A turn-off trigger signal is applied to the gate of the active power switch S1. The inductor current then naturally commutates from active power switch S1 to freewheeling diode D2. Mode III begins at ωot3, then the system is considered as unstable. The L indices are calculated for all the load buses and the maximum of the L indices gives the proximity to the system to voltage collapse.

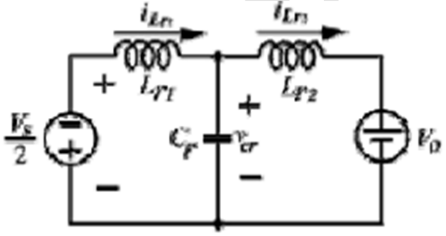


Fig.Equivalent circuit of Mode 3

When diode D2 is turned on, subsequently producing a resonant stage between inductors Lr1, Lr2 and capacitor Cr. Inductors Lr1, Lr2, and capacitor Cr resonate. Before ωot4, trigger signal vgs2 excites active power switch S2. This time interval ends when iLr1 (t) reaches zero at ωot4. Figure shows the equivalent circuit.

D.Mode 4 (Between ωot4 and ωot5)

When capacitor voltage iLr2 is positive, rectifier diodes DR1 and DR2 are turned on with zero-voltage condition at instant ωot4. Figure shows the equivalent circuit. When inductor current iLr2 changes direction, rectifier diodes DR1 and DR2 are turned off at instant ωot5, and Mode IV ends.

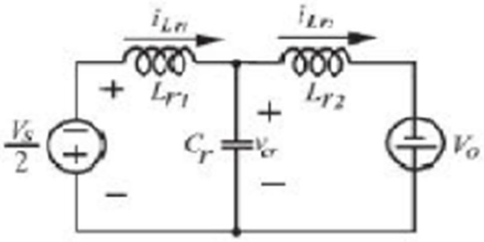
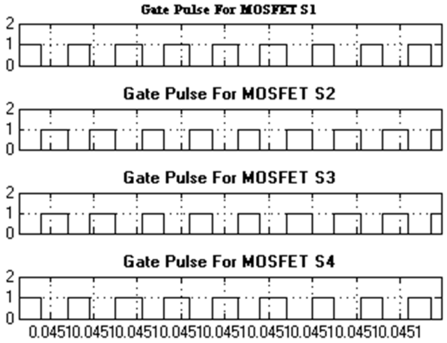


Fig.Equivalent circuit of Mode 4

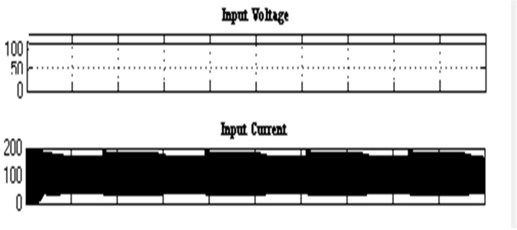
When driving signal Vgs1 again excites active power switch S1, this mode ends and the operation returns to mode I in the subsequent cycle. During the positive half-cycle of the inductor current iLr2, the power is supplied to the load through bridge rectifier diodes DR1 and DR2. During the negative half-cycle of the inductor current, the power is supplied to the load through bridge rectifier diodes DR3 and DR4.

VIII SIMULATION RESULT

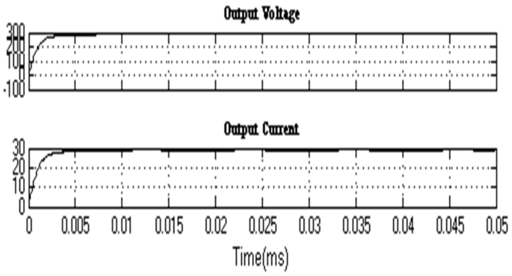
A.GATE PULSES OF S1,S2,S3 AND S4



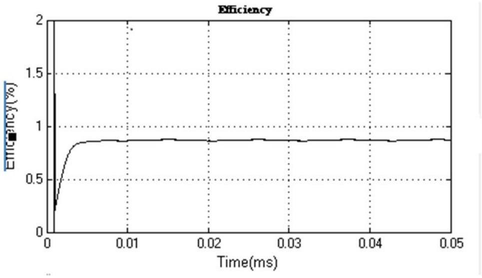
B.INPUT VOLTAGE AND CURRENT



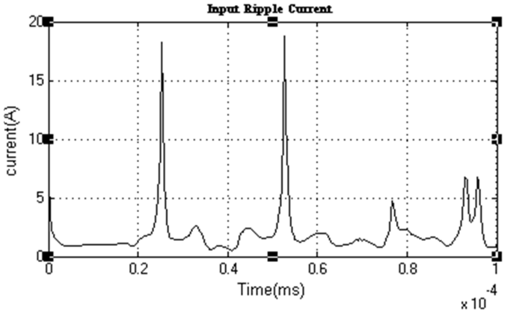
C. OUTPUT VOLTAGE AND CURRENT



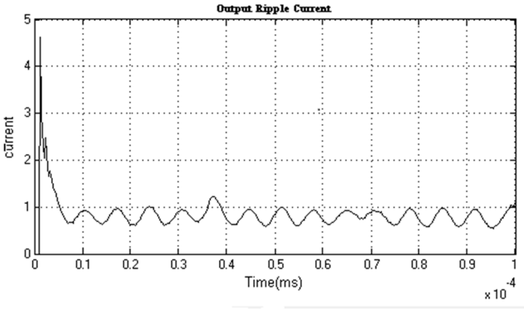
D. EFFICIENCY



E.INPUT RIPPLE CURRENT



F.OUTPUT RIPPLE CURRENT



IX.CONCLUSIONS

The loaded-resonant converter with a bridge rectifier is developed for the application of dc-to dc energy con-version. The circuit structure is simpler and less expensive than other control mechanisms, which require many components. The developed topology is characterized by zero-voltage switching, reduced switching losses, and increased energy conversion efficiency. The project is done with the help of MATLAB software.

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