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High Frequency Full-Bridge LLC Resonant Converter with Interleaved Buck-Boost Stage for Low THD and High-Efficiency

[1]R.Yalini, [2]M.G.Yogapriya, [3]S.Shanthi, [4]S.Velmurugan, [5]A.Ambika

[1]HOD/Associate Professor, Dept. of EEE, Jayam College of Engineering and Technology, Tamilnadu, India

[2,3,4]PG Scholar, Power Electronics and Drives, Jayam College of Engineering and Technology, Tamilnadu, India

[5]Assistant Professor, Dept. of EEE, Jayam College of Engineering and Technology, Tamilnadu, India

***Abstract* - A novel technique has been adapted for achieving high PFC in AC-DC conversion by introducing dual buck–boost power- factor correction (PFC) converters and a full Bridge series resonant DC/DC converter for higher power quality improvement. We aim to comply with the more regulation on current harmonics and to improve the power factor. Our Ac-dc converters will incorporate an active power factor correction (PFC) and harmonic current reduction technique at the point of common coupling (PCC) which improves voltage regulation and efficiency. We develop a circuit for PFC using active filtering approach by implementing two boost converters arranged in parallel. It shall be based on an optimized power sharing strategy to improve the current quality and at the same time reduce the switching losses. The conventional rectifiers inject unwanted ac line current harmonics and low power factor into ac sources. The adverse effects of power system harmonics are well recognized and include heating and reduction of transformers and induction motors life, degradation of system voltage waveforms, insecure currents in power-factor-correction capacitors and malfunctioning of certain power system protection elements. Conventional rectifiers are harmonic polluters of the ac power distribution system. With the extensive use of electronic equipment, rectifier harmonics have become a major problem. Therefore, there is a need for high-quality rectifiers that can operate with high power factor, high efficiency and reduce generation of harmonics. A number of international standards now exist that in particular limit the magnitude of harmonics currents, for both high-power equipment such as industrial motor drives, and low-power equipment such as electronic ballasts. Power Factor gives a measure of how effective the real power utilization of the system is. It is a figure of merit that measures how effectively power is transmitted between a source and load network.**

Keywords: High Frequency, Full-Bridge, LLC, Resonant Converter, Buck-Boost, Low THD, High-Efficiency.

I. INTRODUCTION

With great advances of power semiconductor switching devices such as MOSFETs, IGBTs, and ESBTs as well as high-frequency passive circuit components, the leading development of the high frequency resonant pulse inverter type switching mode DC-DC power conversion circuits and systems have attracted special interest for high voltage DC power applications. The "hard - switching" dc – dc converter suffer from high switching loss and reduced reliability. Even increasing power densities has been limited by the size of both reactive elements and the isolation transformer. While component sizes tend to decrease with an increase in the switching frequency, device switching losses are proportional to frequency attainable in a given circuit. The high frequencies are a key to realizing multiple benefits of high power density and good transient response. To prevent distortion of the ac line current, the standards of harmonic regulation, such as IEC and IEEE, are enacted to limit the input current harmonics and to guarantee a power factor of at least 0.9. With the goal to comply with the more stringent regulations on current harmonics and to improve the power factor, an additional ac/dc conversion stage of power factor correction (PFC) is required to cascade in front of the dc/dc converter.

The use of soft-switching techniques, alleviate switching loss problems and allow a significant increase in the converter switching frequency. Further, the proposed topology features device stress, reduced EMI, high power density, improved power factor, etc.

Resonant converters (RCs) eliminate much of the switching losses encountered in pulse width modulation (PWM) converters. The active device is switched with either zero current (ZCS) or zero voltage (ZVS) at its terminals. Included in the specification of any dc/dc converters are criteria for line regulation, load regulation, response time and stability. Normally, the supply voltage and the load regulation have a wide range of variation, so the controller must be designed to give suitable behavior in any working condition of

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the converter. The design of a controller for resonant converters is often done with classical control methods. If there can be a large change in the operating point, changes in the linear model must also be considered. One way to fulfill all the specifications is to study the design of the controller for worst conditions. Resonant topologies are typically applied when low EMI is needed or when the switching losses have to be reduced in order to allow higher frequencies for miniaturization. In addition, resonant operation enables high frequency power transfer via a transformer. For a high efficiency dc-dc converter, the LLC series-resonant half-bridge converter is gaining its popularity. Resonant converters have the advantages of soft-switching characteristics and moderate component stress; therefore, they are preferred to serve as the dc/dc conversion stage to operate at high switching frequency to meet the circuit requirements of small size and energy efficiency. In these single-stage approaches, a boost or buck–boost converter is usually served as a PFC circuit, and a full- or half bridge resonant circuit is adopted as the dc/dc converter. The full-bridge type is suitable for high-power application, while the half-bridge type has the advantages of simple topology, high efficiency, and low cost.

II. EXISTING SYSTEM

Single ended primary inductance converter (SEPIC) at the front end of an SMPS provides stiffly regulated output dc voltage even under frequent input voltage and load variations. Traditional design of ac/dc converter consists of a diode-bridge rectifier, followed by a bulky capacitor and a high-frequency dc/dc converter. This kind of converter inevitably introduces a highly distorted input current, resulting in a large amount of harmonics and a low power factor. With the goal to comply with the more stringent regulations on current harmonics and to improve the power factor, an additional ac/dc conversion stage of power factor correction (PFC) is required to cascade in front of the dc/dc converter. It leads to a two-stage approach that includes a PFC stage to shape the input current into a sinusoidal waveform and a dc/dc conversion stage to regulate the output voltage.

2.1 Disadvantages

The two-stage approach requires more circuit components and two power-conversion processes, resulting in higher cost and lower efficiency.

III. PROPOSED SYSTEM

The objective of the present work is to design the AC-DC converter with a power factor of at least 0.9. Also we aim to comply with the more regulation on current harmonics and to improve the power factor. A novel technique has been adapted for achieving high PFC in AC-DC conversion by introducing dual buck–boost power- factor correction (PFC) converters and a full Bridge series resonant DC/DC converter for higher conversion efficiency.

3.1 Advantages

- Here the changes in load conditions don't affect the PF of the AC source.
- Since a resonant bridge converter is used, the rectifier efficiency remains high at all load conditions.

IV. METHODOLOGY USED

This project work started with the study and analysis of power factor of a system by doing simulations on P-SIM Software using full wave rectifier in the beginning. After studying and analyzing the input current and voltage waveforms and the power factor of the system using Rectifier circuit, we introduced a Buck Converter in the circuit and then analyzed its effect in improving the power factor of the system.

4.1 Block Diagram

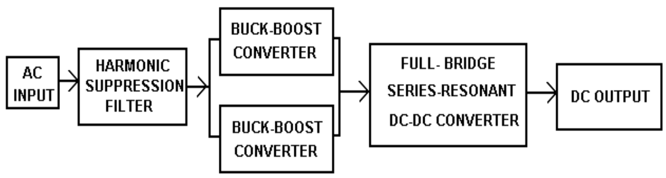

Figure 1: Functional Block Diagram

4.2 AC Input

Ac input is given from the supply mains to the converter.

4.3 Harmonic Filter

The harmonic filter consists of a Inductor-Capacitor based LC harmonic suppression filter which reduces power source harmonics.

4.4 Buck-Boost Converter

Here we introduce a dual Buck-Boost Converter for power factor correction at the input. 3.5.4 Full Bridge DC-DC converter In order to raise the power capability for higher power application and to improve efficiency, the full-bridge resonant converter is adopted.

4.5 Circuit Diagram Description

In order to raise the power capability for higher power application, this project adopts the full-bridge resonant converter, which is integrated with two buck–boost-type PFC circuits.

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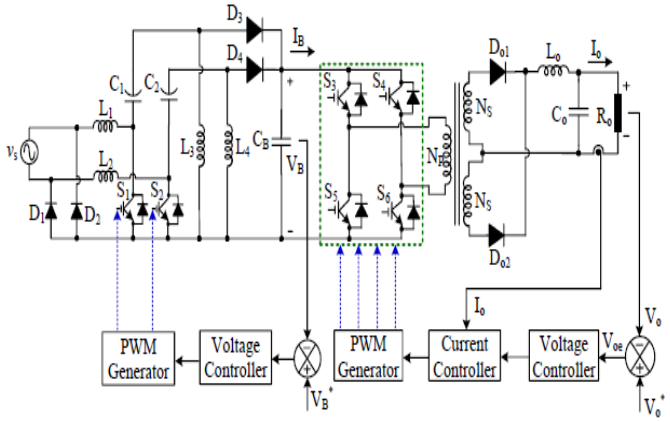

Figure 2: Circuit Diagram of LLC Resonant Converter

Two active power switches serve in the PFC circuits; therefore, their power-handling compatibility is doubled. The PFC circuit should operate at discontinuous conduction mode (DCM) for obtaining unity power factor, these single-stage converters have low switch-utilization factor and are then only applicable to low-power systems. Here we simulate the HPF AC-DC converter circuit AC source voltage is supplied to the input of a Buck-Boost Converter.

Then the output is rectified and a DC voltage is obtained by a diode rectifier. The rectified DC output is given to the input of a Resonant Full-Bridge Converter. For the converter switching, a set of high frequency PWM Signals are applied (PWM1, PWM2) as shown. The DC voltage given to the Bridge converter is again converted into a high-frequency AC. Then the output of the converter is given to High frequency Transformer. Transformer output is connected to a diode full-bridge rectifier. Finally a DC output is obtained through the converter which is connected a load.

- Here we simulate the HPF AC-DC converter circuit
- AC source voltage is supplied to the input of a Buck-Boost Converter.
- Then the output is rectified and a DC voltage is obtained by a diode rectifier.
- The rectified DC output is given to the input of a Resonant Full-Bridge Converter.
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- The DC voltage given to the Bridge converter is again converted into a high-frequency AC.
- Then the output of the converter is given to High frequency Transformer.
- Transformer output is connected to a diode full-bridge rectifier.
- Finally a DC output is obtained through the converter which is connected a load.

V. SYSTEM IMPLEMENTATION WITH HARDWARE

Conventionally the AC –DC conversion is done by making use of full wave bridge rectifier and a capacitor filter at the output to absorb the input power pulsation thereby reducing the ripple in the output voltage. But this conventional technique does not take account of the input power factor which must be high. Low power factor reduces the power available from utility grid. An ideal power factor corrector must have a resistor on the supply side and at the same time it should maintain fairly regulated output voltage. The objective of the present work is to design the proposed two switch cascaded Buck- Boost converter with high power factor, low voltage stresses, low switch losses and with the ability to set the output voltage arbitrarily. However, although resonant mode power conversion achieves low switching loss at high frequency compared to the pulse width modulation (PWM) converter, these converters have some difficulties such as size reduction, EMI noise, and filter design because a wide variety of switching frequency is needed to control the output voltage. Also, the resonant converters typically have large component stresses due to high peak currents and voltages. Therefore, the trend in power processing technology has been toward combining the simplicity of PWM converters with the soft-switching characteristics of the resonant converters.

5.1 AC Input and Harmonic Filter

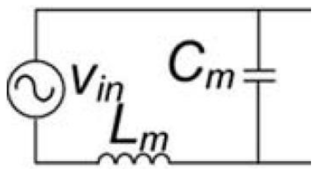

Figure 3: AC input and harmonic Filter

5.2 Dual Buck-Boost Circuit

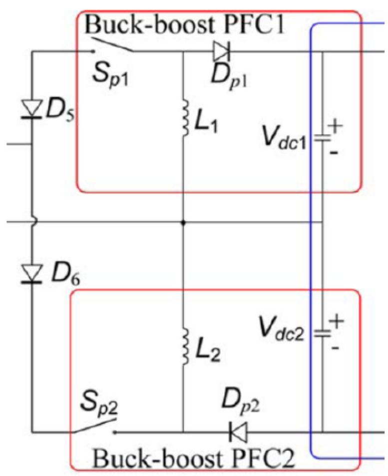

Figure 4: Dual buck Boost Converter

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5.3 Operation

A small low-pass filter (Lm and Cm) is used to remove the high frequency current harmonics at the input line. Two active power switches serve in the PFC circuits; therefore, their power-handling compatibility is doubled. A high power factor (HPF) can be achieved by operating the PFC circuit at discontinuous conduction mode (DCM). The dc output voltage is regulated by adjusting the switching frequency of the active switches. All the active switches can be operated at ZVS to effectively reduce the switching losses. The circuit operation of the Full-Bridge Resonant converter can be divided into six modes in accordance with the conducting power switches within one high-frequency cycle.

5.4 Buck–Boost PFC

The ac/dc converter is supplied from the ac line-voltage source $v_{in}(t)$ = Vm sin(2πfLt) where f_L and V_m are the frequency and amplitude of the line voltage source, respectively. In practice, f_L is much lower than the switching frequency (f_s) of the active switches. It is reasonable to consider the rectified input voltage as a constant over a high-frequency cycle. In the positive half cycle of the input voltage, the unfiltered input current ip is equal to the rising part of ip1.

Contrarily, in the negative half cycle, i_p is equal to negative of the rising part of ip^2. Since the buck–boost converts are operated at DCM over an entire line-frequency cycle, i_p rises from zero at the beginning of Mode I and reaches its peak at the end of Mode III. The waveform of ip is conceptually shown in Fig. Its peaks follow a sinusoidal envelope and can be expressed as ip, peak(t) = Vm sin(2πfLt)Ts/2Lp where Ts is the high-frequency switching period and L_p is the inductance of L1 and L2. The high-frequency contents of ip can be removed by Lm and Cm. Therefore, the input current iin is equal to the average of ip over a high-frequency cycle.

$$i_{\text{in}}(t) = \frac{1}{T_s}\int_0^{T_s} i_p(t)\cdot d(t) = \frac{V_m T_s}{8L_p}\sin(2\pi f_L t)$$

$$P_{\text{in}} = \frac{1}{2\pi}\int_0^{2\pi} v_{\text{in}}(t)\cdot i_{\text{in}}(t) d(2\pi f_L t) = \frac{V_m^2}{16 L_p f_s}$$

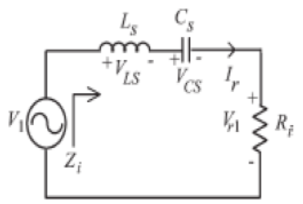

Figure 5: Equivalent circuit of the load resonant circuit

Then, the dc output power can be calculated

$$P_o = \eta \cdot P_{\text{in}} = \frac{\eta V_m^2}{16 L_p f_s}$$

Where η represents the circuit conversion efficiency.

$$I_{p\text{-}peak}(t) = \frac{V_m \sin(2flt)Ts}{2L_p}$$

It is reasonable to consider the rectifier

Ts are the high frequency switch period and lp is the induction of L1andL2.

Equation above reveals that the input current is sinusoidal and in phase with the input line voltage if the switching frequency remains constant over an entire line cycle. As a result, an HPF can be achieved. The input power can be obtained by taking the average of the input power over one line-frequency cycle.

VI. RESULT AND SIMULATION OUTPUTS

PSIM is an Electronic circuit simulation software package, designed specifically for use in power electronics and motor drive simulations but can be used to simulate any electronic circuit. Developed by Powersim, PSIM uses nodal analysis and the trapezoidal rule integration as the basis of its simulation algorithm. PSIM provides a schematic capture interface and a waveform viewer Simview.

6.1 LLC Resonant Full Bridge AC-DC Converter Simulation Circuit

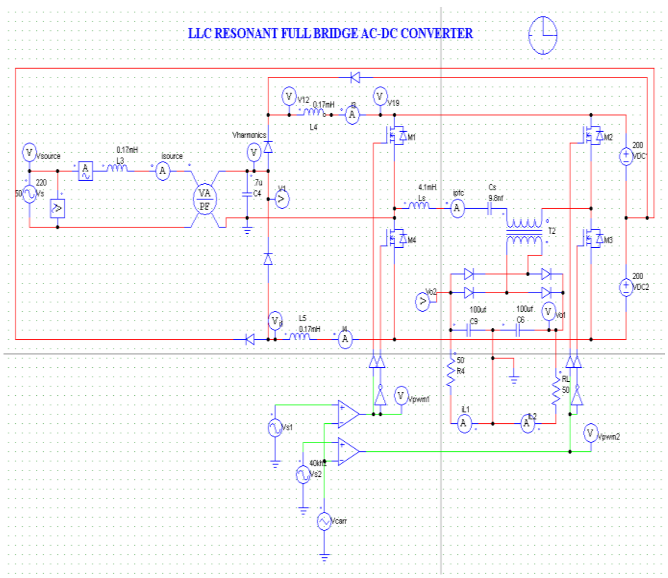

Figure 6: LLC Resonant Full Bridge AC-DC Converter Simulation Circuit

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6.2 Output Waveforms

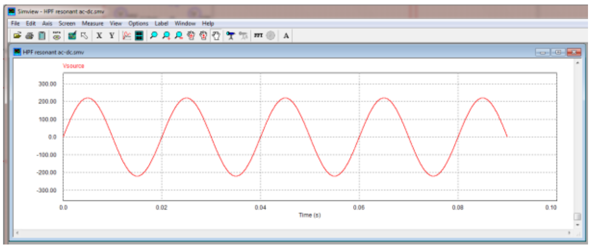

Figure 7: V-AC Source

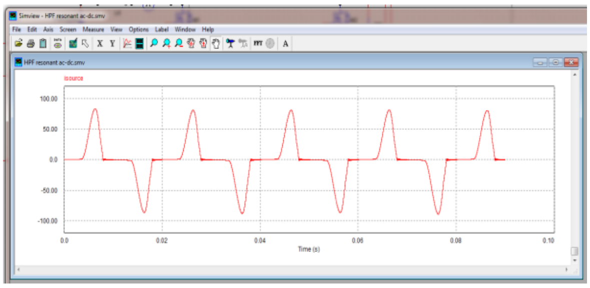

Figure 8: i-AC Source

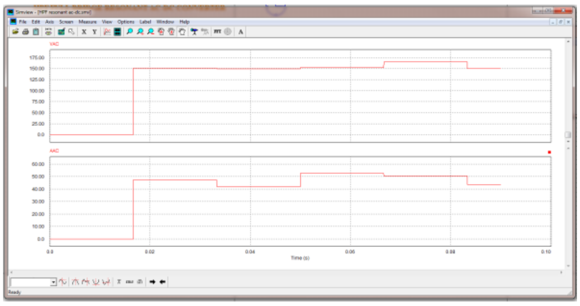

Figure 9: i-v AC Source

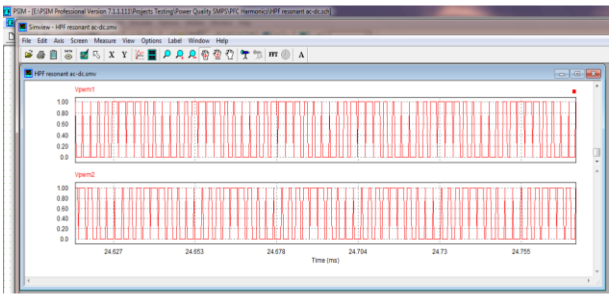

Figure 10: PWM Signals

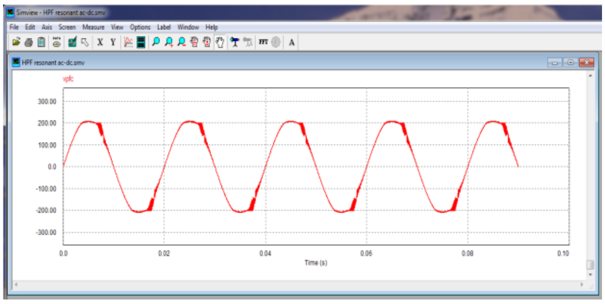

Figure 11: V-PFC

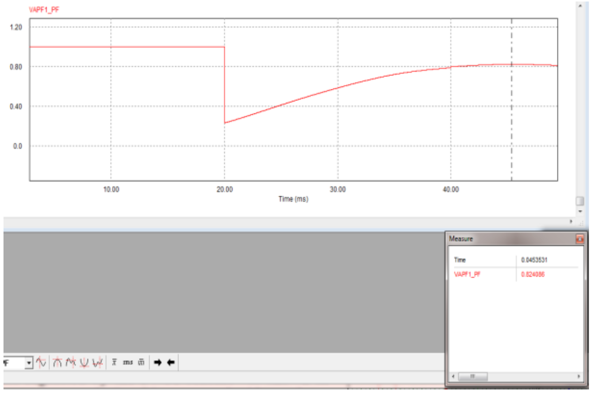

Figure 12: Power Factor

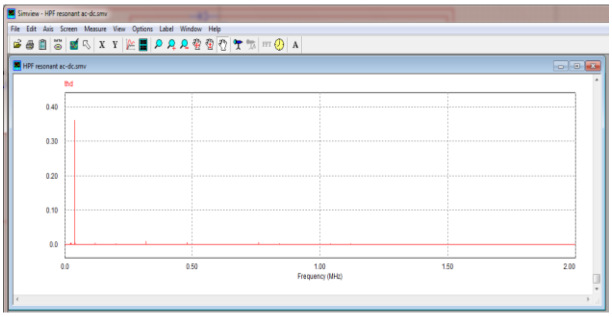

Figure 13: THD

6.3 Simulation Results Obtained

- Source Voltage: 150-220v AC
- Source Frequency: 50-60Hz
- Output Voltage: +12v,-12v DC
- Rated Power: 60w
- Switching Frequency: 400 KHz
- Duty Cycle: 0.3-0.5
- Efficiency: 96.3%
- Power Factor: 0.84
- THD: 3.7

VII. CONCLUSION

The converter improves the power factor by properly shaping the input current in accordance with its reference. This reference signal is always synchronized and proportional to the line voltage hence the input current comes in phase with the input voltage. Here the changes in load conditions don't affect the PF of the AC source. Since a resonant bridge converter is used, the rectifier efficiency remains high at all load conditions. We hereby achieve a output efficiency of 96.3% with Low THD of 3.7 and Power factor of 0.84 which is considerably higher than the existing system. By improving the power factor maximum active power can be delivered to the load with less harmonics and thus maintain better power quality.

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