ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 4, Issue 12, December 2018

Three Phase Single Stage PFC Converter Using Flying Capacitor

[1] SK.Parveen Begam, [2] R. Yedukondalu
[1]M.Tech Research Scholar (PE), [2] Associate Professor
[1][2] Dept. of EEE, Dr. Samuel George institute of engineering and technology, Markapur, AP, India

***Abstract*: Today the wide usage of non-linear loads like variable speed drives has made power factor improvement difficult due to the presence of harmonic currents. These harmonics cause overheating, and the amplification of these harmonics cause failure or damage of Capacitors and other system components. Thus this paper presents a new integrated AC-DC converter with single stage power factor correction with flying Capacitor. Due to the interleaved structure, the proposed converter operates at lower input ripple current and has improved load efficiency along with peak switch currents and soft switch operation. The convertor has improved efficiency and due to single stage 3 levels AC-DC converter it has voltage regulation along with power factor correction. This proposed converter is stimulated in the MATLAB software and the design and performance is further studied and analysed.**

Keywords: Flexible PF(Power Factor), PFC(Power Factor Correction), AC-DC Converter.

1. INTRODUCTION

In the field of power electronics, application of interleaving technique can be traced back to very early days, especially in high power applications. In high power applications, the voltage and current stress can easily go beyond the range that one power device can handle. Multiple power devices connected in parallel and/or series could be one solution. However, voltage sharing and/or current sharing are still the concerns. Instead of paralleling power devices, paralleling power converters is another solution which could be more beneficial. Furthermore, with the power converter paralleling architecture, interleaving technique comes naturally. Benefits like harmonic cancellation, better efficiency, better thermal performance, and high power density can be obtained. In earlier days, for high power applications, in order to meet certain system requirement, interleaving multi-channel converter could be a superior solution especially considering the available power devices with limited performance at that time. One of such example can be found in the application of Superconducting a Magnetic Energy Storage System (SMES). The current stress of such application is extremely high, yet certain system performance stillneed to be met. On the ac side, the total harmonic distortion (THD) in voltages and currents of the regulatory standards must be respected. A further constraint comes from the switching loss that is proportional to the valve switching frequency.

In this paper, the proposed solution in the referred paper consists of using multiple interleaved three-phase current-source converters. With this multi modular converters the current stress can be divided to a level that can be handled by gate turn-off thyristor (GTO), the static induction thyristor (SI), etc, and reduces the ohmic component of their conduction losses. The results shows interleaving technique was applied quite successful in this application. Such examples also can be found in many other applications, such as Static VAR Generator (SVG), high voltage direct current (HVDC) applications etc.

Power Factor

Power factor is defined as the cosine of the angle between voltage and current in an accircuit. There is generally a phase difference Ø between voltage and current in an accircuit. cos Ø is called the power factor of the circuit. If the circuit is inductive, the current lags behind the voltage and power factor is referred to as lagging. However, in a capacitive circuit, current leads the voltage and the power factor is said to be leading. In a circuit, for an input voltage V and a line current I,VIcos Ø –the active or real power in watts or kW.VIsin Ø- the reactive power in VAR or kVAR.VI- the apparent power in VA or kVA. Power Factor gives a measure of how effective the real power utilization of the system is. It is a measure of distortion of the line voltage and the line current and the phase shift between them. Power Factor=Real power(Average)/Apparent power Where, the apparent power is defined as the product of rms value of voltage and current.

Power Factor Correction (PFC)

Power factor correction is the method of improving the power factor of a system by using suitable devices. The objective of power factor correction circuits is to make the input to a power supply behave like purely resistive or a resistor. When the ratio between the voltage and current is a constant, then the input will be resistive hence the power factor will be 1.0. When the ratio between voltage and current is other than one due to the presence of non-linear loads, the input will contain phase displacement, harmonic distortion.

APPLICATIONS OF PFC:

Electricity industry: Power factor correction of linear loads.

Power factor correction is achieved by complementing an inductive or a capacitive circuit with a (locally connected) reactance of opposite phase. For a typical phase lagging PFload, such as a large induction motor, this would consist of a capacitor bank in the form of several parallel capacitors at the power input to the device. Instead of using a capacitor, it is possible to use an unloaded synchronous motor.

Switched mode power supply: Power factor correction of non-linear loads.

A typical switched-mode power supply first makes a DC bus, using a bridge rectifier or similar circuit. The output voltage is then derived from this DC bus. The problem with this is that the rectifier is a non-linear device, so th e input current is highly non-linear. That means that the input current has energy at harmonics of the frequency of the voltage.

2. SYSTEM MODEL AND ASSUMPTIONS

AC-DC Converters:

One of the first and most widely used application of power electronic devices have been in rectification. Rectification refers to the process of converting an ac voltage or current source to dc voltage and current. Rectifiers specially refer to power electronic converters where the electrical power flows from the ac side to the dc side. In many situations the same converter circuit may carry electrical power from the dc side to the ac side where upon they are referred to as inverters. In this lesson and subsequent ones the working principle and analysis of several commonly used rectifier circuits supplying different types of loads (resistive, inductive, capacitive, back emf type) will be presented.

- Waveforms and characteristic values (average, RMS etc) of the rectified voltage and current.
- Influence of the load type on the rectified voltage and current.
- Harmonic content in the output.
- Voltage and current ratings of the power electronic devices used in the rectifier circuit.
- Reaction of the rectifier circuit upon the ac network, reactive power requirement, power

factor, harmonics etc.

- Rectifier control aspects (for controlled rectifiers only) In the analysis, following simplifying assumptions will be made.
- The internal impedance of the ac source is zero.
- Power electronic devices used in the rectifier are ideal switches.

The first assumption will be relaxed in a latter module. However, unless specified otherwise, the second assumption will remain in force. Rectifiers are used in a large variety of configurations and a method of classifying them into certain categories (based on common characteristics) will certainly help one to gain significant insight into their operation. Unfortunately, no consensus exists among experts regarding the criteria to be used for such classification.

Applications

With the wide spread of electronics and technology the necessary of DC power has increased

as the used of DC electronics has increased over the decades. Here comes an AC-DC converter in play. With the wide spread of DC power needs, the application of AC-DC converter has covered a range from milli-watts to megawatts. Some applications of AC-DC

Converter is given below.

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
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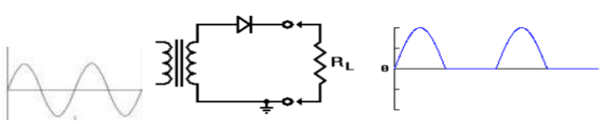
- ➢ Use in detection of amplitude modulated radio signal
- ➢ Use to supply polarized voltage for welding
- ➢ Use in Uninterruptible power supplies
- ➢ Use in Induction heating
- ➢ Use in HVDC power transmission
- ➢ Use in Variable-frequency drives
- ➢ Use in Electric vehicle drive Application
- ➢ Use in vacuum cleaners
- ➢ Use in Air conditioning
- ➢ Use in cordless telephone
- ➢ Use in DC motor control
- ➢ Use in rice cookers
- ➢ Use in electric carpets
- ➢ Use in washing basket
- ➢ Use in washing machine
- ➢ Use in air cleaner

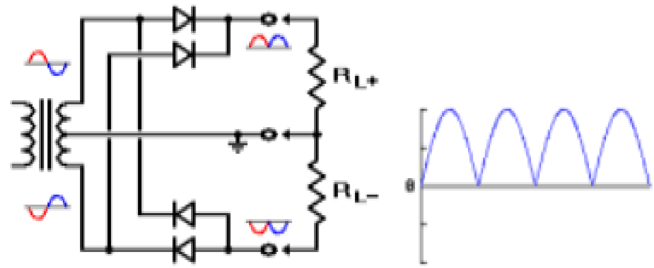
Single phase rectifier

Half-Wave Rectifier: In half-wave rectifier, half of the ac cycle (either positive or negative) pass, while during the other half cycle the diode blocks the current from flowing. Basic half-wave rectifier circuit may be constructed with a single diode in a one phase supply, or three diodes with a three-phase supply. Such circuits are known as half wave rectifier as they only work on half of the incoming ac wave.



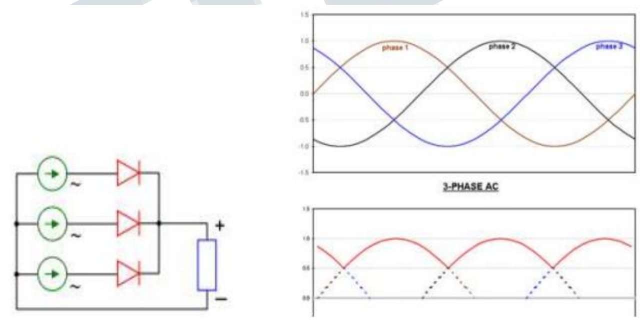
Half Wave Rectifier

Full-Wave Rectifier: A full-wave rectifier converts the whole incoming ac wave so that both halves are used to cause the output current to flow in same direction (either positive or negative). Full-wave rectification is more efficient because it converts both polarities of input waveform to DC. A full-wave rectifier circuit requires four diodes instead of one needed for half-wave rectification. For the arrangement of four diodes the circuit is called a diode bridge or bridge rectifier.



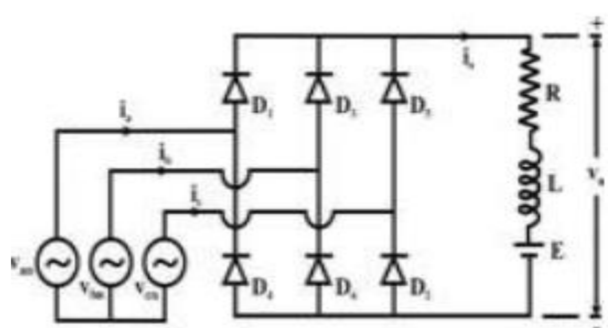
Full Wave Rectifier

Three-phase half wave rectifier:

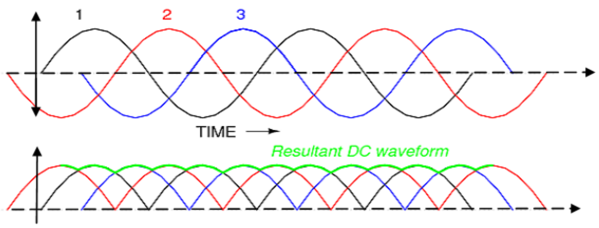


Phase half wave rectifier

The operation theory is like a single phase half wave rectifier. As each of the phases reach 0.7V the diode of the respective phase start conducting. The resultant current flows through the load.



Phase full wave rectifier



Input and output voltage waveform for 3 phase full wave rectifier

3. IMPLEMENTATION

In this Paper the proposed Power Factor Correction presents a new integrated AC-DC converter with single stage power factor correction with flying Capacitor. Due to the interleaved structure, the proposed converter operates at lower input ripple current and has improved load efficiency along with peak switch currents and soft switch operation. The convertor has improved efficiency and due to single stage 3 levels AC-DC converter it has voltage regulation along with power factor correction. This proposed converter is stimulated in the MATLAB software and the design and performance is further studied and analysed.

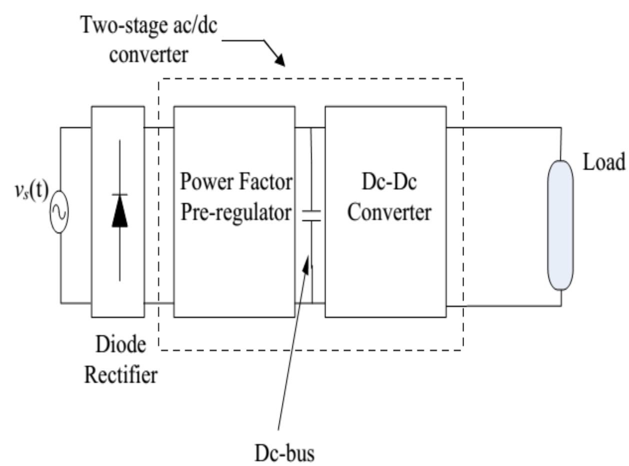
Active Power Factor Correction

Active PFC can be implemented by controlling the conduction time of the converter switches to force the ac current to follow the waveform of the applied ac voltage. There are two-stage and single-stage power factor correction techniques. These techniques are discussed below.

Two-stage power factor correction

Two-stage PFC using an input current shaper followed by a dc/dc converter is the fundamental approach for active PFC. The power factor pre-regulator allows the rectifier to draw current from the supply during the whole power cycle, instead of the current pulses drawn by the traditional diode rectifier, and this current is made to follow a sinusoidal reference in phase with the supply voltage. The most widely used pre-regulator circuit is the boost converter and it can be operated either in discontinuous conduction mode (DCM) in the voltage mode control or in continuous conduction mode (CCM) in the current mode control. Buck and buck-boost converters can also be used as input current shapers but some distortion must be allowed in the case of buck converters; whereas efficiency is degraded and component stresses are high in the case of buck-boost converters. The boost converter provides superior performance at the expense of the necessity of having the output voltage higher than the peak input voltage. Pulse width modulation (PWM) is most commonly used to achieve those two tasks. Several control methods can be used for input current shaping, such as average current mode control, peak current mode control or hysterisis control and nonlinear carrier control. The dc/dc converter stage (mostly an isolated converter) can be a forward, a fly back or any other step down converter.

Two-stage PFC using an input current shaper followed by a dc/dc converter is the fundamental approach for active PFC.



Block diagram of standard two-stage PFC ac/dc converter

4. PROPOSED METHODOLOY

This paper presents a new integrated AC-DC converter with single stage power factor correction with flying Capacitor. Due to the interleaved structure, the proposed converter operates at lower input ripple current and has improved load efficiency along with peak switch currents and soft switch operation. The convertor has improved efficiency and due to single stage 3 levels AC-DC converter it has voltage regulation along with power

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
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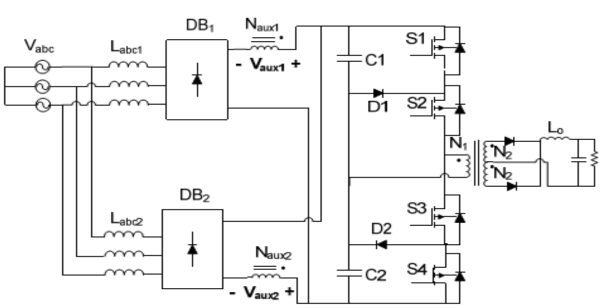
factor correction. AC-DC power supplies are forced to be implemented with some sort of input power factor correction (PFC) to comply with harmonic standards such as IEC 1000-3-2. There are three general methods that can be used for PFC.

• The first method is to add inductors to filter out low frequency input current harmonics and make the input current more sinusoidal. Although the resulting converter is simple and inexpensive, it is also heavy and bulky and thus this method is used in a limited number of applications.

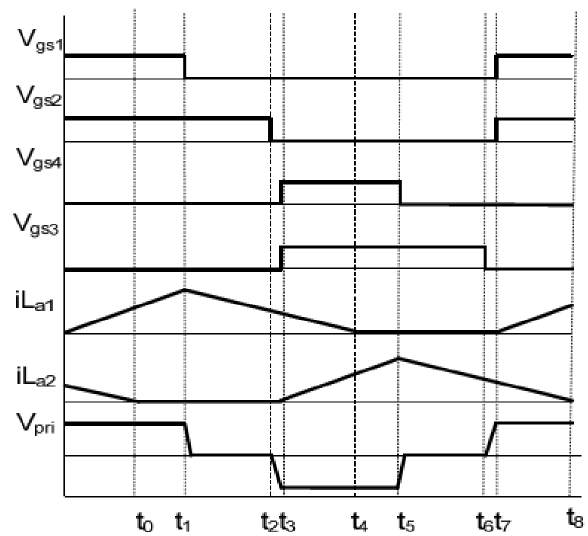
• The second method, which is the most common approach, is to use two stage converters - one stage as a pre-regulator to shape the input current so that it is sinusoidal and to control the dc bus voltage and one stage as a dc-dc converter to regulate the output voltage. Two stage converters, however, require two separate switch mode converters and thus can increase the cost, size, and complexity of the overall ac-dc converter.

• The third method is to integrate the functions of power factor correction (PFC) and isolated dc-dc conversion in a single power converter; this has led to the emergence of single-stage power-factor-corrected (SSPFC) converters. This method reduces the cost associated with operating two separate switch-mode converters for higher power applications. Several single-phase and three-phase converters have been proposed in the literature, with three phase converters being preferred over single-phase converters for higher power applications. Previously proposed three phase single-stage AC-DC converters, however, have at least one of the following drawbacks that have limited their widespread use:



An interleaved three-phase three-level converter

An interleaved three-phase, single-stage rectifier that has an output current that is continuous for all load ranges, a dc bus voltage that is less than 450 for all load conditions, and superior input current harmonic content. The PWM method that is needed to operate the converter is shown in Figure. As can be seen, this PWM method is not standard phase-shift PWM (PWM) and is therefore not found in commercially available integrated circuits (ICs). Moreover, this converter cannot operate with soft-switching except under heavy load conditions. A new interleaved three-phase single-stage PFC AC-DC that can operate with standard phase-shift PWM and with soft switching over a wider load range is proposed in this project. In this project, the operation of the converter and its steady-state characteristics are explained and its design is discussed. The feasibility of the new converter is confirmed with experimental results obtained from a prototype converter.



Typical waveforms describing the modes of operation

PHASE-SHIFT MODULATED PWM TECHNIQUE

The converter and its key waveforms are shown in Figure.

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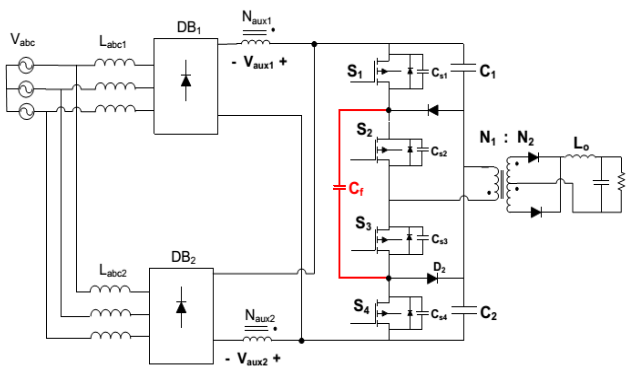
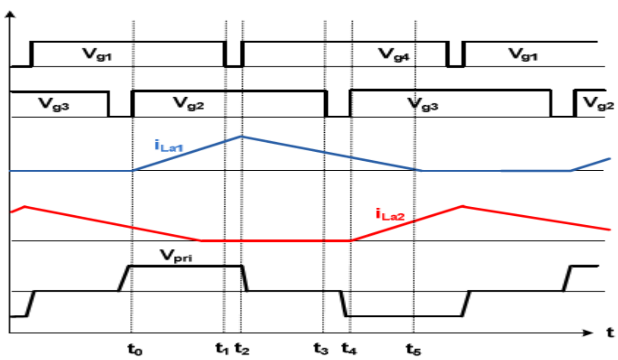


Proposed single-stage three-level AC-DC converter



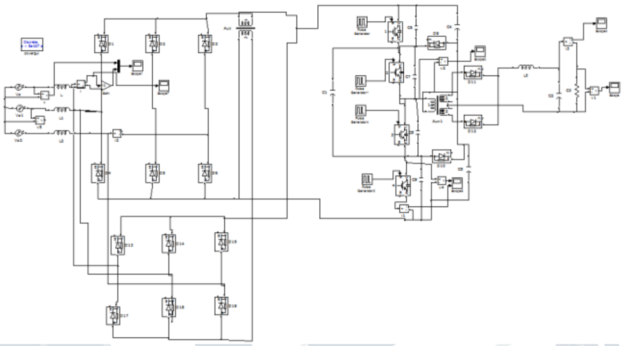
Typical waveforms for proposed converter

The proposed converter uses auxiliary windings that are taken from the converter transformer to act as "magnetic switches" to cancel the dc bus capacitor voltage so that the voltage that appears across the diode bridge output is zero. When the primary voltage of the main transformer is positive, Auxiliary Winding 1 (Naux1/N1=2) cancels out the dc bus voltage so that the output voltage of Diode Bridge 1 (DB1) is zero and the currents in input inductors La1, Lb1, and Lc1rise. When the primary voltage of the main transformer is negative, Auxiliary Winding 2 (Naux2/N1=2) cancels out the dc bus voltage so that the output voltage of Diode Bridge 2 (DB2) is zero and the currents in input inductors La2, Lb2, and Lc2 rise When there is no voltage across the main transformer primary winding, the total voltage across the dc bus capacitors appears at the output of the diode bridges and the input currents falls since this voltage is greater than the input voltage. If the input currents are discontinuous, the envelope of the input current will be sinusoidal and in phase with the input voltages.

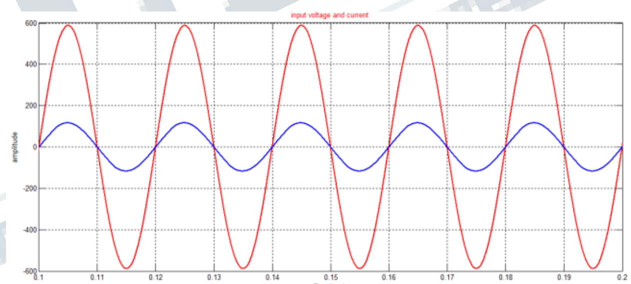
5. RESULTS AND DISCUSSION

Simulation circuit and Results:

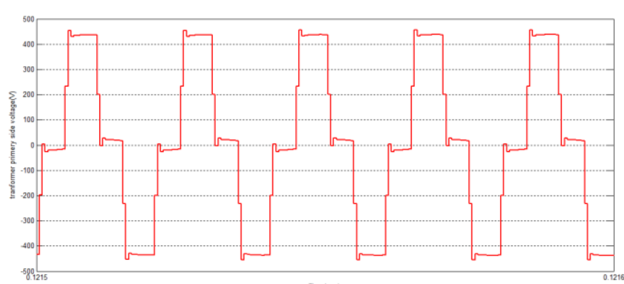
PROPOSED BLOCK DIAGRAM



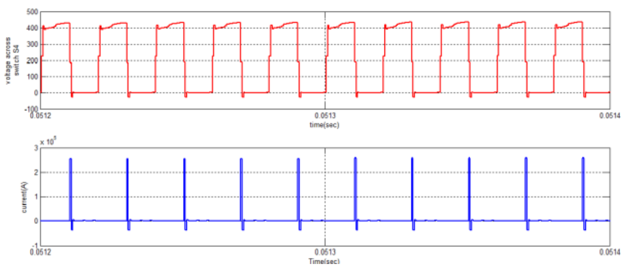
Simulation Results



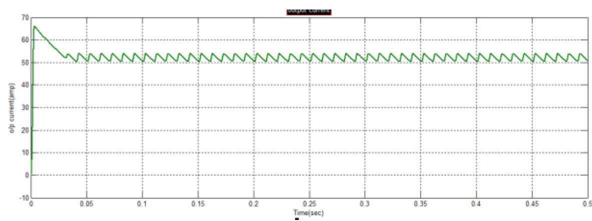
In put power factor



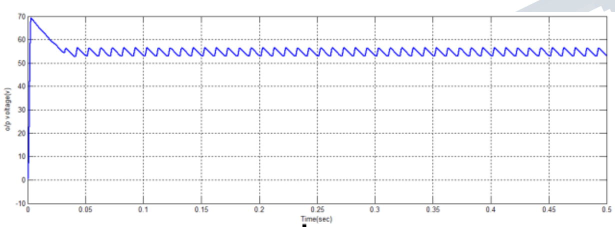
Voltage across primary winding of transformer



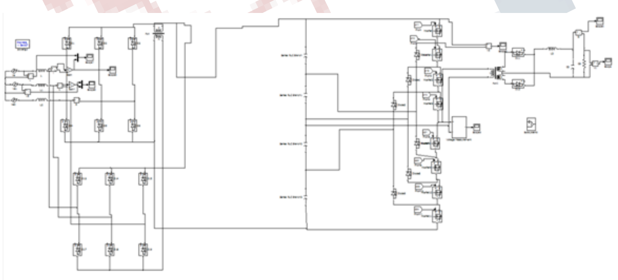
Voltage and current in switches



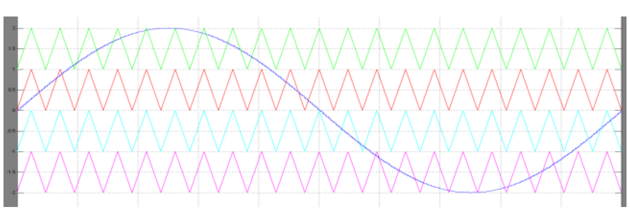
Load Current

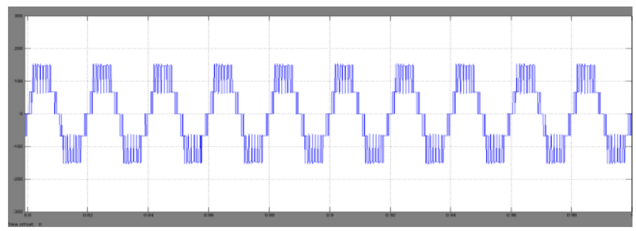


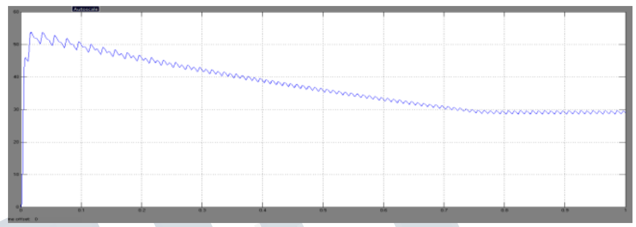
Extension:

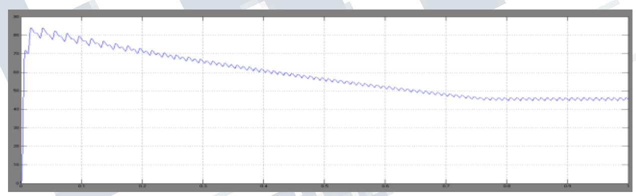


Simulation Results









THD

6. CONCLUSION

A new three-phase three-level single-stage power-factor corrected ac–dc converter with interleaved input has been proposed in this project. The converter operates with a single controller to regulate the output voltage and uses auxiliary windings taken from its power transformer as magnetic switches to cancel the dc bus voltage so that the input section operates like a boost converter. The proposed converter has the following features.

1) The proposed converter can operate with lower peak voltage stresses across its switches and the dc bus capacitors as it is a three-level converter. This allows for greater flexibility in the design of the converter and ultimately improved performance.

2) The proposed converter can operate with an input current harmonic content that meets the EN61000-3-2 Class Astandard with reduced input filter due to the interleaved structure.

ISSN (Online) 2395-2717

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3) The output inductor of the proposed converter can be designed to work in continuous conduction mode over a wide range of load variation and input voltage. This results in a lower output inductor current ripple than that found in previously proposed converters which helps reduce secondary component stresses and filtering.

4) The aforementioned features are all an improvement on the original non interleaved converter that was presented in Moreover, the proposed interleaved converter operates with greater efficiency than the converter proposed in because it has fewer diodes in the dc bus and it has less turn-on losses.

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