Abstract: A new interleaved single-stage ac–dc converter is proposed in this paper to reduce line current harmonics while achieving power factor correction (PFC). The proposed rectifier can produce input currents that do not have dead band regions with high PFC, operate with a continuous output current, and minimize the input electromagnetic interference filter size. In this paper, the operation of the new converter is explained, its features and design are discussed in results, and its operation is confirmed with simulation results obtained.

Keywords: PFC, Flyback Converter, RFID.

I. INTRODUCTION

Power factor correction (PFC) is very important nowadays for AC–DC power supply to comply with harmonic standards IEC 1000-3-2. By adding passive filters to the rectifier /LC filter input combination, results the converter become very bulky and heavy because of low frequency inductor and capacitor. The single stage power factor corrected converter (SSPFC) provides the features of both power factor pre-regulators and the DC-DC converter cascaded with it. In the two stages AC–DC converters have two stages1. Rectifying stage2 Isolation DC-DC conversion stages AC-DC converter is used for rectifying stage for most of the applications. The Boost converter shapes the line current so it is almost nearer to sinusoidal. Many methods have been used to remove current harmonics and thus improve the overall system power factor. There are two methods to eliminate or at least reduce the input line current harmonics: one is passive power factor correction (PPFC), and another one is active power factor correction (APFC). Passive PFC is the simplest and most straightforward method to eliminate the harmonics of input current.

This is achieved by using passive reactive elements either at the input or at the output side of input rectifier employed in the design of AC/DC converter. Advantages of this method are high efficiency, low EMI and simple implementation However, the main drawbacks particularly at the low frequency the size and weight and also cost. In active power factor correction switching converters are used to shape the input current drawn by the AC/DC converter into a sinusoidal waveform that is in phase with the input voltage waveform. Therefore, the power factor reaches almost unity and the AC/DC converter emulates a pure resistive load. The Active PFC has more advantages over passive PFC such as higher power factor lower harmonics, smaller converter size due to ability to use high switching frequencies, lighter weight and higher reliability. 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. Previously proposed single stage AC-DC full bridge converters have the following drawbacks:

- The current source converter with boost inductor connected to the input of the full bridge circuit, they lack an energy storage capacitor across the primary side DC bus. It causes the output voltage to have a large low frequency 120-HZ ripple.
- Some converters have two converter stages and thus have the cost and complexity associated with two stage converters.
- Resonant converter that must be controlled using different switching frequency control, which makes it difficult to optimize the design. The proposed converter and its key waveforms are shown in Figs. 1.

Fig.1. Proposed interleaved three-phase three-level converter.

II. AC –DC CONVERTER

A. Introduction

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as rectification. Physically, rectifiers take a number of forms, including vacuum tube diodes, mercury-arc valves,
copper and selenium oxide rectifiers, semiconductor diodes, silicon-controlled rectifiers and other silicon-based semiconductor switches. Historically, even synchronous electromechanical switches and motors have been used. Early radio receivers, called crystal radios, used a "cat's whisker" of fine wire pressing on a crystal of galena (lead sulfide) to serve as a point-contact rectifier or "crystal detector". Rectifiers have many uses, but are often found serving as components of DC power supplies and high-voltage direct current power transmission systems. Rectification may serve in roles other than to generate direct current for use as a source of power. As noted, detectors of radio signals serve as rectifiers. In gas heating systems flame rectification is used to detect presence of a flame. Because of the alternating nature of the input AC sine wave, the process of rectification alone produces a DC current that, though unidirectional, consists of pulses of current. Many applications of rectifiers, such as power supplies for radio, television and computer equipment, require a steady constant DC current (as would be produced by a battery). In these applications the output of the rectifier is smoothed by an electronic filter (usually a capacitor) to produce a steady current. A more complex circuitry device that performs the opposite function, converting DC to AC, is called an inverter.

B. Rectifier devices
Before the development of silicon semiconductor rectifiers, vacuum tube thermionic diodes and copper oxide- or selenium-based metal rectifier stacks were used.[1] With the introduction of semiconductor electronics, vacuum tube rectifiers became obsolete, except for some enthusiasts of vacuum tube audio equipment. For power rectification from very low to very high current, semiconductor diodes of various types (junction diodes, Scotty diodes, etc.) are widely used. Other devices that have control electrodes as well as acting as unidirectional current valves are used where more than simple rectification is required—e.g., where variable output voltage is needed. High-power rectifiers, such as those used in high-voltage direct current power transmission, employ silicon semiconductor devices of various types. These are thyristors or other controlled switching solid-state switches, which effectively function as diodes to pass current in only one direction.

C. Rectifier circuits
Rectifier circuits may be single-phase or multi-phase (three being the most common number of phases). Most low power rectifiers for domestic equipment are single-phase, but three-phase rectification is very important for industrial applications and for the transmission of energy as DC (HVDC).

D. Single-phase rectifiers
1. Half-wave rectification
In half wave rectification of a single-phase supply, either the positive or negative half of the AC wave is passed, while the other half is blocked. Because only one half of the input waveform reaches the output, mean voltage is lower. Half-wave rectification requires a single diode in a single-phase supply, or three in a three-phase supply. Rectifiers yield a unidirectional but pulsating direct current; half-wave rectifiers produce far more ripple than full-wave rectifiers, and much more filtering is needed to eliminate harmonics of the AC frequency from the output.

![Fig.2. Half-wave rectifier](image)

III. THREE-LEVEL CONVERTERS

A. Introduction
A phase converter is a device that converts electric power provided as single phase to multiple phases or vice versa. The majority of phase converters are used to produce three-phase electric power from a single-phase source, thus allowing the operation of three-phase equipment at a site that only has single-phase electrical service. Phase converters are used where three-phase service is not available from the utility, or is too costly to install due to a remote location. A utility will generally charge a higher fee for a three-phase service because of the extra equipment for transformers and metering and the extra transmission wire.

B. Conversion systems
Three-phase induction motors may operate adequately on an unbalanced supply if not heavily loaded. This allows various imperfect techniques to be used. A single-phase motor can drive a three-phase generator, which will produce a high-quality three-phase source but with high cost for apparatus. Several methods exist to run three-phase motors from a single-phase supply; these can in general be classified as:

- Electronic means of creating three phases where the incoming power is rectified, and the three-phase power is synthesized with electronics. Power electronic devices directly produce a three-phase waveform from single-phase power, using a rectifier and inverter combination. This also offers the advantage of variable frequency.
- A digital phase converter uses a rectifier and inverter to create a single voltage with power electronics, which is added to the two legs of the single-phase source to create three-phase power. Unlike a phase-converting VFD, it cannot vary the frequency and motor speed, since it generates only one leg, which must match the voltage and frequency of the single-phase supply. It does have the advantage of a sine-wave output voltage and excellent voltage balance between the phases.
- Rotary phase converters constructed from a three-phase electric motor or generator "idler". These normally require some kind of starting aid and capacitors to

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A Novel Interleaved Three-Phase Single Stage PFC with Flyback Converter

D. Electric railways

In Europe, electricity is normally generated as three-phase AC at 50 hertz. Five European countries, Germany, Austria, Switzerland, Norway and Sweden have standardized on single-phase AC at 15 kV 16⅔ Hz for railway electrification. Phase converters are, therefore, used to change both the phase and the frequency.

E. Three-phase electric power

Three-phase electric power is a common method of alternating-current electric power generation, transmission, and distribution. It is a type of poly phase system and is the most common method used by electrical grids worldwide to transfer power. It is also used to power large motors and other heavy loads. A three-phase system is usually more economical than an equivalent single-phase or two-phase system at the same line to ground voltage because it uses less conductor material to transmit electrical power. The three-phase system was independently invented by Galileo Ferraris, Mikhail Dolivo-Dobrovolsky, Jonas Wenström and Nikola Tesla in the late 1880s.

1. Principle

Fig.3. Normalized waveforms of the instantaneous voltages in a three-phase system in one cycle with time increasing to the right. The phase order is 1-2-3. This cycle repeats with the frequency of the power system.

Fig.4. Three-phase electric power transmission lines.

In a symmetric three-phase power supply system, three conductors each carry an alternating current of the same frequency and voltage amplitude relative to a common reference but with a phase difference of one third the period. The common reference is usually connected to ground and often to a current-carrying conductor called the neutral. Due
to the phase difference, the voltage on any conductor reaches its peak at one third of a cycle after one of the other conductors and one third of a cycle before the remaining conductor. This phase delay gives constant power transfer to a balanced linear load. It also makes possible to produce a rotating magnetic field in an electric motor and generate other phase arrangements using transformers (For instance, a two phase system using a Scott-T transformer). The symmetric three-phase systems described here are simply referred to as three-phase systems because, although it is possible to design and implement asymmetric three-phase power systems (i.e., with unequal voltages or phase shifts), they are not used in practice because they lack the most important advantages of symmetric systems.

In a three-phase system feeding a balanced and linear load, the sum of the instantaneous currents of the three conductors is zero. In other words, the current in each conductor is equal in magnitude to, but with the opposite sign of, the sum of the currents in the other two. The return path for the current in any phase conductor is the other two phase conductors. Compared to a single-phase AC power supply that uses two conductors (phase and neutral), a three-phase supply with no neutral, the same phase-to-ground voltage and current capacity per phase can transmit three times as much power using just 1.5 times as many wires (i.e., three instead of two). Thus, the ratio of capacity to conductor material is doubled. The same (but not the other properties of three-phase power) can also be attained with a center-grounded single-phase system. Three-phase systems may also utilize a fourth wire, particularly in low-voltage distribution. This is the neutral wire. The neutral allows three separate single-phase supplies to be provided at a constant voltage and is commonly used for supplying groups of domestic properties which are each single-phase loads.

The connections are arranged so that, as far as possible in each group, equal power is drawn from each phase. Further up the distribution system, the currents are usually well balanced. Transformers may be wired in a way that they have a four-wire secondary but a three-wire primary while allowing unbalanced loads and the associated secondary-side neutral currents. Three-phase supplies have properties that make them very desirable in electric power distribution systems:

- The phase currents tend to cancel out one another, summing to zero in the case of a linear balanced load. This makes it possible to reduce the size of the neutral conductor because it carries little or no current. With a balanced load, all the phase conductors carry the same current and so can be the same size.
- Power transfer into a linear balanced load is constant, which helps to reduce generator and motor vibrations.
- Three-phase systems can produce a rotating magnetic field with a specified direction and constant magnitude, which simplifies the design of electric motors.

Most household loads are single-phase. In North American residences, three-phase power might feed a multiple-unit apartment block, but the household loads are connected only as single phase. In lower-density areas, only a single phase might be used for distribution. Some large European appliances may be powered by three-phase power, such as electric stoves and clothes dryers. Wiring for the three phases is typically identified by color codes which vary by country. Connection of the phases in the right order is required to ensure the intended direction of rotation of three-phase motors. For example, pumps and fans may not work in reverse. Maintaining the identity of phases is required if there is any possibility two sources can be connected at the same time; a direct interconnection between two different phases is a short-circuit.

F. Generation and distribution

![Fig.5. Animation of three-phase current flow.](image)

At the power station, an electrical generator converts mechanical power into a set of three AC electric currents, one from each coil (or winding) of the generator. The windings are arranged such that the currents vary sinusoidally at the same frequency but with the peaks and troughs of their wave forms offset to provide three complementary currents with a phase separation of one-third cycle (120° or \(\frac{2\pi}{3}\) radians). The generator frequency is typically 50 or 60 Hz, varying by country. At the power station, transformers change the voltage from generators to a level suitable for transmission minimizing losses. After further voltage conversions in the transmission network, the voltage is finally transformed to the standard utilization before power is supplied to customers. Most automotive alternators generate three phase AC and rectify it to DC with a diode bridge.

G. Transformer connections

A "delta" connected transformer winding is connected between phases of a three-phase system. A "wye" ("star") transformer connects each winding from a phase wire to a common neutral point. In an "open delta" or "V" system, only two transformers are used. A closed delta system can operate as an open delta if one of the transformers has failed or needs to be removed. In open delta, each transformer must carry current for its respective phases as well as current for the third phase; therefore capacity is reduced to 87%. With one of three transformers missing and the remaining two at 87% efficiency, the capacity is 58% (\((2/3) \times 87\%)\). Where a delta-fed system must be grounded for detection of stray current to
A Novel Interleaved Three-Phase Single Stage PFC with Flyback Converter

ground or protection from surge voltages, a grounding transformer (usually a zigzag transformer) may be connected to allow ground fault currents to return from any phase to ground. Another variation is a "corner grounded" delta system, which is a closed delta that is grounded at one of the junctions of transformers.

IV. SIMULATION RESULTS AND CONVERTER COMPARISON

Simulation result of the proposed converter was built to confirm its feasibility. The prototype was designed according to the following specifications:

- Input voltage $V_{in} = 208 \pm 10\% \text{ Vrms (line–line)}$
- Output voltage $V_o = 48 \text{ V}$
- Output power $P_o = 1.1 \text{ Kw}$
- Switching frequency $f_{sw} = 100 \text{ kHz}$

The typical converter waveforms are shown in Fig. 7. It can be seen that the proposed converter can operate with nearly sinusoidal input currents with no dead band regions. It is a multilevel full-bridge converter that the switch stresses are half the dc bus voltage; it also can operate with a continuous output current, unlike most other converters of the same type. The experimental results obtained for the proposed converter are compared to those of the converter proposed in, as shown in Tables I and II. The converter in is a single-stage three-level PFC converter and is a non interleaved version of the proposed converter with just one set of input inductors instead of two. The output inductor current in was designed to be continuous for heavy loads and discontinuous for light loads to keep the dc bus voltage less than 450 V. Compared to the non interleaved converter that was presented in, the interleaved converter that is proposed in this paper has several advantages in addition to reduced input current ripple. The proposed converter can operate with a continuous current at the output from 10% of the full load to full load, which makes the output current have less ripple. This is because the proposed converter has an interleaved structure that results in a change of the energy equilibrium at the dc bus (the net equivalent inductance at the input is larger in the proposed converter), which makes the dc bus small enough to permit the output inductor to be sufficiently large.

V. CONCLUSION

The purpose of the project was to develop open loop control for the single-stage three level full-bridge converters. A single-phase, three-level, single-stage power-factor corrected AC/DC converter that operates with a single controller to regulate the output voltage was presented. This converter has an auxiliary circuit that can cancel the capacitor voltage in which way the input inductor act as a boost inductor to have a single stage power factor correction. The outstanding features...

Fig. 6. Simulation model diagram.

Fig. 7. Simulation results (a) Top switch voltages Vds1 and Vds2 (V: 100 V/div; t: 4 μs/div). (b) Primary voltage of the main transformer (V: 100 V/div; t: 4 μs/div). (c) Input current and voltage (V: 100 V/div; I: 4 A/div).
of the rectifier is that it can produce input currents that do not have dead band regions and an output current that can be continuous when the converter is operating from maximum load to at least half of the load. The converter can operate with lower peak voltage stresses across the 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.

VI. REFERENCES


