# An Overview of Single Phase Telecommunication Converter Topologies: A Comparative Study

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**ABSTRACT:**
This paper describes the development of a new generation of single phase rectifier which is used to power telecommunications equipment. A rectifier is designed in such a manner to meets with all the requirements of the telecommunications industry. A number of common single phase topologies exist that could be realized as telecommunication power supplies, however, they do not completely satisfy all the industry requirements. This paper reviews recent progress in topology, control and design aspects in single phase PFC techniques. Different switching rectifier topologies are presented for various applications. Merits and limitations of these techniques are discussed. A detailed report of an investigation in the power converter system performance is also provided.

**KEYWORDS:** Single Phase Rectifier, Telecom, Boost Converter, Single Stage Approach and Two Stage Approach.

## 1. INTRODUCTION

Telecommunications is one of the rapidly expanding fields in today's world. For example recent statistics indicate that India now has 49.5 million mobile subscribers and 95.5 million fixed telephone users. The growth in the new users added from 2009 onwards is beyond expectations. It is recorded that, on an average, 9 million new users are added to the list every month. The growth in urban areas is projected at 5.2%, where as the rural India has registered a growth rate of 9.2%. This growth in telecommunications field is always associated with growth in supporting equipment like power supply for telephone exchanges. Given the fact that the rural growth is more, the telecom regulatory authority revised the specification of the power supply units to suit the environmental conditions such as wide input fluctuations, generally present in villages In the fast growing field of Telecommunications, the backup DC power supply plays a vital role in powering the telecom equipment. [1]. Telecommunication systems are designed primarily to provide the backup infrastructure to facilitate communication.

Typically a telecommunication system has the AC mains input as the primary power source for the installation, with some critical set-up having an alternative supply in the form of a standby generator. A typical telecommunication set-up is shown in Fig.1 In this case both the generator output and the AC mains input are routed to the power supply cabinets via a mains/generator transfer switch. In the event that the mains supply is compromised this switch is activated allowing the generator to supply energy to the system.

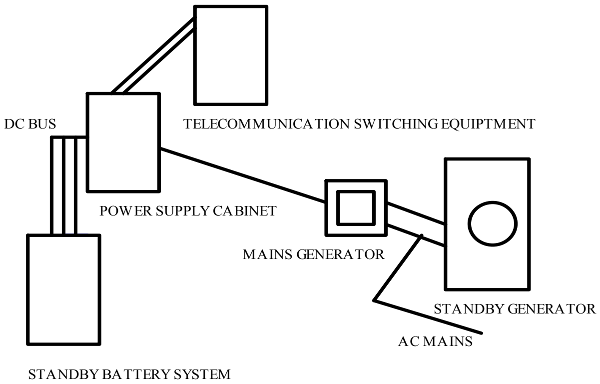

**Fig. 1.** Typical Telecommunication Power System Setup.

During the generator start-up phase the standby batteries provide power to the telecommunication switching equipment. Power converter systems which convert the AC mains voltage to a -48V DC supply are housed inside the power supply cabinets. These power converter systems are used to provide the batteries with charging current when necessary, as well as powering the telecommunication switching equipment, which mainly consists of board mounted power converter units used to convert the -48V to 5V and ±12V.

## 2. TELECOMMUNICATION INDUSTRY STANDARDS

Telecommunication power converter systems have to comply with various industry standards to sell their products to customers. Two standards which have a significant impact on the design of the power converters are described in this section.

### 2.1. ITU-T 0.41 (psophometric) standard

The term psophometric is used to describe a method of measuring noise within the speech band, while weighting the value of each frequency component present in accordance with its relative effect on the human ear. The psophometric standard was introduced by the International Telecommunications Union (ITU); its purpose is to regulate the amount of audible noise appearing on telephone networks. This was due to the fact that in the telecommunications industry (SCR) full bridge converters were used before the introduction of switched mode technology into the market place. These SCR converters had no output filtering and as a result had considerable noise on the output due to the presence of lower order harmonics [2].

Telephone systems were originally analogue, and as a result of the lower order harmonics on the thyristor controlled converter output, audible noise was produced on the telephone lines. Reducing this audible noise was achieved by adding passive LC filtering components on the output of the thyristor controlled converters. However, this resulted in an increase in size and cost. Nowadays, with digital exchanges, the telephone systems have become more immune to DC power supply noise. Since digital signals only exist in discrete states and not continuous signals, it is therefore only necessary to detect a high or low state on a digital signal. The psophometric standard is still used, however new standard are defined for the interface between telecommunication switching equipment and telecommunication power converter systems, hence companies must meet the standard in order to sell their products. The psophometric noise limit is defined for telecommunication power converter systems such that the AC output voltage is not to exceed 2mVrms while the system is operating under full load at nominal mains voltages.

### 2.2. IEC 1000-3-2 Standard

The IEC1000-3-2 standard was introduced in 1995 to regulate harmonic currents drawn from the mains supply [3]. These harmonic currents reduce the supply efficiency and can excite resonances, as well as causing heating in transformers and wiring. Telecommunication power converter systems fall under a class A classification, which defines all electrical and electronic equipment having an input current up to and including 16A per phase. The Class A limits of harmonics for each phase of the line current are shown in Table I. These limits are absolute, i.e. not related to power ratings of the equipment. The limits are only applicable to steady-state harmonic currents since harmonic distortion is a characteristic of the steady-state current or voltage and is not a disturbance [4].

**Table 1.** Class A Harmonic Current Limits [IEC1000-3-2] [4].

| Harmonic order (n) | Maximum harmonic current |
|---|---|
| | Odd Harmonics |
| 3 | 2.3 |
| 5 | 1.14 |
| 7 | 0.77 |
| 9 | 0.4 |
| 11 | 0.33 |
| 13 | 0.21 |
| 15 ≤n ≤ 39 | 2.25/n |
| | Even harmonics |
| 2 | 1.08 |
| 4 | 0.43 |
| 6 | 0.3 |
| 8≤ n≤ 40 | 1.83/n |

### 2.3. Standards Compliance

Compliance with these two standards has dictated the way in which telecommunication power converter system manufacturers have to design their products. The most popular choice is a single-phase two-stage topology [5] as shown in Fig.2.

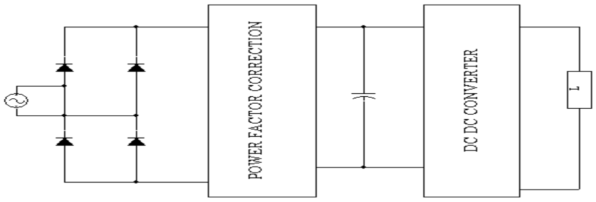

**Fig. 2.** Traditional telecommunication Power Converter system

The first stage of the power converter system comprises a boost stage, used to provide power factor correction (PFC) and hence regulate the maximum allowable input harmonic current content defined by the IEC1000-3-2 standard [6]. The simple boost converter topology is the most popular choice for a PFC stage, due to its high efficiency and good silicon utilization [7]. Traditional single-phase telecommunication power converter systems typically operate up to 6kW power range, with the cost of bulk storage capacitors becoming the limiting factor as well as the ability to draw larger amounts of power off one phase of a supply transformer. Also, the boost stage requires that the output voltage selected is higher than the highest peak value of input voltage, which in a universal boost topology capable of operating on both 110V and 220V systems, typically resulting in an output voltage of 400V or more. Since telecommunication switching equipment runs off a -48V supply, there is the additional need for voltage transformation [8].

Also, telecommunication companies have chosen not to have isolation of their systems, and since the standby batteries have their positive 48V rail earthed it therefore becomes a functional requirement for the power converter system to have galvanic isolation. The second stage takes the form of a DC-DC converter which is required to provide fast regulation of the output voltage to reject the psophometric noise, as well as providing the isolation and voltage transformation. As a consequence of having a single-phase supply no power can be transferred during the mains zero crossings; hence a large storage capacitor is needed to provide the output power during these times. As a result of having a two-stage topology there are losses across both stages as the power is processed twice, this results in a cascading effect which reduces the overall efficiency of the system, resulting in typically around 90% efficiency. Having a boost stage has the disadvantage that there is no protection from short circuit conditions and startup inrush currents [9]. Also, two separate control circuits are required, one for each stage adding to the overall cost of the system.

## 3. SINGLE PHASE CONVERTERS

In this part, a study is conducted into the various single-phase topologies available that could be used in the telecommunications industry, and the reasons for the use of the single-phase two-stage approach being highlighted. Various other single-phase topologies are also investigated, and their suitability as telecommunication power converters is discussed. The traditional two-stage power converter topology has been a popular choice for single-phase telecommunication power converter systems. This is due to the ability of the power converter system to provide both PFC and tight output voltage regulation, which guarantees compliance with the IEC1000-3-2 standard and the psophometric standard. The popularity of this topology can be attributed to the following reasons:

- Achieves sine line current.
- Good performance under universal line voltage.
- Many options for isolation.
- Has a constant second stage input voltage, which allows for optimal design of the second stage.

In general, telecommunication power converter systems consist of a non-isolated PFC stage, used to force the line current to follow the line voltage. This PFC stage creates an intermediate DC voltage with a relatively large second harmonic ripple, due to the single-phase nature of the power flow as well as its low bandwidth control [10]. The fact that there is a second harmonic ripple necessitates the use of a large storage capacitor. The second stage consists of a DC converter, providing isolation and high bandwidth output voltage regulation. This topology requires the use of two controllers, the first being a PFC controller, which consists of a current and voltage loop; and, the second, a DC-DC controller, which requires only a voltage feedback loop. Considering the system from a power transfer point of view, the converter's input power oscillates at twice the mains frequency, and, in a single-phase system, because there can be no natural energy transfer from source to load at the mains zero crossing, an energy storage medium, normally in the form of a capacitor, is always required.

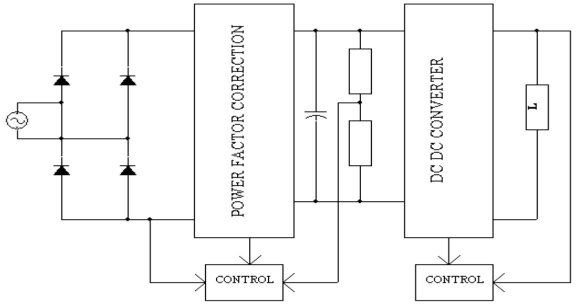

**Fig. 3.** Two-Stage Telecommunication Power Converter System

In a single-phase system, the total DC power that can be delivered to the load is half the peak input power as illustrated in Fig.4 The area under the DC power line of the positive half line cycle constitutes 68% of the input power, while the area above the DC power line consists of the remaining 32% of the input power. This 32% excess power is stored and then used later in each cycle, when the input power drops below the required output DC power.

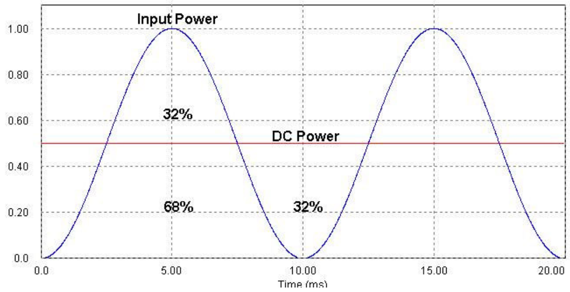

**Fig. 4.** Single-Phase Normalised Energy Transfer

Many methods of improving the traditional two-stage single-phase power converter system are referred. These include using a voltage follower approach, where the power converter system is designed to work in a discontinuous conduction mode, making it a natural voltage follower, hence, the PFC current loop can be removed [11], resulting in a simplification of the control circuit. The use of passive filters is another method, whereby using reactive elements, it is possible to obtain near sinusoidal line current [12] without the use of a PFC stage. Other attempts have been undertaken to decrease the amount of energy processing in power converter systems compared with the two-stage approach, where the output power is processed twice [13,14]. In addition, there have also been attempts to improve the PFC stage in the conventional two-stage design. These include using multi-level topologies [15,16] as well as the use of soft-switched and resonant topologies [17-21], to reduce switching loss and thereby increase the power converter system efficiency. Several authors have introduced single-stage PFC converter topologies, which offer some advantages. However, their field of application is limited to low power [22-25].

### 3.1. Voltage Follower

A boost converter operating in continuous conduction mode, using the multiplier approach, is commonly used as a power factor correction topology due to its excellent performance. Recently, power factor correction topologies derived from the buck-boost converter have been proposed, mainly because they emulate a natural resistor load when operating in the discontinuous conduction mode. It has been proposed by various authors that, using buck-boost derived topologies, which are natural voltage followers, the current control loop can be removed and, in so doing, provide a simpler control circuit. In using these topologies, it would be possible to comply with the IEC1000-3-2 and the psophometric standards, with a second stage only needed if a non-isolated buck-boost derived topology was used. Therefore, it is possible to implement this approach as a single-stage solution. However, there is a disadvantage in the fact that these topologies are limited to low power applications only.

### 3.2. Passive Filtering

Under the passive PFC approach, the use of LC input filters is required, providing a method that is both simple and reliable as in Fig. 5. In using this technique, it becomes possible to draw close to sinusoidal current, thereby requiring only a DC-DC converter. This means a single-stage power converter system can be implemented. The use of passive filtering also makes it possible to gain compliance with the IEC1000-3-2 standard. The DC-DC converter stage must provide isolation, voltage transformation, and output voltage ripple reduction, thus achieving compliance with the psophometric standard. A disadvantage with using this approach is that the input filter tends to be bulky and heavy, which is due to the fact that the passive components are operating at line frequencies (50/60 Hz), resulting in the use of large reactive components.

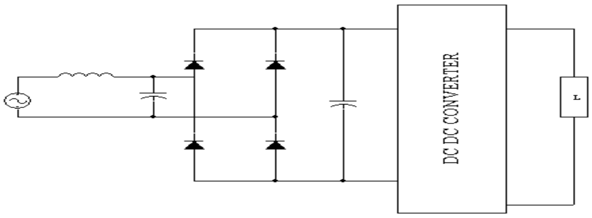

**Fig. 5.** Power Converter System using Passive Filtering

## 4. POWER CONVERTER SYSTEMS WITH IMPROVED ENERGY PROCESSING

### 4.1. Shunt Regulator

A topology is proposed in [26] with the aim of the design to reduce the amount of power processing required and reducing the overall system losses as in ig 6. The topology operates by having the PFC stage for controlling the input current, and the DC-DC regulator stage controlling the output current, thus providing the regulation.

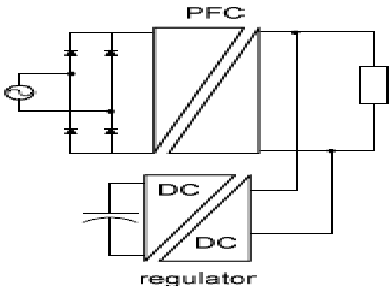

**Fig. 6.** Power Converter System with Shunt Regulator

The DC-DC regulator absorbs 32% of the average input power, which is the difference between the input and output power within a half line cycle and then releases it to the load at the appropriate time, providing a constant flow of power to the load during the mains zero crossings. Since 68% of the average input power can reach the output through one power conversion stage, with only the remaining 32% needing to be processed twice, the average output power is therefore processed 1.64 times with this topology, instead of twice as with the traditional power converter. This topology does however require a large storage capacitor to hold up the output when the input is in a low portion of the line cycle. In using this type of topology, it would be possible to comply with the IEC1000-3-2 and the psophometric standard, however, this topology needs isolation on both the PFC and DC-

DC regulator stage in order to meet telecommunication industry requirements. Also, the DC-DC stage requires bi-directional power flow capability, which increases the overall design complexity.

### 4.2. Harmonic Reducer

The topology proposed in [27] uses a bi-directional DC-DC converter to perform the function of the PFC stage as shown in fig.7. The bi-directional DC-DC converter takes the role of an active filter in reducing harmonic currents drawn from the mains. As a result, the power converter system would be able to comply with the IEC1000-3-2 standard. A DC-DC output stage is required for isolation, voltage transformation and ripple reduction. Accordingly, using this topology, it would be possible to comply with the necessary telecommunication standards. Also, similar to the shunt regulator topology discussed the average output power is processed 1.64 times.

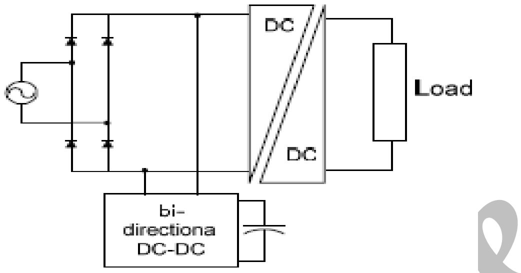

**Fig. 7.** Power Converter System with Harmonic Reducer

### 4.3. Active Filtering

The topology shown in Fig. 8 is a variation in that the active filter is now placed on the mains side [28, 29]. The active filter is a four quadrant converter and is responsible for maintaining a sinusoidal line current, i.e. performing the PFC functions. The DC-DC converter stage is used for isolation, voltage transformation and ripple reduction. Using this topology, it would be possible to comply with the required telecommunication standards. This topology also results in the average output power being processed 1.64 times, but has the disadvantage in that the active filter is a four quadrant converter requiring four switches.

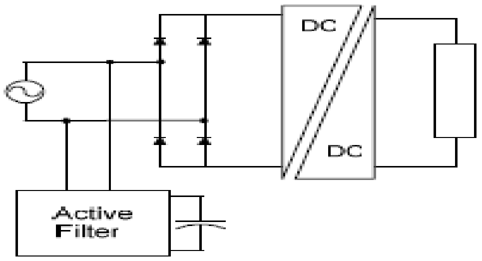

**Fig. 8.** Power Converter System with Active Filtering

### 5. IMPROVED PFC STAGE DESIGNS

There have been many papers published about the overall efficiency of the conventional two-stage power converter system and how it can be improved by reducing the losses experienced in the PFC stage, which has traditionally used a hard-switched boost topology. These various methods are discussed in the following subsections.

### 5.1. Multi-Level Power Converter System

A method to reduce the switching losses in the boost converter stage is to use a multi-level topology and, in so doing, double the number of switching devices required as in Fig. 9. This results in reduced voltage stress, thus lowering the voltage rating requirements for the semiconductors [30]. An increase in efficiency over the conventional hard-switched boost topology was noted [31], but this is offset by the additional requirement of extra components.

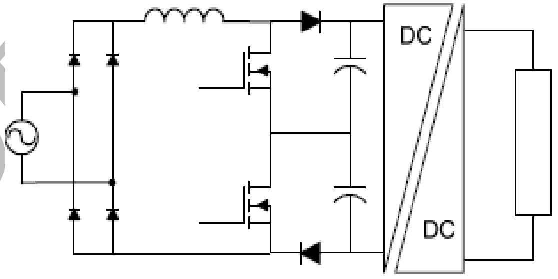

**Fig. 9.** Two-Stage Converter with Multi-Level Boost

### 5.2. Soft-Switched Power Converter

The soft-switching boost converter approach combines PWM mode and resonant mode techniques. A topology is proposed in [32] that operates in PWM mode during most of the switching cycle, but operates in a resonant mode during the main boost switch turn-on and turn-off intervals as in fig. 10. As a result, zero voltage switching (ZVS) takes place in both the boost switch, as well as the output diode, and, in so doing, reduces the switching losses encountered by hard-switched boost converters. This solution requires an additional switch as well as some reactive elements. The authors reported a 2% increase in efficiency over a hard switched boost converter. However, this gain in efficiency is offset by the need for additional components and control circuitry. An alternative is to replace the diode bridge rectifiers and other diode components with switches, thereby reducing conduction losses [33]. This however does make the soft switching strategy more complicated due to the addition of auxiliary circuits with active switches that are connected to the main power circuit. This can be made easier by using quasi-resonant techniques [34].

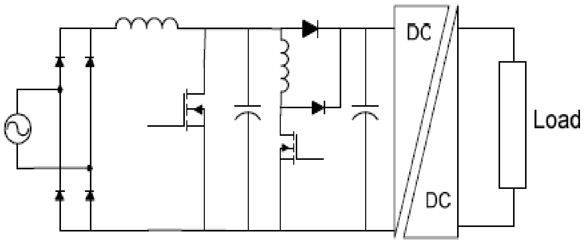

**Fig. 10.** Two-Stage Converter with Soft Switched Boost

### 5.3. Resonant Converter Design

In a resonant power converter, voltage across a switch or current through a switch is shaped by the resonance of the inductive and capacitive elements. When the voltage or current becomes zero, the switch is then turned on or off, thus, reducing the switching loss. A PFC technique is proposed in [35] and [36] that use a parallel and series resonant topology respectively. A high power factor is achieved by the natural boosting characteristic of the resonant topology. A major disadvantage is the high voltage and current stresses on the switches as well as the use of variable frequency control. Another approach is to place a resonant network between the input diode rectifier and the DC-DC converter [37]. However, this results in a complex arrangement of reactive components for the resonant network, with no clear advantage over the traditional boost converter.

## 6. SINGLE-STAGE POWER CONVERTER

The use of an active single-stage power converter requires only one controller and is, therefore, an advantage when compared to the two-stage approach. Also, being single-staged, the output power is only processed once, giving it a theoretical efficiency advantage over a conventional two-stage approach. Many different power converter topologies have been proposed that integrate functions of PFC and isolated DC-DC conversion in a single stage [38], thus, maintaining telecommunication compliance requirements. However, a major problem with any single-stage approach is the fact that the voltage on the internal bulk capacitors varies with the line voltage and load current. This can result in high peak voltages, which makes these circuits impractical above about 200W due to the high cost of the storage capacitors required.

## 7. BIDIRECTIONAL ZVS POWER CONVERTER

Bidirectional DC-DC converters allow transfer of power between two dc sources, in either direction. Due to their ability to reverse the direction of flow of power, they are being increasingly used in many applications such as telecom power supplies. The proposed converter also has both transformer-less version and transformer one as in [39].

## 8. ZVS AND ZCS WITH ACTIVE SNUBBER

The main feature of the active approaches introduced in [40]–[71] is that they either offer zero-voltage switching (ZVS) or zero-current switching (ZCS) of the boost switch besides the soft switching of the boost rectifier. Specifically, in the active-snubber implementations in the snubber switch turns off with ZCS, whereas in the implementations in it turns on with ZVS. The main drawback of these methods is that, the majority of these active approaches exhibit voltage and current stresses on the semiconductor components that are similar to those in the boost circuit without a snubber. The major demerit of the active snubber approaches is a relatively large component count, as well as the need for a driver for the auxiliary switch. In addition, the active snubbers introduced and proposed in [71] require a less-desirable isolated (high-side) drive for the auxiliary switch.

## 9. BRIGDE LESS PFC CONVERTER

One approach that is getting a lot of attention is the bridgeless PFC boost converter [72]–[77]. Although the bridgeless PFC boost converter was introduced a long time ago, it is only recently that power supply designers have shown serious interest in this technology. Generally, the bridgeless PFC boost converter reduces the overall conduction loss of the PFC converter stage by reducing the number of rectifiers that conduct current from the input to the output by essentially eliminating the diode bridge rectifier.

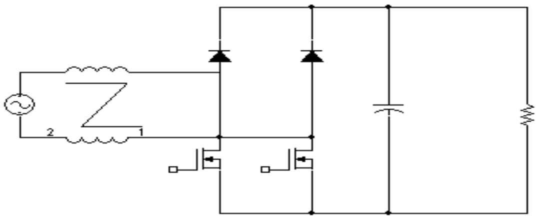

**Fig. 11.** Bridgeless PFC Converter

## 10. FAST SI RECOVERY RECTIFIER

The recent development of silicon carbide (SiC) technology that have made SiC rectifiers [78] available are completely restructuring the converter design optimization priorities [79]–[82]. Since SiC rectifiers virtually have no reverse-recovery charge, active snubbers to control the turn-off rate of the rectifier are unnecessary, which greatly simplifies the circuit design. However, as the switching frequency of the PFC boost circuit with the SiC rectifier is increased to minimize the size of the boost choke, some additional circuitry for creating soft-switching conditions of the boost switch may be required. Nevertheless, due to the relatively high cost compared to corresponding fast-recovery Si rectifiers, the SiC technology will need some time to gain a wide acceptance in telecom applications. Until then, conventional Si technology will continue to dominate the telecom applications.

## 11. MICROCONTROLLER AND DSP CONTROL

Finally, it is noted that the availability of low-cost, high-performance microcontrollers and digital signal processors (DSPs) has generated a strong genuine interest in digital control of single-phase converters. Besides significant research work conducted at companies and research labs, some major IC manufacturers are also making accelerated efforts to optimize their MCs and DSPs for power-supply applications [84]–[90]. The major merits of digital control system includes controller redesign that can be accomplished through software changes, immunity to temperature and aging, ability to easily implement complex control algorithms (e.g., adaptive control, fuzzy logic control, nonlinear control, etc.), intelligence capability (self-diagnosis, parameter estimation, etc.), and real-time communication capabilities There is no doubt that in the future the digital control of single-phase converters will find applications in telecom power supplies.

## 12. CONCLUSION

Due to the various requirements of the telecommunication industry, it is necessary to design telecommunication power converter systems to meet certain criteria. As a result, the common two stage converter topology is used, with the first stage providing PFC, in order to comply with the IEC1000-3-2 standard, as well as the use of a DC-DC converter to comply with the psophometric standard. There have been many attempts to improve the two-stage design while still meeting the industry requirements. Although it has been shown to result in an increase in the efficiency over the two stage converter, more complex control and switching devices are required. Other methods discussed, regarding optimization of the traditional two-stage converter by using multi-level and resonant topologies, can result in increased efficiency. However, this also comes with the cost of extra components. There is therefore no significant decrease in the dollar per watt ratio, in using these alternative designs, when compared to the conventional two-stage power converter topology. To attain high efficiencies in high-power PFC converters, it is of paramount importance to eliminate the switching losses introduced by the reverse-recovery characteristic of the boost rectifier. For fast-recovery rectifiers, the reduction of the reverse-recovery- related losses can be achieved by controlling the turn-off rate of the rectifier current. So far, a larger number of boost topologies that employ various active snubbers to reduce the reverse- recovery losses have been proposed. All of them also offer either ZVS or ZCS of the boost switch. In addition, some topologies feature soft switching of the snubber switch. Since in the topologies with ZCS the IGBT is used as a boost switch, where the boost switch is the MOSFET ZCS boost PFC topologies offer much better silicon utilization than the ZVS topologies. The design of the high-performance boost PFC converter can be simplified if the SiC boost rectifier is used instead of a fast-recovery rectifier. Since SiC rectifiers virtually do not exhibit reverse-recovery characteristic, no active snubber circuit is necessary as long as the switching frequency of the converter is not too high so that the switching losses of the boost switch start limiting the efficiency. Because the SiC technology makes it possible to significantly increase the switching frequency of the boost PFC circuits with a minimal degradation of the efficiency, the size of the boost inductor can also be significantly reduced. Further improvement of the efficiency can be obtained with the bridgeless boost PFC topology which minimizes the conduction losses by eliminating the line-voltage bridge rectifier. The bridgeless boost PFC converter implemented with SiC rectifiers and DSP control may become the mainstream telecom technology for the next generation of high-performance converters. Table-2 shows comparison of performance of various single phase telecom topologies.

**Table 2.** Comparison of performance of various single phase telecom topologies

| | Traditional Two- Stage | Isolated Buck Boost | Passive Input Filtering | Shunt Regulator | Harmonic Reducer | Active Filtering | Multi level boost | Soft Switched PFC | Resonant PFC | Single-Stage | Bi Directional ZVS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **PFC** | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 |
| **I-THD %** | < 5 | >5 | >5 | >5 | <5 | >5 | <5 | <5 | <5 | >5 | >5 |
| **Control** | complex | simple | simple | complex | complex | complex | complex | complex | complex | complex | complex |
| **Efficiency** | 90 | 95 | 92 | 90 | 90 | 90 | 90 | 93 | 95 | 90 | 90 |
| **Power(kw)** | <6 | <0.2 | <6 | <6 | <6 | <6 | <6 | <6 | <0.2 | <0.2 | <0.2 |
| **Chokes** | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 |
| **Switches** | 5 | 1 | 4 | 4 | 6 | 8 | 6 | 6 | 4 | 1 | 2 |
| **Comments** | More components | Poor Utilization | Bulky input filters | Isolation required | Two quadrant | Four quadrant | More components | More components | HV stresses | HV stresses | Low losses |

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