Single-Phase Single-Stage Power-Factor-Corrected Converter Topologies

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***Abstract*—Single-phase single-stage power-factor-corrected converter topologies are reviewed in this paper. The topologies discussed in the paper are related to ac–dc and ac–ac converters that are classified on the basis of the frequency of the input ac source, the presence of a dc-link capacitor, and the type of control used (resonant or pulsewidth modulation). The general operating principles and strengths and weaknesses of the converters, which the authors have investigated over the last decade, are discussed in detail, and their suitability in practical applications is stated. Considering practical design constraints, it is possible to effectively employ many single-stage converter topologies in a wide range of applications.**

***Index Terms*—AC–AC converters, ac–dc converters, harmonic reduction, power-factor correction (PFC), power quality, single-stage converters, switch-mode power supplies.**

I. Introduction

It is generally the task of power electronics to convert the electric power available from a power source into the form best suited for user loads. Some sort of power converter is required to serve as an interface between power source and load to achieve this objective. The input power source for equipment handling less than 3 kW of power is usually a single-phase ac source. The converter itself may be an ac–dc or an ac–ac converter, with or without transformer isolation, depending on the requirements of the load.

It was very common in the past to use a simple, single-phase diode bridge rectifier with a capacitive output filter as the first stage of the converter as is shown in Fig. 1. The diode bridge rectifies the ac input voltage and the capacitor smoothes out the resulting voltage to make it an almost pure dc waveform. The current drawn from the ac utility source, however, is very nonsinusoidal because the bridge diodes conduct current only when the rectified input voltage is equal to or greater than the dc capacitor voltage. It is only then that current flows to charge the capacitor.

For any electrical equipment drawing power from the utility, the input power factor is an indication how effectively this is accomplished. The diode bridge rectifier shown in Fig. 1 has a poor power factor because of the nonsinusoidal current it draws from the utility. This current has a very high peak and contains large harmonic components that are injected into the utility supply. If vast numbers of such converters were to be used in industry, the harmonics that would be injected in the utility would be so large that they would create a need for increased volt-ampere ratings of utility equipment (i.e., transformers, transmission lines, and generators) and distort the utility voltage. Since a severely distorted ac utility voltage can damage sensitive electrical equipment, regulatory agencies around the world have established standards on the current harmonic content produced by electrical equipment, such as EN61000-3-2 [1]. The significant rise in the use of electrical equipment in recent years due to increased consumer demand has made the inefficient use of power less tolerable than in the past.

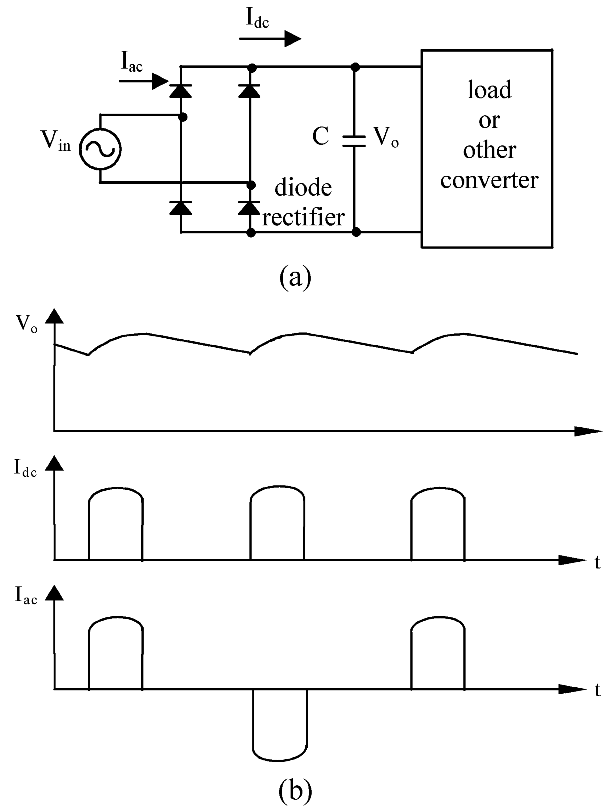

Fig. 1. (a) Single-phase diode bridge rectifier with capacitive output filter. (b) Diode bridge rectifier output voltage, output current, and input current waveforms.

Stricter regulatory agency standards on harmonic content have led to the demise in popularity of the simple diode-bridge rectifier as the front-end converter in electrical equipment operating off of an ac supply. More and more, electrical equipment manufacturers are being forced to improve or "correct" the input power factor of products supplied by an ac utility source.

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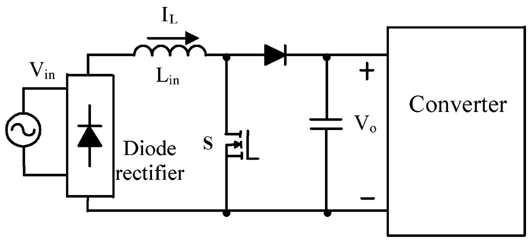

Fig. 2. AC–DC PWM boost converter.

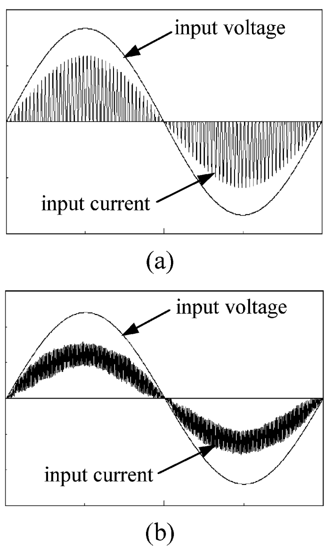

Fig. 3. AC–DC boost PFC converter input current waveforms. (a) Discontinuous current. (b) Continuous current.

The most common approach to power factor correction (PFC) in a front-end ac–dc converter is to use an active, pulsewidth-modulated (PWM) ac–dc boost converter, which is shown in Fig. 2 along with some typical input current waveforms in Fig. 3. The converter can produce input current waveforms that are either continuous and sinusoidal with some ripple, or discontinuous and bounded by a sinusoidal envelope with substantially more ripple. The current in both cases is effectively sinusoidal.

Although an excellent input power factor can be achieved by using an ac–dc PWM boost converter as the front-end converter in an overall two-stage ac–dc or ac–ac converter, the overall converter becomes more expensive and complicated than it would be if a diode-bride rectifier were used instead. This is because there are two separate switching converter stages present, each requiring a separate controller. In order to reduce the cost and complexity of the overall converter, yet operate with a power factor better than that produced by a converter with a front-end ac–dc diode-bridge rectifier, power electronics researchers have proposed converters that combine the PFC and power conversion functions in a single converter.

Single-stage power conversion is a topic that has been of substantial interest to power electronics researchers in recent years, and numerous converters have been proposed. These converters can generally be classified according to the diagram shown in Fig. 4. In this paper, a number of single-stage converters will be reviewed according to this classification. The issues associated for each converter type will be discussed and various approaches for PFC will be examined. The focus of the paper will be placed on single-stage converters that the authors have investigated over the past decade. The key points of the paper will be summarized at the end.

II. Converters Operating With a Low-Frequency AC Source and Without a DC-Link Capacitor

An ac source can produce an ac voltage with low frequency such as the standard 50/60-Hz utility voltage frequency, or an ac voltage with high frequency such as 100 kHz. In both cases, the most efficient utilization of power will occur when the current flowing out of the source is sinusoidal and in phase with the source voltage. Given the nature of the two types of sources, however, techniques that are appropriate for one type of source are not appropriate for the other.

According to the classification diagram shown in Fig. 4, single-stage converters operating with a low frequency ac source can be further divided into two types—converters with very small or no dc-link capacitor and converters with a large dc-link capacitor. Converters of the first type generally have the output of a front-end diode bridge rectifier fed directly into the input of a converter, but the diode rectifier does not have a large capacitive output filter. Since this capacitor does not exist, current can flow from the input source to the converter throughout the line cycle instead of being restricted to flowing only during the limited portion of the cycle when the input voltage is greater than the capacitor voltage, as is the case with the converter shown in Fig. 1. Without a large capacitor placed at the diode bridge output, the single converter can be made to operate in a way that shapes the input current so that an excellent input power factor can be achieved. Moreover, the absence of a large dc-link capacitor also reduces the size and weight of the converter.

In this section of the paper, three types of single-stage converters without a dc-link capacitor are examined—resonant ac–dc converters, PWM ac–dc converters, and ac–ac converters that produce a low-frequency ac waveform. For each converter type, the key issues concerning converter operation are discussed and example converters are presented.

A. AC–DC Converters

1) Resonant Converters: A converter must draw a sinusoidal current from the source that is in phase with the input ac voltage if it is to be operated with unity input power factor. The converter must therefore be heavily loaded near the peak of the input line and lightly loaded near the zero. Parallel and series-parallel resonant converters, such as the one proposed in [2] and shown in Fig. 5, can operate with high input power factor and constant output voltage because they can be made to have a high voltage gain under light-load conditions and a lower gain at full load. The voltage gain depends on the ratio between the switching frequency and the resonant frequency. It was demonstrated in [2] that it is possible to make a resonant converter operate with unity input power factor by adjusting the switching frequency along the input line cycle. Moreover,

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