

# A Simple Control Strategy Technique for a Single-phase Bridgeless Active Rectifier with High Power Factor and Voltage Stabilization Using Partial Digital Implementation

Rahul Ganpat Mapari and D.G. Wakde

**Abstract** A partial digital implementation approach to improve the power factor of single-phase rectifiers and to regulate the output voltage against the change in line voltage and load is presented in this paper. A two-leg configuration, which has single IGBT in each leg, is adopted to reduce the number of switching devices compared with conventional AC–DC converter. This converter topology is evaluated on the basis of performance, and its salient features such as simplicity, low cost, and high performance are discussed to analyze its applicability. The proposed control strategy using continuous switching pulse width modulation (CSPWM) is bridgeless and transformer-less. A control technique and operational procedure are also developed, both theoretically and experimentally. The experimental results clearly verify the theoretical analysis from the prototype connected to grid unity.

**Keywords** Active rectifier (AC–DC) · Boost rectifiers · Continuous switching pulse width modulation (CSPWM) · Power factor · Single phase · Voltage regulation

## 1 Introduction

In this paper, a proposed approach to improve the power factor of single-phase rectifiers and to regulate the output voltage against the change in grid voltage and load is presented. This converter topology is evaluated on the basis of performance, and its salient features such as simplicity, low cost, and high performance are

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discussed to analyze its applicability. The proposed control strategy is bridgeless, transformer-less, and output current sensor-less and consists of only two bi-directional IGBTs and two diodes. The voltage regulation is achieved by a simple voltage divider to communicate to a controller to control the duty cycles of PWM. A control technique and operational procedure are also developed, both theoretically and experimentally. The experimental results clearly verify the theoretical analysis from the prototype connected to grid unity.

The single-switch rectifier has one of the simplest circuit structures. Typical voltage and current waveforms for the circuit, using hysteresis current control, are represented in [5–7]. Hysteresis band is made large in the figure for illustrative purposes. The two-switch rectifier [8, 9] performs the same switching action as the single-switch rectifier but has the advantage of higher efficiency.

Conventionally, AC–DC converters, which are also called rectifiers, are developed using diodes and thyristors to provide controlled and uncontrolled DC power with unidirectional and bi-directional power flow [10]. They have the demerits of poor power quality in terms of injected current harmonics, caused voltage distortion, and poor power factor at input AC mains and slow varying rippled DC output at load end, low efficiency, and large size of AC and DC filters [11]. The simplest line-commutated converters use diodes to transform the electrical energy from AC to DC. The use of thyristors allows for the control of energy flow. The main disadvantage of these naturally commutated converters is the generation of harmonics and reactive power.

Vienna rectifier is a three-switch, unity power factor boost rectifier. This rectifier operates by having the input stage creating a DC voltage across the two switches connected to the primary transformer [12–14]. The Vienna rectifier, even though it operates with only three switches, endures higher stresses than that of six-switch converter. This type of converter, however, has issues with start-up over current, as well as lack of current limiting during overload conditions.

Generally, the control structure of a three-phase six-switch PWM boost converter consists of an inner current control loop and outer voltage control loop [15]. The current controller senses the input current and compares it with a sinusoidal current reference. To obtain the current reference, the phase information of the utility voltage or current is required. This information is obtained by employing a phase lock loop (PLL), which creates transients if the frequency ratio changes [16]. To simplify the control structure, one-cycle-control (OCC)-based AC-to-DC converter has been proposed [17–19]. However, the scheme based on OCC exhibits instability in operation when magnitude of the load current falls below a certain level or when the converter is operating in the inverting mode of operation. To avoid it a modified OCC, bi-directional high-power factor AC-to-DC converter is proposed in [20]. This scheme uses saw-tooth wave to generate PWM pulses which incorporate low-frequency harmonics [21].

OCC presents some drawbacks intrinsic with its physical realization: the controller and its parameters cannot be modified without hardware re-design; moreover, they are influenced by temperature drifts, typical of analog systems. Another disadvantage is the need of both voltage and current measurements [22]. To overcome

these limitations, the OCC technique is implemented digitally using field programmable gate array (FPGA) [23]. This system uses PLL to find phase information of utility voltage and current. Another drawback of this system is that controller takes integer numbers only. The split operation is limited only to dividing number by a power of two.

This paper presents a simple control strategy which removes most of the drawbacks present in the classical methods for a single-phase active rectifier consists of only two bi-directional switches and two diodes. The grid voltage is directly delivered to the switches without using bridge and transformer.

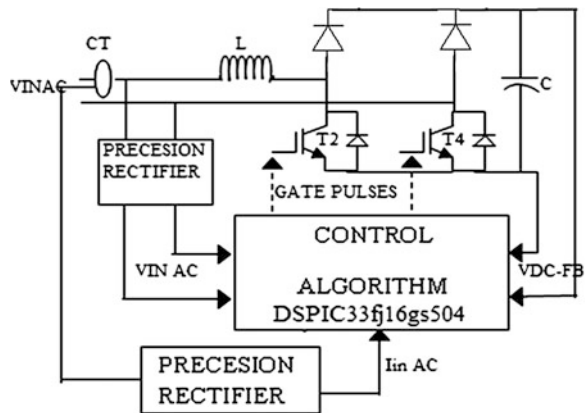
The use of bridge and transformer created losses which reduces the efficiency of total system. Also in most of the paper, output voltage regulation is achieved using output current sensor; in this prototype without using current sensor, results are achieved. The prototype model is validating for 0.1, 0.3, 0.5, 0.7, and 1 kW experimentally. The voltage regulation is achieved for 250 VDC output voltage.

## 2 Circuit Configuration

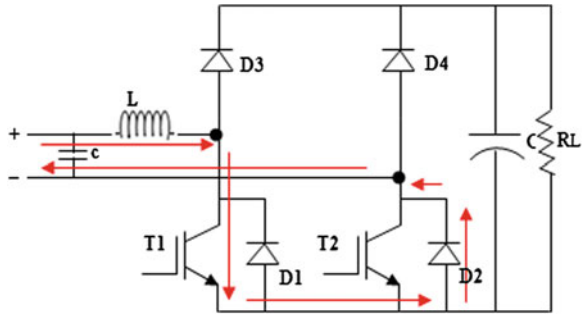
The circuit shown in Fig. 1 consists of a prototype AC–DC converter with two bi-directional switches and two diodes. The bi-directional switches are connected at the lower side of the legs.

It is assumed that the anode-to-cathode voltage of each diode of the rectifier as well as the voltage drop through bi-directional switches is of negligible quantity. Figure 2 shows the waveforms of the considered power circuit. The bi-directional switches,  $T1$  and  $T2$ , are turned on at an appropriate interval, conducting a partial line current. As a result, the input voltages,  $V_{Ao}$ ,  $V_{Bo}$ —the voltages between each input terminal ( $A$ ,  $B$ ) and the zero point of the main source—become the staircase waveforms, and the input current waveforms become similar to the sinusoidal input voltages; in this case, it is clear that the power factor is improved.

**Fig. 1** Circuit of prototype AC–DC converter with two bi-directional switches



**Fig. 2** Configuration of PFC technique when  $T1$  is ON



The characteristics of the rectifier can be controlled by adjusting the duty cycle  $D$ , where  $D$  is a constant value between 0 and 1 which determines the pulse width for  $Q1$  and  $Q2$ . The phase angle between the supply voltage and the fundamental component of the rectifier input voltage is also controlled by the duty ratio. Therefore, we can improve the characteristics of the considered rectifier by selecting a suitable  $D$  and the phase angle.

### 3 Operation Sequence

Based on line frequency, period of each half cycle of line voltage is 10 ms. To achieve more accurate results and high switching frequency, each half cycle is divided into 200 parts. Each part is of  $50\text{-}\mu\text{s}$  period. Four different configurations describing the sequence of operation to achieve high power factor and regulating the output voltage are as follows.

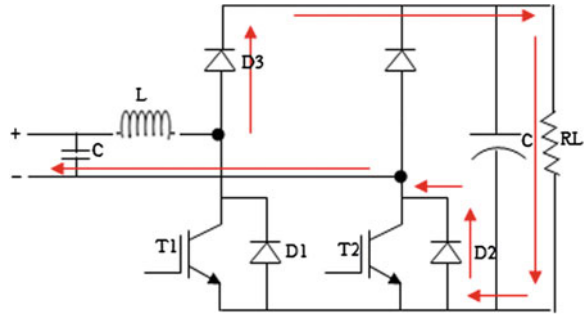
#### 3.1 Case 1: Positive Half Cycle, $T1$ is ON

When  $T1$  switch is turned on, the configuration is shown in Fig. 2. In this case, during the ON period of 200 parts, current  $IL$  is flowing through the inductor to charge it. The voltage across the inductor ( $Ldi/dt$ ) is less than the DC output voltage.

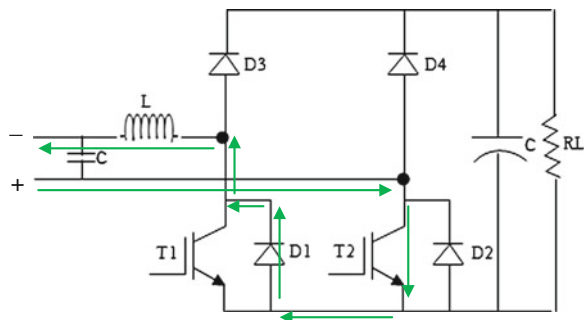
#### 3.2 Case 2: Positive Half Cycle, $T1$ is OFF

The configuration is shown in Fig. 3. During the OFF period of 200 parts,  $T1$  is turned OFF. Maximum peak voltage across the inductor is greater than the DC output voltage. This voltage is moved toward the load through diode  $D3$ . The inductor acts as a boost inductor.

**Fig. 3** Configuration of PFC technique when  $T1$  is OFF



**Fig. 4** Configuration of PFC technique when  $T2$  is ON



### 3.3 Case 3: Negative Half Cycle, $T2$ is ON

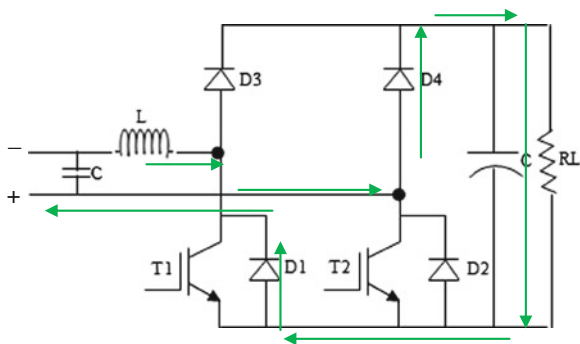
When  $T2$  switch is turned on and  $T1$  is turned OFF, the configuration is shown in Fig. 4. In this case, during the ON period of 200 parts, current  $I$  is flowing from positive terminal through switch  $T2$  toward the inductor to charge it. The voltage across the inductor ( $Ldi/dt$ ) is less than the DC output voltage.

### 3.4 Case 4: Negative Half Cycle, $T2$ is OFF

The configuration is shown in Fig. 5. During the OFF period of 200 parts,  $T2$  is turned OFF. Maximum peak voltage across the inductor is greater than the DC output voltage. This voltage is move toward the load through diode  $D4$ . The inductor acts as a boost inductor.

The output DC voltage is controlled using a continuous switching digital technique. By taking the feedback of actual DC output voltage, the controller takes the action to regulate it. Here, we perform a simple program to adjust the duty ratio  $D$  according to the actual DC voltage. The DSPIC33fj16gs504 controller is used to generate the switching signals. A 10-bit ADC is used; hence, total count is 1,024.

**Fig. 5** Configuration of PFC technique when  $T2$  is OFF



For the safe margin, we consider it is 70 % as 700. The regulated voltage we consider is 200 V. The threshold of 10 V is provided. The feedback voltage VDCFB can be mathematically represented as,

$$VDCFB = \frac{\text{ADC result count}}{\text{ADC full scale count}} \times 500 \quad (1)$$

The duty ratio  $D$  is directly proportional to the VDCFB. The ON time of the duty cycle is scaled by VDCFB factor.

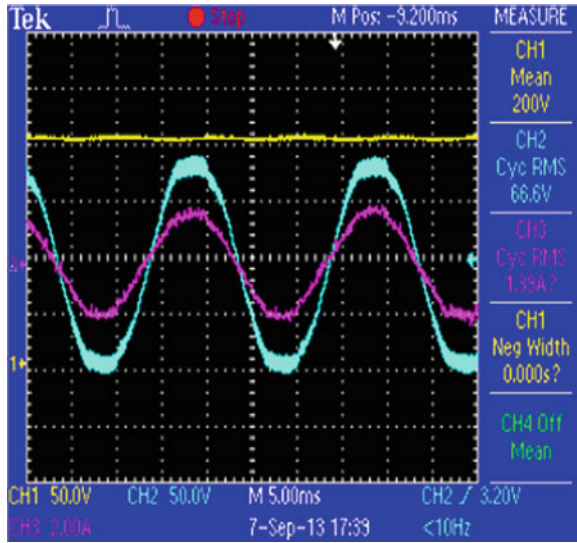
$$T_{ON} = K \times D \quad (2)$$

According to the ZCD status (positive or negative half cycle), controller decides switching of IGBTs. By default, duty cycle is 10 %. As per VDCFB, the duty cycle increases step by step in each 50  $\mu$ s to achieve desired VDC.

## 4 Experimental Results

The following are details of the experimental laboratory prototype: The rated output power ( $P_{out}$ ) = 1 kW,  $V_{rms}$  = 90 V,  $L$  = 2 mH,  $C$  = 440  $\mu$ F, and utility grid frequency  $f$  = 50 Hz.

**Fig. 6** The input voltage  $V_s$  and current waveforms  $I_s$



### 4.1 Input Power Factor and Current Waveforms

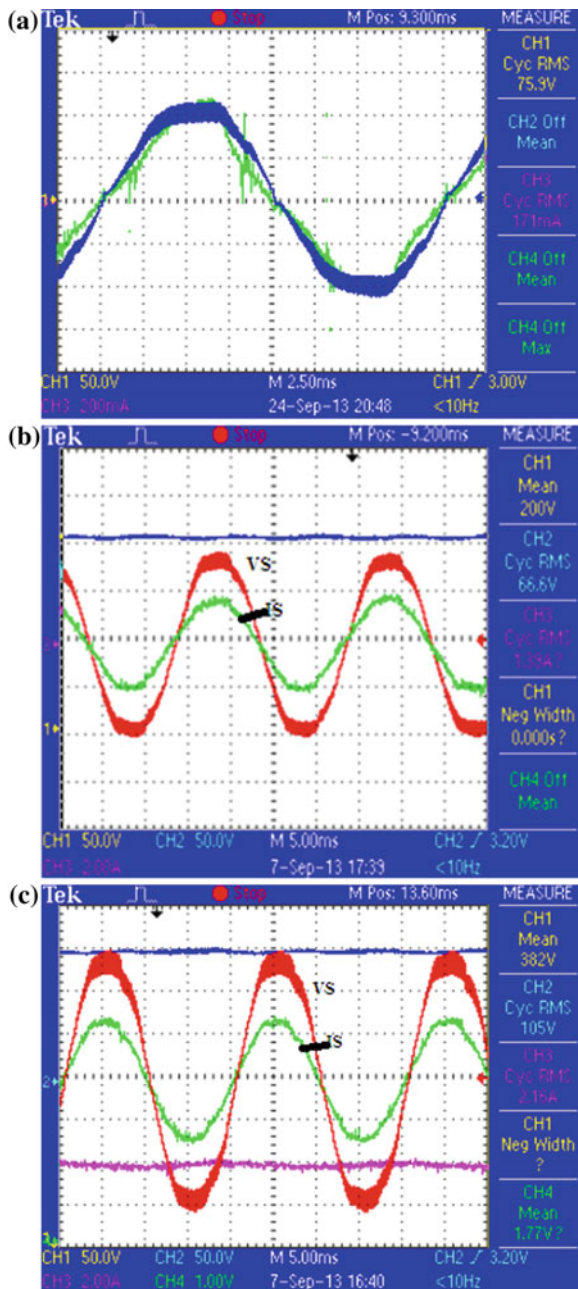
The prototype is implemented at different levels of loads 0.2, 0.4, 0.7, and 1.0 kW. In Fig. 6, the input current is and the input voltage  $V_s$  is depicted. Notice that the experimental waveforms are similar to the ones obtained with the simulation.

Figure 7 shows that the line current is becoming a more sinusoidal, and it follows the line voltage at any load. Figure 8 describes the power factor remains approximately same for all loads.

### 4.2 Regulating the Output Voltage at Load Variance

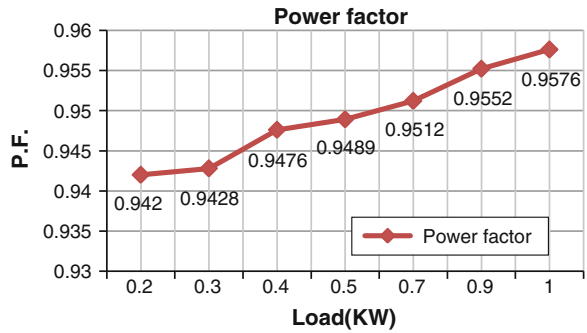
The proposed control method keeps the output voltage stable even though the load is suddenly changed to different levels during operation. This is evaluated by the settling time in Fig. 9, where the settling time at the load variance from 100 to 300 W is approximately 55 ms. The experimental results illustrate that the proposed approach has been accurately analyzed with respect to efficiency and stability.

**Fig. 7** The input voltage  $V_s$  and current waveforms  $I_s$  with different loads, **a** 400 W, **b** 700 W, **c** 1,000 W

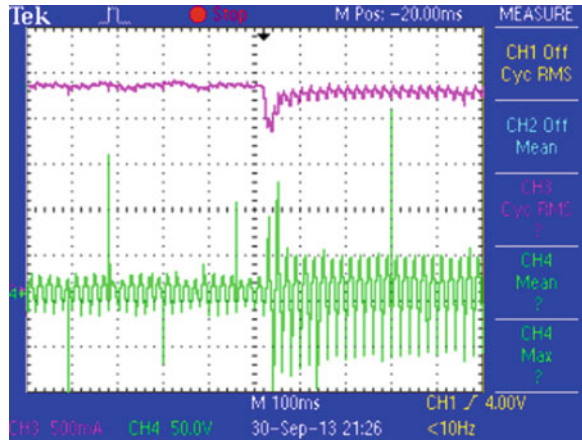




**Fig. 8** Theoretical results of power factor versus load



**Fig. 9** Step load changes from 100 to 300 W, upper part is DC voltage and lower part is source current



## 5 Conclusion

In this paper, a proposed approach to improve the power factor of single-phase rectifiers and to regulate the output voltage is presented. The proposed control strategy is bridgeless, transformer-less, and output current sensor-less, and consists of only two bi-directional IGBTs and two diodes. As a result, the proposed control method is able to improve the power factor of the single-phase rectifier connected with grid unity, increase the quality of the harmonics of the input current, and stabilize the output voltage.

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