Abstract- This paper presents a new current control method for three phase pulse width modulation rectifiers using single dc current sensor. Conventional three-phase PFC control requires sensing of at least two input phase currents. The proposed current control method solves the problems of conventional methods by controlling a three phase PWM rectifier using only the dc-rail current as the feedback signal. The speed of a DC motor can be controlled by varying the duty cycle of the switches. The control circuit can be implemented using a DSPIC30F2010 controller which improves the power factor and reduces the harmonic distortion. Finally the circuit can be tested by driving a DC motor.

Keywords-Current sensing, nonlinear current control, power factor correction, PWM rectifiers.

I. INTRODUCTION

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows only in one direction. The process is known as rectification. Active power factor correction (PFC) is an effective means for dealing with equipment harmonic distortion problems.

This paper presents a new current control method for three phase PFC converters that directly uses the dc-rail current measurement as feedback for input current control. It provides an effective PFC control method for low-cost applications by avoiding the use of bulky phase current sensors or complicated current estimation algorithms.

II. TRADITIONAL CURRENT CONTROL METHODS

Various current control methods for three-phase PFC converters have been reported. One of the methods is direct linear phase current control, which treats three phase currents as independent variables and uses one linear current controller for each phase [1]. The steady state tracking error and leading phase of the current inherent in this method can be eliminated by control in the dq reference frame [2]. The transformation between abc and dq reference frames, however, necessitates the use of high-speed digital control devices, particularly in high-switching frequency designs. Nonlinear current control methods, such as one-cycle control, can help to overcome the control bandwidth limitation of linear feedback control and have been generalized to three-phase PFC converters using dual-phase control [3]. One general problem of dual-phase current control is the harmonic distortion around the sector transition points of the input voltages where the inputs to the current compensator become discontinuous. This is fortunately not a problem for one cycle control because of its small integration time constant and the periodic reset of integrator. On the other hand one cycle control as reported in the literature regulates the peak of the input current, hence it may suffer from high-input current harmonic distortion under light load conditions, or in general when the current ripple is large. Almost all existing three-phase PFC control methods require sensing of the input currents, which typically requires three current sensing transformers. Such sensing transformers not only increase the size but also complicate the design of the control circuit. To avoid the use of such current sensing transformers, various algorithms have been proposed [4]-[8] to reconstruct the phase currents from dc-rail current. The current reconstruction is based on pulse width modulation (PWM) control signals of the switches in each switching cycle, and the reconstructed current signals are used as feedback for control in the following switching cycle. One principal difficulty with such reconstruction or state estimation approach is that the dc-rail current consists of more than one phase currents in some intervals such that individual phase currents cannot be directly extracted. It also introduces a one cycle delay in the control loop, because the reconstructed input currents are not available until the next switching cycle. The proposed scheme minimizes the complexities associated with the traditional methods by directly sensing a dc rail current which is the combination of various input phase currents. The power factor can be corrected by varying the duty ratio of the switches. Finally the circuit can be tested on a dc motor; the speed of the motor is boosted as the duty ratio is increased.
III. BLOCK DIAGRAM AND ITS EXPLANATION

The block diagram of proposed system is shown in figure 1. It is powered from a three phase supply system where each phase conducts for a period of 120°.

The input three-phase supply contains the harmonics which are eliminated by the boost inductors present at the input. Three phase PWM rectifier block which consists of 6 MOSFET switches, each switch conducts for a period of 60°. At the input three voltage sensors are used \( V_r \), \( V_y \), and \( V_b \) sensor in order to sense the three phase voltages. In order to provide isolation between controller circuit and the converter a gate drive circuit is used, which also provide the gate pulses to the six MOSFET switches. These pulses varies as switching action is performed, indicating the variation of duty cycle. The controller DSPIC30F2010 is used to generate the PWM pulses. Finally the circuit is tested by driving a DC motor.

IV. ANALYSIS

Fig 2 shows the circuit diagram of three-phase PWM rectifier it consists of six MOSFET switches. When the switch \( S_{rp} \) is on the current flows through the switch charges the capacitor during the positive half cycle of the input voltage and flows through the anti-parallel diode of \( S_{bn} \) and returns to the input. Hence the switching action is performed the energy is supplied to the load that is real power is supplied to drive the load. When the switch \( S_{bp} \) is off during the negative half cycle of supply voltage the capacitor discharges and the energy stored in capacitor during previous cycle drives the load. In this manner different switches conducts and drives the energy to load. The sequence of operation of switches is \( S_{rp}, S_{mn}, S_{yp}, S_{pn}, S_{bp}, S_{yn} \). By operating the switches in the proper sequence the power factor and hence efficiency can be improved.

For the boost three-phase PFC converter, as shown in fig 4, the variable \( d_{ff} \) is the so-called feed forward duty ratio signal and is defined as:

\[
d_{ff} = 1 - \frac{V_m}{V_o}
\]  

or, when the voltage drop across the boost inductor cannot be ignored the equation can be written as:

\[
d_{ff} = 1 - \frac{1}{V_o} \left| V_m \right| - L \frac{d_i ref}{dt}
\]  

Phase converters operate the switches in only two phases at a time, while the third phase is not switched. The method works by dividing a line cycle into six sectors each spanning over a 60° interval, as defined in figure 3. In each sector, the two phases that have the smallest voltages (hence smallest currents under the assumption of unity power factor operation) are controlled; the third phase current is uncontrolled and flows to or from the dc link through the high or the lower side diode depending on the sector of operation.
ses do not conduct bp n be summarized by table 2, where “0” indicate OFF state of a switch and “1” indicate the on. F ig 6 depicts the responses of currents $i_r$, $i_b$, and $i_{dc}$ over a switching cycle in sector 1.

Fig 4: Boost three phase PFC converter

Fig 5 shows the equivalent circuit of a three-phase PFC converter working in Sector I, in which phase r and b are controlled. Only the lower side switches $S_{rn}$ and $S_{bn}$ are shown because, due to the direction of $i_r$ and $i_b$, the high-side switches in these two phases do not conduct current even when they are turned on; instead, the currents flow through their antiparallel diodes, which are shown on the top in Fig 2. Phase $y$ is uncontrolled in this sector. The lower side switch $S_{yn}$ can be left on, but because of its polarity, the current $i_y$ flows through the antiparallel diode of $S_{yn}$ all the time. Hence, only this diode is shown for phase $y$.

Note that each of the controlled phase currents ($i_r$ and $i_b$) is part of the dc rail current $i_{dc}$, whenever the corresponding lower side switch ($S_{rn}$ and $S_{bn}$) is off. With different combinations of the switch conduction states, the relationship between $i_{dc}$ and the phase currents in sector I can be summarized by table 2, where “0” indicates OFF state of a switch and “1” indicates the switch is on.

Table 2: dc-rail current relationship to the input currents

<table>
<thead>
<tr>
<th>$S_{m}$</th>
<th>$S_{b}$</th>
<th>$i_{dc}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>$i_r + i_b$</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>$i_b$</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>$i_r$</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Unity power factor operation requires that the average of each input current follows a reference that is proportional to the corresponding phase voltage:

$$\overline{i_r} = g_r V_r$$  (3)

$$\overline{i_b} = g_b V_b$$  (4)

Denoting the duty ratio of the three upper switches ($S_{rp}$, $S_{yp}$, $S_{bp}$) by $d_r,d_y,d_b$, respectively, and assuming that $d_y < d_b$, we have:

$$\frac{1}{T} \int_{0}^{d_y} dt = d_y \overline{i_r} + \overline{i_b}$$  (5)

$$\frac{1}{T} \int_{d_y}^{d_b} dt = (d_b - d_y) \overline{i_b} = (d_b - d_y) g_b V_b$$  (6)

Assuming that the switching cycle starts with the high side switches $S_{m}$ and $S_{b}$ of phase r and b being turned on. Fig 6 depicts the responses of currents $i_r$, $i_b$, and $i_{dc}$ over a switching cycle in sector I.

The “equation (7)" and “equation (8)" define the necessary conditions for unity power factor operation of the converter in Sector I.

V. CONTROLLER CIRCUIT.

The control circuit of the proposed scheme consists of a Digital signal controller DSPIC30F2010. The dsPIC DSC is the “heart” of a 16-bit MCU with robust peripherals and fast interrupt handling capability and the “brain” of a DSP that manages high computation activities, creating the optimum single-chip solution for embedded system designs. The DSPIC30F devices contain extensive Digital Signal Processor (DSP) functionality within high performance 16-bit microcontroller (MCU) architecture. It also consists of optocouplers for isolating the control and power circuits. In this work an optocouplers TLP250 is used to isolate the gate drive circuit and the MOSFET-based power circuit.
VI. EXPERIMENTAL SETUP AND RESULTS

The implementation of three-phase PWM rectifier is done successfully and the developed hardware is tested with a dc motor as a load. The proposed control system is implemented by a DSC (dsPIC30F2010). The device is programmed using MATLAB Integrated Development Environment (IDE) tool. The hardware set is developed and tested in power electronics laboratory and the photograph of complete setup is shown in fig 7. Experimental results are shown in table 3.

Table 3: Experimental results.

<table>
<thead>
<tr>
<th>V_in (V)</th>
<th>V_out (V)</th>
<th>D = (V_in/V_out)</th>
<th>D = T_on/(T_on+T_off)</th>
<th>RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>50V</td>
<td>58V</td>
<td>13%</td>
<td>13%</td>
<td>0900</td>
</tr>
<tr>
<td>55V</td>
<td>65V</td>
<td>16%</td>
<td>16%</td>
<td>1000</td>
</tr>
<tr>
<td>60V</td>
<td>77V</td>
<td>23%</td>
<td>23%</td>
<td>1200</td>
</tr>
</tbody>
</table>

By seeing the experimental results it can be seen that the output voltage increases with the input voltage, the duty cycle increases and varies proportionally with the input voltage, the RPM also varies and increases as the input voltage increases. Hence the speed of the motor can be controlled by varying the duty ratio.

Figure 8 shows the sensed dc rail current waveform with the help of a current sensor, it follows the input voltage, hence improving the power factor. Figure 9, 10, 11 shows the pulse showing the variation of duty cycle for different values of input voltages.

REFERENCES


