Microprocessor based power factor improvement for single phase controlled rectifiers using Symmetrical Angle Control

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Abstract :-

Power Electronics have proved itself as an encompassing field for power generation and management. Traditionally conversion of ac to dc voltages has been dominated by phase controlled or diode rectifiers. The non-ideal character of the input current drawn by these rectifiers creates number of problems like increase in reactive power, high input current harmonics and low input power factor, lower rectifier efficiency, large input voltage distortion etc. To compensate for the higher reactive power demand by the converters at high power transfer levels, power factor correction becomes mandatory. In addition to this industrial load on the power supplies being increased to reduce the power factor. A poor power factor is translated in heavy expenses to the user i.e. for the same power demand if the power factor is poor the system draws more current. There is a growing concern regarding pollution of the power distribution system. Adoption of the International Electrical Commission standard IEC 555-2 and IEEE-519-1992 has helped greatly in the awareness for clean ac line currents and a power factor close to unity. In this paper a high performance input power factor correction technique using Symmetrical Angle Control implemented and analyzed for single phase controlled converters. From simulation and experimental results obtained on a laboratory prototype it can be concluded that input power factor remains nearly unity for variations in the load.

Keywords :- power factor correction, Symmetrical Angle Control, controlled converters, power transistors.

I. Introduction

Traditionally conversion of ac to dc voltages has been dominated by phase controlled or diode rectifiers. The non-ideal character of the input current drawn by these rectifiers creates number of problems like increase in reactive power, high input current harmonics and low input power factor, lower rectifier efficiency, large input voltage distortion etc. To compensate for the higher reactive power demand by the converters at high power transfer levels, power factor correction becomes mandatory. To overcome these problems number of passive and active current wave shaping techniques [1-11] have been suggested in the literature. But the passive power factor correction techniques have the disadvantages like large size of reactive elements, power factor improvement for a narrow operating region, large output dc voltage ripple [1]. Active current wave shaping techniques overcome these disadvantages and significantly improve the performance of rectifiers. Hysteresis current control is a simple active current wave shaping technique that gives close to unity power factor operation while delivering near sinusoidal currents. But when applied for three-phase rectifiers requires three such identical stages of single-phase rectifiers [2]. Three-phase diode rectifiers using discontinuous conduction of rectifier current with a single boost switch gives close to unity power factor at constant turn-on time and frequency of the boost switch [3-4]. Current control method may use continuous conduction mode or discontinuous conduction mode. The phase-controlled mode of conduction with switch on rectifiers are hysteresis current control with constant hysteresis window, Bang bang hysteresis current control and constant switching frequency current control with error triangulation [5-7]. Discontinuous mode of conduction operates with constant switching frequency and variable turn-on time using one or two switches [8,9]. Several dedicated power factor controller integrated circuits such as Micrel ML4812 [10] and Unitrode UC2854 [11] are currently available. Zheren Lai [12] proposed family of constant switching frequency Pulse-Modulated controllers for power factor correction that uses continuous conduction mode. P. M. Patil proposed a method for single-phase to three-phase conversion using sinusoidal Pulse-Width-Modulation [13,14].

This paper is based on application of Symmetrical Angle Control (SAC) technique in order to improve the power factor. In this technique, the supply voltage pulse is placed symmetrical with respect...
Voltage peak and therefore the fundamental current is in phase with the supply voltage. This makes displacement factor unity and improves the power factor. The control circuit for SAC is based on microprocessor. The application gives an approximate relation by which a correction can be established between desired input fundamental current (hence power) and turn-on time (variable) of the control switch. In AC, the supply current pulse is placed symmetrically with respect to the supply voltage peak and therefore, the fundamental current is in phase with the supply voltage. This makes displacement factor unity and thus improves the power factor. Thus, criterion yields greater accuracy for single-phase since it has a freedom to vary the turn-on time.

The remainder of this paper is organized as follows: Section II provides some background concerning the SAC. Section III describes the implemented scheme (hardware and software) along with its design details. Section IV presents some simulation results. Section V compares various results. Section VI presents some results along with future issues that need to be addressed.

I. Symmetrical Angle Control (SAC)

The SAC Microprocessor control circuitry is for automatic operation of base pulses which are given some time delay so that output of the PC is not short circuited. Here the main transistor is the PC is turned on at $\alpha$ by giving sufficient current to it and turned off at $(\pi - \alpha)$. The current pulse is placed symmetrical with respect to supply voltage peak and therefore displacement factor is unity and improve the PF.

\[
\text{Power factor} = \frac{I_1}{I_s} \cos \phi_1
\]  
where,
\[
I_1 \text{ is the fundamental component of supply current,}
\]
\[
I_s \text{ is the rms value of the supply current,}
\]
\[
\phi_1 \text{ is the displacement angle between the supply voltage and } I_1.
\]

The rms value of supply current with SAC is given as,
\[
I_s = I_n \sqrt{1 - \frac{2\alpha}{\pi}}
\]

The supply current $i$ can be represented as
\[
i = \sqrt{2} I_n \sin(\omega t + \phi_n)
\]

where,
\[
I_n \text{ is the } n \text{th harmonic component of the supply current, whose value for SAC is given as,}
\]
\[
I_n = \frac{2\sqrt{2}}{n\pi} I_0 \cos n\alpha
\]

$\phi_n$ is the displacement angle between the supply voltage and $n$th harmonic component of current. Thus power factor and harmonic factor for SAC is given by,

\[
\text{Power factor} = \frac{2\sqrt{2} \cos \alpha}{\pi \sqrt{1 - \frac{2\alpha}{\pi}}}
\]

\[
\text{Harmonic Factor} = \frac{\pi(\pi - 2\alpha)}{8 \cos^2 \alpha} - 1
\]

III. Implemented Scheme

The supply current in a phase control drive is non-sinusoidal. This will affect the performance of the drive as far as the supply is concerned. The performance can be assessed in terms of Input power factor, Input displacement factor, and Harmonic Factor. Symmetrical angle control (AC Chopper) technique is used for improvement of power factor.

\[\Rightarrow \text{ Power Circuit}\]

Power circuit is realized by connecting the diodes in the bridge. The first bridge is for controlling the actions and second for freewheeling action. The diodes in the bridge are mainly to increase the power factor. The conducting sequence after diodes is as follows

1. In positive half cycle, conducting components are D1, Q1 & D4.
2. In positive freewheeling action, conducting components are D8, Q2 & D5.
3. In negative half cycle conduction components are D2, Q1 & D3.
4. In negative freewheeling action conducting components are D6, Q2 & D7.

Control Circuit
Operation of this circuit has the following steps
1. Step down transformer
2. Rectifier
3. Comparator circuit
4. Microprocessor
5. Opto Isolator
6. Driver circuit connected to base or gate of power switches in power circuit.

Better electrical utilization & efficiency can be achieved with use of power factor improvement system:
1. Reduction of electricity charges.
2. Reduction of load.
3. Reduced losses.
4. Increased machine performance.
5. Soft start action – It is used in AC motors where they require high starting current.
6. Closed loop system – It can provide a stable closed loop system in AC motor control by feeding its output voltage to be compared in place of regulated DC voltage.
7. To drive DC motor – It can also be used to drive DC motor by rectifying its output.

IV. Results and Discussion
The obtained results are shown in the Fig 3 to Fig 7 including the waveforms obtained in the control circuit at various test points.

For ½ hp AC motor load
Drive of 0.05 KW, 0.75 A cont.
α = 12.8°, V0 = 52 V, I0 = 0.14 A
By Fourier series analysis,
\[ a_0 = 0, \quad b_1 = 1.912 \times 10^{-1}, \]
\[ i_1 = 1.352 \times 10^{-1}, \]
For α = 12.8°, \[ \phi_1 = -0.023, \]
\[ \cos \phi_1 = 0.99, \]

For lamp load of 40 watts
\[ a_0 = 0, \quad b_1 = 1.912 \exp(-3), \]
\[ i_1 = 1.352 \exp(-3), \]
\[ \phi_1 = \tan^{-1}\left(\frac{a_0}{b_1}\right) = 0.023, \]
\[ \cos \phi_1 = 0.99, \]

V. Conclusions
In this paper application of SAC for single-phase controlled rectifiers is presented. Effect of the criterion is analyzed with variable ON time. The higher order harmonics can be easily filtered out with a suitable input filter. The criterion yields the following advantages.
1. Linear relation between reference and actual current.
2. Power factor is close to unity even at low output voltages.
3. Harmonics ratio with respect to fundamental remains almost constant at all load conditions.

The experimental results are found to be almost matching with the theoretical results. Further refinements in the results to make power factor exactly unity is the subject of future work.

References:


About the Author:

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