Power Factor Correction Rectifier for Computer Power Supply

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Abstract—In this paper, a power factor correction rectifier for computer power was proposed. The power factor correction rectifier is a system cascading in the front of computer power supply unit for improving the input current waveform distortion. The DC-DC boost converter was designed to operate as the switching rectifier in continuous conduction mode (CCM). To control an active switch of the rectifier for achieving low harmonic current distortion (THD) in the input current waveform, the switch duty ratios were performed by conventional power factor correction control method. This rectifier was designed for installing at the frontend of the power supply of computer. To verify the proposed rectifier, the circuit experimentation of 350W boost converter with the averaging switch current controller was applied. In the experimentation, the variation of load was done from 10% to full-load conditions. From the result, the input current waveform was shaped to be closely sinusoidal, implying low harmonic current (about 5% at full-load and not higher 15% in light load condition).

Keywords—Power factor correction converter, high power factor rectifiers, continuous conduction mode (CCM), PWM current control mode.

I. INTRODUCTION

As technology is advancing, electric power usage is moving from simple, non-electronic loads (tungsten lamps, motors, relays, resistive heaters, etc.) to electronic ones (fluorescent lamps with energy-efficient ballasts, motors with solid-state drivers, personal computers and home appliances) with more electronics in them. A power supply in instrumentation system has a function of converting AC voltage signal to DC standard signals. The AC voltage signal from the power utilities is rectified by a full bridge rectifier with large filtered capacitor output. The DC filtered output voltage of rectifier is regulated by DC-DC power switching converter to generate the DC standard signal. The construction of the power supply is shown in Fig.1. The electric current drawn by these new devices is typically different from that of the predecessors, and causes problems in overall capacity of the electric utilities. Modern power supplies are among the devices that have a characteristic of distorted input current. Quite different from resistive heaters, toasters and tungsten light bulbs, typical switching power supplies in personal computer draw input current in short pulses rather than in smooth sine waves. In order to deliver the same amount of power in short pulses, the current peaks are much higher. This puts more stress on wiring in the home or office, the circuit breakers, and even the generation and distribution equipment provided by the electric utilities.

Fig. 1 Conventional controller for high power factor rectifier

To minimize these stresses or harmonic currents and maximize the power handling capabilities of a switching power supply, circuitry can be added to improve the shape of the input current. Ideally, the input current should have a sine waveshape, and be in-phase with the input voltage. Boost converter called as PWM rectifier is one of the most popular choices for adding to input port of power supplies achieves harmonic current reduction. The converter is supplied from a full wave rectified line voltage and operated so that the input current follows the input voltage. The input current wave-shaping can be achieved using a number of techniques. When the converter is operated at fixed frequency and fixed duty ratio in the discontinuous conduction mode (DCM), the low frequency component of the input current is approximately proportional to the input voltage, so that the power is automatically close to one [1]. However, the DCM operation...
causes a large current stress on semiconductors and demands more effort to attenuate the current ripple so as to have a satisfactory low electromagnetic interference (EMI) to the line. Therefore, in medium and high power applications, the continuous conduction mode (CCM) is preferred because the current stress and current ripple become too large when operating the converter in the DCM. Traditionally, to operate the boost PFC converter in the CCM, the conventional controller [2] was applied as shown in Fig.1. The control circuit needs a multiplier, current sensor, and the input voltage sensor. The current reference is the rectified line voltage with its amplitude modulated by the modulation voltage, the output of the feedback compensator.

To apply this control to the power supply for computer in normally, the power supply have to be re-designed that means in available for only new system. For old systems that installed the power supply without power factor correction part, the harmonic current still generate and the harmonic problem on power line still is not be solved. Therefore, this paper, the power factor correction rectifier was designed for solving the harmonic current problem on the old power supply type. The proposed rectifier was designed to install in front of the old power supply as DC power supply.

![Fig. 2 Proposed system](image)

II. CONTROL IMPLEMENTATION

To design the operation of the control circuit of the proposed control, the operations of the system in Fig.1 in switch turned on mode and in switch turned off mode were considered. In the operation in switch turned on mode

\[ v_g(t) = L \frac{di_L(t)}{dt} \]

and in switch turned off mode,

\[ v_g(t) = L \frac{di_L(t)}{dt} + V_o \]

where \( v_g(t) \) is the input voltage, \( i_L(t) \) is the current though the inductor, and \( V_o \) is the output voltage. Define a quantity \( D \) as the average off-duty ratio of the switch in one switching period, then the input voltage is

\[ v_g(t) = L \frac{di_L(t)}{dt} + DV_o \]

where \( D = 0 \) for switch turned on mode, and \( 1 \) for switch turned off mode. For boost converter in the CCM operation, the average value of input voltage is

\[ V_g = V_o(1 - D) \quad \text{or} \quad V_{g,max} = \frac{\pi}{2} V_o(1 - D) \]  (4)

where \( D, V_g \) is the average value of on duty ratio and of the input voltage respectively and \( V_{g,max} \) is the maximum value of the input voltage.

From switch turned on mode, the current \( i_d(t) \), which flows through diode \( D \) and the inductor currents \( i_L(t) \) can be related as follows:

\[ i_d(t) = D' i_L(t) \]  (5)

Assuming that perfect sinusoidal current is drawn from the ac line, the quantity \( D' \) can be defined as

\[ D' = (P) \frac{V_{g,max} \sin \omega t - aLI_{L,max} \cos \omega t}{V_o} \]  (6)

where \( P \) is equal to 1 in the positive half cycle of the ac input voltage and \(-1\) in the other half cycle.

Combining equations (5) and (6), then, the average of the diode current \( I_d \) over a half cycle of the ac input voltage is found as

\[ I_d = \frac{V_{g,max} I_{L,max}}{2V_o} \]  (7)

Equations (4) and (7) yield

\[ I_d = \frac{\pi}{4}(1 - D)I_{L,max} \]  (8)

However,

\[ I_d \equiv \frac{V_o}{R} \]  (9)

Therefore, equations (4), (8) and (9) give

\[ I_{L,max} = \frac{4V_o}{R \pi (1 - D)} \]  (10)

Since the power circuit in Fig.1 is the full wave rectifier circuit, then we assume the input current \( i_d(t) \) as

\[ i_d(t) = I_{L,max} |\sin \omega t| \]  (11)

where \( I_{L,max} \) is the maximum value of the inductor current.

By combining equations (10), an (11), the new relation can be re-written as
\[ i_L(t) = \frac{4V_o}{R \pi (1 - D)} \sin \omega t \]  \hspace{1cm} (12)

or

\[ i_L(t) = \frac{2V_o}{RM_g} \sin \omega t \]  \hspace{1cm} (13)

where the conversion ratio \( M_g \) is

\[ M_g = \frac{V_{g,max}}{V_o} \]  \hspace{1cm} (14)

To determine the boundaries between CCM and DCM operations of the power circuit in Fig.1, firstly, the duty ratio must be determined. From the conversion ratio of boost converter in CCM operation in equation (3), the relation of \( |\sin \omega t| \) function and \( 1/(1-d(t)) \) function can be yielded as

\[ |\sin \omega t| = \frac{1 - d(t)}{M_g} \]  \hspace{1cm} (15)

Therefore, the duty ratio \( d(t) \) can be determined by

\[ d(t) = 1 - M_g |\sin \omega t| \]  \hspace{1cm} (16)

Equation (16) is used to make the plots of duty ratios at several values of the conversion ratio \( M_g \) and these plots are shown in Fig.3. Here, at the large value of \( M_g \), the maximum value of the duty ratio is low and it is not started from the zero value.

From Fig.5, the power circuit in Fig.1 will be operated in the DCM operation when

\[ \Delta t_1 < D' \]  \hspace{1cm} (17)

and operated in the CCM when

\[ \Delta t_1 \geq D' \]  \hspace{1cm} (18)

by the time interval \( \Delta t_1 \) is

\[ \Delta t_1 = \frac{2LI_o}{V_g D T_s} \]  \hspace{1cm} (19)

Then,

\[ K < K_{crit} \rightarrow \text{in DCM operation} \]
\[ K > K_{crit} \rightarrow \text{in CCM operation} \]  \hspace{1cm} (20)

where the load parameter \( K \) is defined as

\[ K = \frac{2L}{RT_s} \]  \hspace{1cm} (21)

and the boundary parameter \( K_{crit} \) is defined as

\[ K_{crit} = DD' \]  \hspace{1cm} (22)

From the waveforms in Fig.5, the relation of the inductor voltage \( v_L(t) \), the duty ratio \( d(t) \) and the time interval \( \Delta t \) in one switching period can be obtained as

\[ v_L(t) = L \frac{di_L(t)}{dt} = V_g D + (V_g - V_o) \Delta t \]  \hspace{1cm} (23)
The average value of the inductor voltage waveform is equal to zero. So,

\[ V_g D = (V_o - V_g) \Delta t \]  \hspace{1cm} (24)

then the time interval \( \Delta t \) can be yielded by

\[ \Delta t = \frac{V_g}{V_o - V_g} D \]  \hspace{1cm} (25)

By using the relation in equations (24) and (25), the relation of the inductor current can be obtained by

\[ i_L(t) = V_g \frac{T}{2L} D(D + \Delta t) \]  \hspace{1cm} (26)

or

\[ i_L(t) = V_g \frac{T}{2L} D^2 \frac{1}{(1 - \frac{V_g}{V_o})} \]  \hspace{1cm} (27)

Equation (27) is re-written as

\[ i_g(t) = V_o \sin \omega t \frac{T}{2L} d(t) \frac{1}{(1 - \frac{V_g}{V_o})} \]  \hspace{1cm} (28)

Equation (28) is used to plot the input current \( i_g(t) \) waveform at several values of the conversion \( M_g \) as shown in Fig.7. The shape of the input current waveform or the input current waveform distortion is depended on the value of the conversion ratio \( M_g \) of the converter. From the figure, the input current waveform distortion, we will design by selecting the value of \( M_g \) during 0.3 - 0.47.

![Fig.7 Theoretical plots of the normalized input current at several conversion ratio \( M_g \) values with ideal sine wave](image)

### III. EXPERIMENTAL RESULTS

To verify the proposed control method that uses to control the low harmonic currents boost pre-regulator, the circuit experimentation was applied by designing to meet the following specifications: the output power \( P_o = 350 \) W, the output voltage \( V_o = 440 \) V, the input voltage \( V_{g \text{rms}} = 220 \) V, the line frequency \( f = 50 \) Hz, the switching frequency \( f_s = 40 \) kHz, Inductance \( L = 2.5 \) mH, and the load resistance \( R \) at full load is equal to 500 \( \Omega \).

![Fig.8 Measured waveforms at full load: (Trace No.1) Input current waveform (1A/div, 10ms/div), (Trace No.2) Input voltage waveform (100V/div, 10ms/div), (Trace No.3) Output voltage waveform (100V/div, 10ms/div)](image)

![Fig.9 Current spectrum of the experimental input current waveform at full load](image)

Fig.8 shows the measured waveforms of input line voltage (trace no.2), input line current (trace no.3) and output voltage at full load (trace no.1). Fig.9 shows the current spectrum of the input current waveform in Fig.8. At full load, the input power factor is equal to 0.96 and the total harmonic distortion (THD) is equal to 10.11%.

### IV. CONCLUSION

Power factor correction rectifier for computer power supply was introduced and experimented. The switch duty ratio is determined by comparing a signal derived from the sensed inductor current with the input voltage waveform and its output is modulated with the sawtooth waveform for generating the gate drive signal. As result, input current is closely sinusoidal waveform, implying the input power factor is closely the unity. The total harmonic distortion THD is about 10% and the power factor is 0.96 at full load.

### REFERENCES
