

AC to DC Converter Power Factor Correction Using Current Controlled Pulse Width Modulation (C.C.P.W.M) Techniques

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Abstract—In any industry, current pulse width modulation (CPWM) converter plays a significant role due to its low cost and simplicity. In industrial set-up, where the concentration of nonlinear load is high, power factor correction is made possible with the use of CPWM converter since it helps to keep the injected harmonics below maximum tolerable level. Again, since it is possible at low speed because of its low frequency of operation, the harmonic content in inverter output voltage drive, for instance, has smooth low-speed operation, free from torque pulsations and cogging with lower derating of motor and higher efficiency. CPWM is made possible where under control line current is forced to track the line voltage, see figures 3.2 and 3.4 and this improves the power factor significantly to about 98%. Therefore, the main contribution of this paper is to proffer solution (use of CPWM converters) at where the concentration of nonlinear load is high and cannot be removed easily by any simple means e.g. use of unloaded synchronous motors, etc.

Index Terms— Converters, CPWM method, harmonic contents, power factor correction, nonlinear loads, thyristors.

1.0 INTRODUCTION

Power factor can be defined in any of the following ways:

- (a) Cosine of angle of lead or lag
- (b) $\frac{\text{Resistance}}{\text{Impedance}}$
- (c) $\frac{\text{True Power}}{\text{Apparent power}}$
- (d) $\frac{\text{KW}}{\text{KVA}}$ among others [1]

Power factor correction is a way of counteracting the undesirable effects of electric load that create a power factor less than unity [4]. Electric load in alternating current (a.c) is under the influence of the apparent power which consists of real power plus the reactive power [1]. Real power is the power consumed by the load, while the reactive power is the power repeatedly demanded by the load but is returned to the source, and it is the “cyclic effect” that occurs when alternating current passes across the load containing reactive components. Reactive power causes the real power to be less than the apparent powers and this causes the load power factors to be less than unity. Reactive power also causes large flow of current between the source and

the load and this results in power loss between transmission and distribution lines [1] & [9].

1.1 The Resultant Effects on Power Utility Companies and Consumers

Following from the power loss between transmission and distribution lines as a result of large flow of current caused by the reactive power, the result is huge operational and financial loss to power companies. The power companies now try to prevail on their costumers and/or consumers especially those with large electric loads to maintain their power factors above certain values (0.9 or more) or be subject to extra charges [1].

Again, electrical engineers involved in generation, transmission, distribution and consumption of electrical powers are interested in power factors because power factors affect efficiencies and costs for power companies and consumers.

Moreover, apart from operational costs, reactive power requires the use of wires, switches, circuit breakers, transformers and transmission lines of higher current capacities and these involve extra costs and money.

2.0 CURRENT-CONTROLLED PULSE WIDTH MODULATION (CCPWM) TECHNIQUES

Power factor corrections can be done in two distinct ways, viz: (i) power factor correction of linear load (ii) power factor correction of nonlinear load. Power factor correction in the first case is very simple and

can be done by switching in and out banks of inductors or capacitors to cancel the inductive and capacitive effects on the load. Nonlinear loads in the second method cannot be removed easily by any simple means and this calls for the use of CCPWM [2]. This method is more reliable and rugged. It is possible at low speed because of the low frequency of operation and can therefore eliminate torque pulsation at low speed. The volume and weight of

CCPWM drive inverter is much larger compared to voltage P.W.M drive inverter because of large commutation capacitor and large d.c link inductors involved [2]. Again, following from low harmonic content in the inverter output voltage, the drive has smooth low-speed operation, free from torque pulsations and cogging with lower derating of the motor and higher efficiency.

3.0 METHODOLOGY

Here a boost converter was subjected to constant switching process by switching on and off two diagonally opposite MOSFET key pairs. Boost converter was employed to realize this for the following simple reasons [3] & [9].

- (a) Continuous shape of the input current (no input filter capacitors required).
- (b) No danger of direct short-circuits of mains line-to-line voltage.

- (c) Direct voltage output and no output inductor required to enhance this.

- (d) Direct control of the mains current.

By closing the two MOSFET key pairs of the configured circuit of the boost converter, the circuit was analyzed for value of voltage and current. The resulting equations were solved in MATLAB using Runge-Kutta method. Figure 3.1 is the configured circuit 1 of the converter [9].

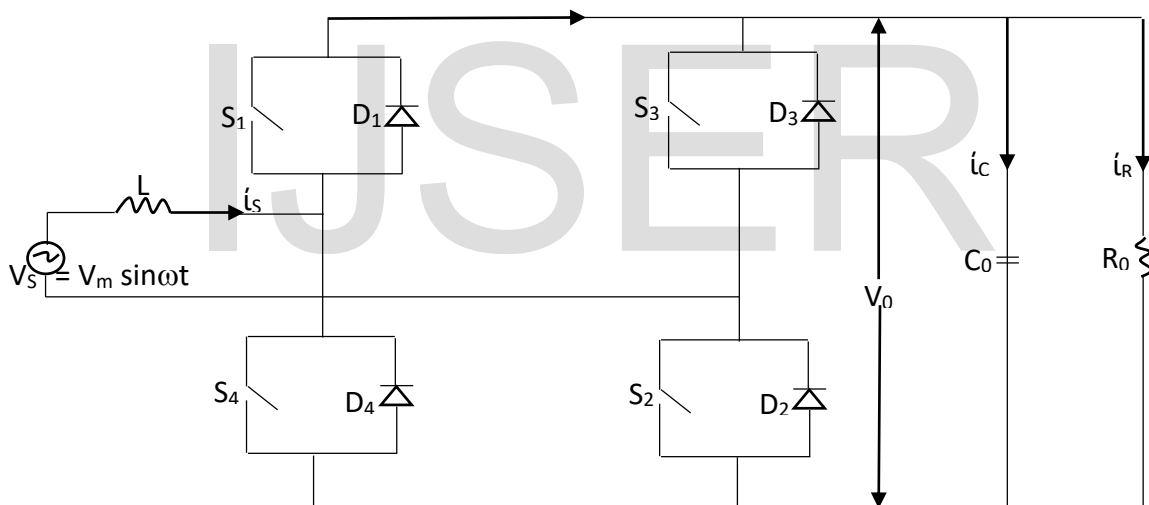


Fig. 3.1: Circuit 1

Analysis of Circuit 1

(a) S_1S_2 closed (current decreasing):

Current loop: $V_s \rightarrow L \rightarrow D_1 \rightarrow V_0 \rightarrow D_2 \rightarrow V_s$

Equation:

$$V_s - \frac{L di_s}{dt} - V_0 = 0$$

$$\frac{di_s}{dt} = \left(\frac{1}{L}\right) [V_s - V_0] = [V_m \sin \omega t - V_0]/L \quad 3.1$$

Again,

$$i_C = C_o \frac{dV_0}{dt}$$

$$i_R = \frac{V_0}{R}$$

$$i_s = i_C + i_R = C_o \frac{dV_0}{dt} + \frac{V_0}{R} = 0$$

$$i_s - C_o \frac{dV_0}{dt} - \frac{V_0}{R} = 0$$

$$\therefore \frac{dV_0}{dt} = \left[\frac{1}{C_o}\right] \left[i_s - \frac{V_0}{R}\right] \quad 3.2$$

(b) S_3S_4 closed (current increasing):

Current loop: $V_s \rightarrow L \rightarrow S_4 \rightarrow V_0 \rightarrow S_3 \rightarrow V_s$

Equation:

$$V_s - L \frac{di_s}{dt} + V_0 = 0$$

$$\frac{di_s}{dt} = (1/L) [V_s + V_0]$$

$$\frac{di_s}{dt} = [V_m \sin \omega t + V_0]/L \quad 3.3$$

Assumptions

For the MATLAB plot, assume $V_s = 220\sqrt{2}$, $\omega t = 2\pi ft$, switching period = 4KHz; assume a.c and d.c input power filters as $L = 5\text{mH}$, $C = 0.6\text{F}$ and load resistance $R = 20\Omega$. Equations 3.1, 3.2, 3.3 and 3.4 were solved in MATLAB using Runge-Kutta method. And the plot of the output voltage and current waveforms are shown in figure 3.2.

Again, $i_s = -i_c - i_R$ [current movement is anticlockwise when S_3S_4 were closed]

$$\text{Given } i_c = C_o \frac{dV_0}{dt} \text{ and } i_R = \frac{V_0}{R}$$

$$\therefore i_s = -C_o \frac{dV_0}{dt} - \frac{V_0}{R} + C_o \frac{dV_0}{dt} + \frac{V_0}{R} = 0$$

$$C_o \frac{dV_0}{dt} = -i_s - \frac{V_0}{R}$$

$$\therefore \frac{dV_0}{dt} = -[i_s + \frac{V_0}{R}]/C_o \quad 3.4$$

Note: What informed the choice of the above parameters is the nature of plots expected in this work. It is intended to control switch in such a way that a.c input current is in phase with a.c input voltage and is also almost sinusoidal. If this is not achieved after the plots, rechoose or assume new values.

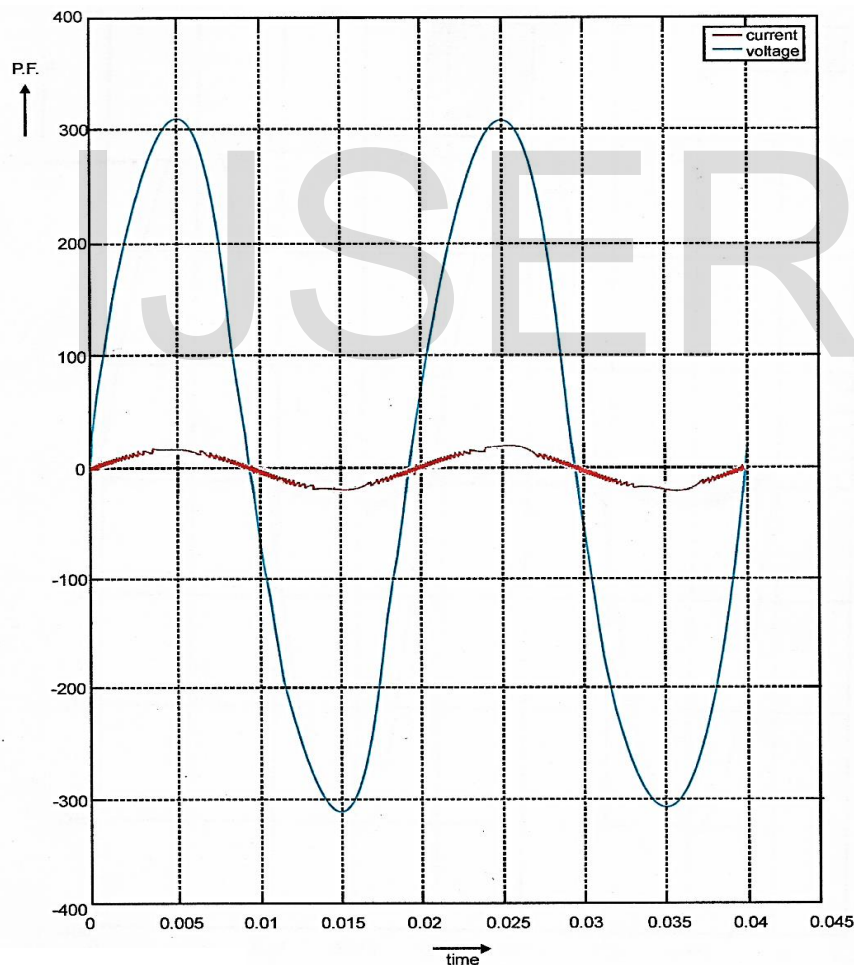


Fig. 3.2: Voltage and current waveforms for the first circuit with current tracking the voltage for a resistive

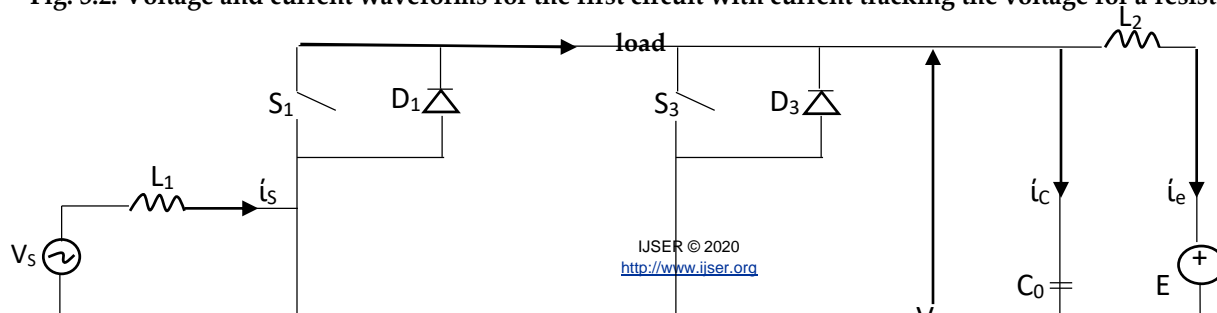


Fig. 3.3: Circuit 2

Analysis of Circuit 2

(a) S_1S_2 conducting:

Current loop: $V_s \rightarrow L_1 \rightarrow D_1 \rightarrow V_0 \rightarrow$

$D_2 \rightarrow V_s$

Equation:

$$V_s - L_1 \left(\frac{di_s}{dt} \right) - V_0 = 0$$

$$\Rightarrow \frac{di_s}{dt} = (V_s - V_0) / L_1 \quad 3.5$$

$$i_s = i_c + i_e$$

$$i_s = C \frac{dV_0}{dt} + i_e$$

$$\frac{dV_0}{dt} = (i_s - i_e) / C \quad 3.6$$

Again, for the 2nd loop:

$$V_0 - L_2 \frac{di_e}{dt} + E = 0$$

$$\frac{di_e}{dt} = (V_0 + E) / L_2 \quad 3.7$$

(b) S_3S_4 conducting:

Current loop: $V_s \rightarrow L_1 \rightarrow S_4 \rightarrow V_0 \rightarrow S_3 \rightarrow V_s$

Equation:

$$V_s - L_1 \frac{di_s}{dt} + V_0 = 0$$

$$\Rightarrow \frac{di_s}{dt} = [V_s + V_0] / L_1 \quad 3.8$$

$$i_s = -i_c - i_e$$

$$i_s = -C \frac{dV_0}{dt} - i_e$$

$$\frac{dV_0}{dt} = -(i_s + i_e) / C \quad 3.9$$

Again, for loop 2:

$$V_0 + L_2 \frac{di_e}{dt} + E = 0$$

$$\frac{di_e}{dt} = -(V_0 + E) / L_2 \quad 3.10$$

With the same assumptions as in circuit 1, equations 3.5, 3.6, 3.7, 3.8, 3.9 and 3.10 were solved in MATLAB using Runge-Kutta method [5]. The plots of the output voltage and current waveforms are shown in figure 3.4.

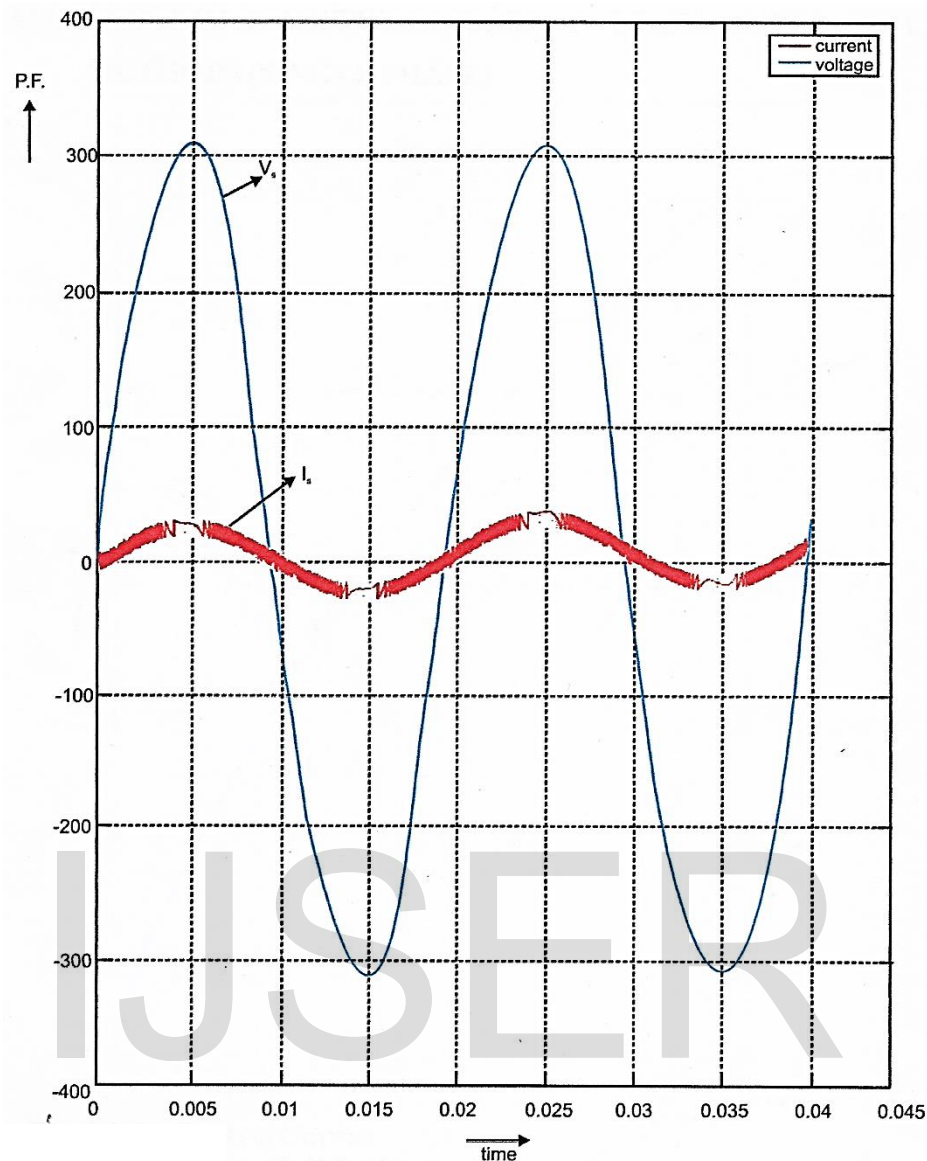


Fig. 3.4: Voltage and current waveforms for the second circuit with current tracking the voltage for a battery load

4.0 ANALYSIS RESULTS

Figures 3.2 and 3.4 showed that current has tracked the voltage for the resistive and battery loads respectively. This improved the system power factor significantly from 100% to about 98%. This has proffered a power factor correction solution for industrial areas where the concentration of nonlinear load is high and cannot be removed by any simple power factor correction methods like use of unloaded synchronous motors, etc. A high load power factor of 0.9 – 1.0 brings about an overall system balance and can enhance the following [3] & [9].:

- i. Improved voltage regulation

- ii. Enhanced transmission system efficiency.
- iii. Can eliminate current harmonic components in the system.

5.0 CONCLUSION

Since current is in phase with the voltage, resulting in a high-power factor (P.F) of about 98%, this method is used in locations where the concentration of nonlinear load is high, e.g. industrial areas. Again, since the circuits are unidirectional and have no inversion capability, they are capable of passing power in one direction only from the source to the load. When a discharged battery load for instance, is connected to the circuit, the d.c power charges the battery. Hence, the circuit acts as a battery charger.

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