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Power Factor Correction In Single Phase Buck Converters By PWM Control [PFC]

P. L. Gawade[1], A .N. Jadhav[2], T. B. Mohite-Patil[3]
1, 2, 3 D. Y. Patil College of Engineering and Technology, Kolhapur.

Abstract

Ac-dc and dc-dc power converters are used in Many applications like UPS, inverters etc.Overall efficiency in power converters depends on power factor, harmonic distortion and power components used in the converter.The rectifiers used for ac-dc conversion have drawbacks of pulsating input current, high harmonic content, low pf, low efficiency and large size of inductors and filters .Performance and efficiency of converters is increased by high pf and low line current distortion. This requirement is usually satisfied by incorporating some form of PFC circuits to shape the input phase currents. The conventional ac-dc converter bus voltage e is derived by using SCR firing angle scheme to control the output load (battery) voltage and current. These converters have a power factor of 0.6 to 0.7. To increase the power factor PFC converters have been developed by using PWM techniques. In this paper power factor correction technique for single phase buck converter is developed. A PWM IC 3525is used to achieve a power factor from 0.864 for 1/4th load to 0.95 at full load. A constant output voltage with 96% efficiency is obtained with PFC technique

1. Introduction

Supply of controlled Electric power is the heart of industry.Conversion efficiency and control techniques are the most important aspects of converters. The solid state ac-dc converters and dc – dc converters are used in uninterrupted power supplies (UPS), switch mode power supplies (SMPS), battery chargers, power supplies for telecommunication systems, and test equipments etc.[1]. The controlled output voltage is obtained by employing phase angle control technique. In these types of supplies ac mains current flows for the period of SCR conduction period only, which is not continuous as shown in Fig 01. The current flows for a short duration in the form of pulses. Many conventional switching power supplies in data processing equipment and low power motor drive systems are operated by rectifying the input ac line voltage and filtering with large electrolytic capacitors as shown in fig 02. The capacitor draws current in short pulses as shown in fig 03. This process results in the generation of harmonics in the line current. The power factor of such supplies is very poor like 0.6 to 0.7.[2] Thus power factor correction (PFC) is necessary for ac-to-dc converters in order to comply with the requirements of international standards, such as IEC 61000–3–2 and IEEE-519. [1]. PFC can reduce the harmonics in the line current, increase the efficiency and capacity of power systems. The Active Power Factor Correction (APFC) is a technique to improve the power factor near to unity, reduces harmonics distortion noticeably and automatically corrects the distorted line current. The PWM width supplied to the switching device depends both on the basic error voltage and the instantaneous value of the mains voltage. Minimizing power loss throughout the converter reduces heat dissipation. Replacing the IGBTs increases the efficiency to 95% at full load.[6]. Where possible, the lowest practical switching frequency should be used for best efficiency and lowest losses. The output bus voltage is probably the most important design parameter of the buck PFC, and is the starting point for a design. There is an inherent "cross-over" distortion in the AC line current when the buck PFC stage is reverse biased. But in many applications, this distortion can be made acceptable with adequate line-current THD and PF performance. Buck PFC design practicalities and challenges have been discussed in terms of power factor, power density, universal input, light load [7].

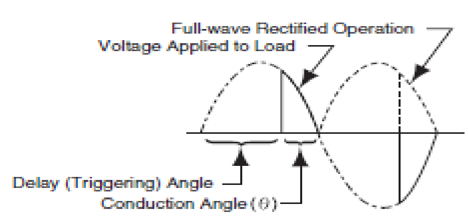

Fig 01: SCR firing in UPS Systems

The basic purpose of a Power Factor Correction circuit is to make the line current follow the waveform of the line voltage so that the input to the power supply becomes purely resistive and hence to improve the power factor. There are two types of correction techniques which are Passive PFC and Active PFC. Passive PFC uses components like inductor and capacitor. This method operates at low (50 or 60 Hz) line frequency so the components become bulky. Active PFC uses high frequency switching which is several times more than the line frequency. At high frequency passive components become smaller so the system becomes lighter. The basic converter topologies are Buck, Boost and Buck-Boost.

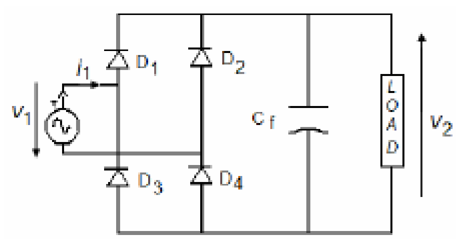

Fig.02- Diode bridge rectifier

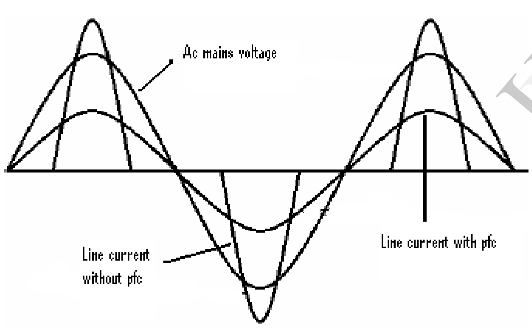

Fig. 03- Input line current of a typical switched-mode power supply with and without PFC

2. Proposed Buck converter

It is a voltage step down and current step up converter. It alternates between connecting the inductor to source voltage to store energy in the inductor and discharging the inductor into the load. The output voltage for buck converter is given by

$$V_o = D * V in;$$

Duty cycle D = V_o / V_{in}.

In this buck converter a PWM IC 3525 is used. The output error voltage from this op amp is used to control the set output load voltage. The load current is set to required value by using error output of the proportional integral controller. The sensed load current is dual amplified and given to integrator summer inverting pin of op amp4 same as voltage control loop. Reference voltage of rectified input line is used to start the PWM pulses at the starting of each cycle to keep the current in phase with input line voltage. Soft start circuit provides

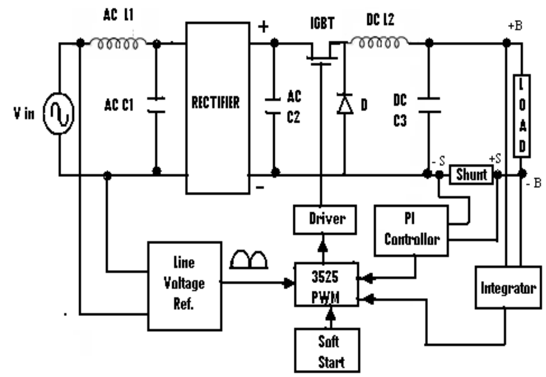

Fig.05 Block diagram of proposed PFC buck converter.

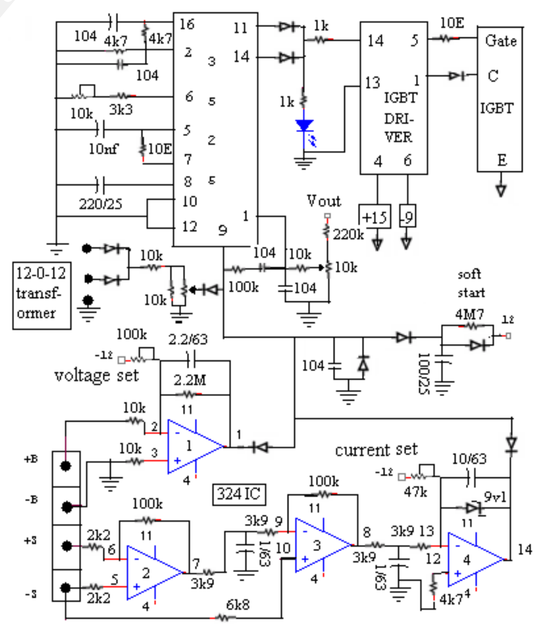

Fig 06. Circuit for PFC using IC 3525

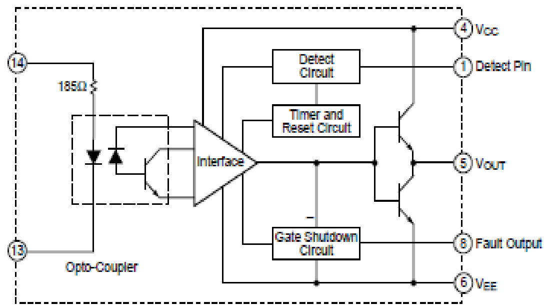

Fig 07. Block diagram of IGBT driver 57962

smooth start of PWM pulses at the starting of the converter to increase the output voltage from zero to set value in a slow and smoothly manner. The error voltages from different op amps have combine effect on PWM pulse width. The switching frequency used in this converter is 10 kHz. The Mitsubishi M57962L IGBT driver is used to drive the Mitsubishi IGBT. (TYPE CM100DU-12H). This converter can be used for higher load current ratings (up to 60-70 A) by using suitable external IGBT and other power circuit components as shown in fig 06. The block diagram of IGBT driver is as shown fig 07.

3. Design considerations

3.1 Design of L

$L= [(V_{in} - V_o) . (D/ F_{sw})] / I_{ripple}$

Where

V_{in} = Input Voltage
L = DC inductor.
V_o = Output Voltage
D = V_{in} / V_o
F_{sw} = Switching frequency.
I_{ripple} = 30% * I_{load} (typically).

3.2 Design of C

C3 = (ΔI · ΔT) / (ΔV - (ΔI · ESR))

Where

C3 = Output dc capacitor
ΔI= inductor ripple
$\Delta T = D/ F_{sw}$
ΔV = Output voltage ripple
ESR = Effective series resistance of capacitor (e.g. 0.03 ohm)

C2 = ΔT ((Vripple / I_{ripple}) - ESR) [5]

The practically tested hardware system is shown in fig.08

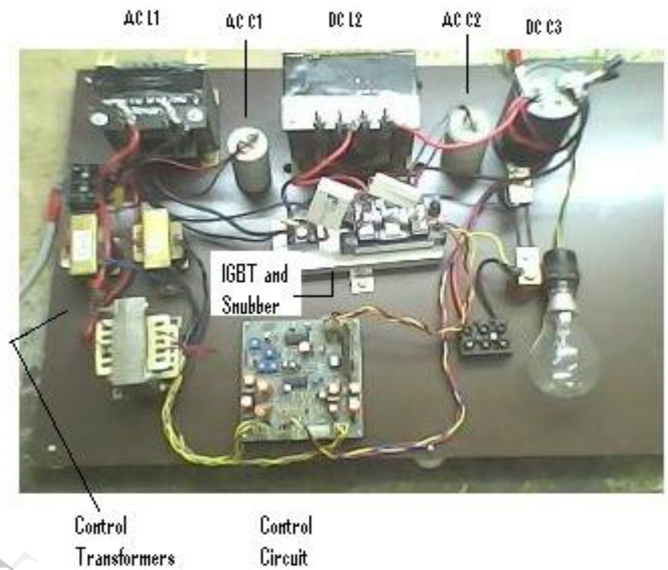

Fig 08. Hardware System of PFC converter

4. Results

The quantitative results obtained from hardware are shown in table 01.It is tested at various load conditions. It is observed that even though the load varies the output voltage remains constant. Converter is designed for 1000W load. The graphs of power factor and efficiency V/S. output load are shown in fig 09. For 270W (1/4th full load) power factor is improved to 0.864 and for 900 W it is 0.954. We get the 96% efficiency at full load.From the graph it is observed that the efficiency and PF improve as the load reaches to designed value i.e 1000W.

Table1: Power Factor results for implemented hardware buck converter for various load conditions.

O/P Load (W)	I/P Volt (V)	I/P Amp (A)	O/P Volt (V)	O/P Amp (A)	PF	Effic-Iency Wo/Wi
54	242	0.4	135	0.4	0.675	55.78
135	242	0.8	135	1.0	0.779	69.73
270	242	1.4	135	2.0	0.864	79.69
473	241	2.2	135	3.5	0.916	89.02
904	240	3.9	135	6.7	0.954	96.52

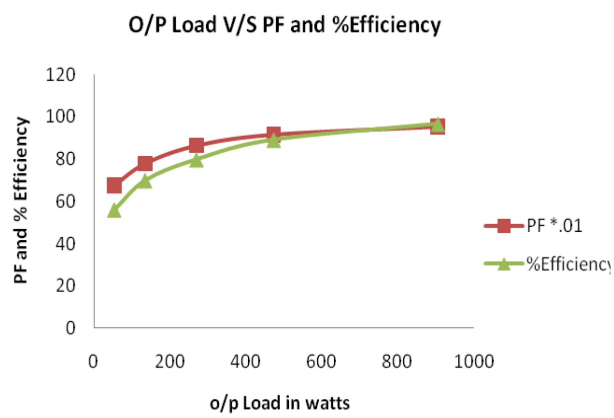

Fig.09. Power Factor and %efficiency V/S output load in watts

5. Conclusions

From the results obtained it is clear that the output voltage remains constant for various loads. Results are better from 1/4th load onwards. Power factor varies from 0.864 to 0.954 for 1/4th load to full load. Efficiency achieved is 96% at full load. The output voltage can be widely controlled from 80V to 200V by selecting suitable power components. The converter is applicable in UPS dc bus, battery chargers, variable speed control of dc motors and similar applications.

6. Acknowledgement

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7. REFERENCES

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