IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321- 5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 6, Issue 6, June 2018

Three Phase Boost Power Factor Correction Converter Using Voltage Follower Approach

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Abstract: A new single-switch three-phase AC-DC boost converter is used to achieve a high power factor and low line current harmonic distortion. The single switch is used so that the voltage stress is reduced thereby switching losses are also low. PI voltage controller is used to generate the gate pulses for the switch. Based on the control scheme, the output voltage is found to be balanced, THD is also reduced and the unity power factor is also achieved.

Keywords: ICS, PI, Power Factor, Total Harmonic Distortion (THD), Power Factor Correction (PFC).

I. INTRODUCTION

Rectifier is a circuit that converts AC input power to DC output power. The input supply may be a single phase or a multi-phase supply. The output is DC voltage and current with certain amount of ripple components. Rectifiers can be classified into a) Uncontrolled rectifier b) Phase controlled rectifier c) Switch mode rectifier. An uncontrolled rectifier uses diodes which produces fixed output voltage. Phase controlled rectifier uses thyristor or popularly known as Silicon Controlled Rectifiers (SCRs) which produces variable output voltage. It is divided into full-controlled rectifier which uses SCR and a half controlled which is a mixture of diodes and thyristors [1-5]. The thyristors need to be turned on using a special triggering circuit. Switch mode rectifier uses fully controlled switch which produces variable output voltage [6]. Such types of rectifiers are mainly used for power factor correction.

Most modern electronic apparatus use some form of rectifiers i.e., AC to DC power conversion within their architecture and it is these power converters that draw pulses of current from the AC network during each half cycle of the supply waveform. The amount of reactive power drawn by a single apparatus (a domestic television for example) may be small, but within a typical street there may be a hundred or more TV sets or other types of equipment drawing reactive power from the same supply phase, resulting in a significant amount of reactive current flow and generation of harmonics. Governments are tightening regulations, setting new specifications for low harmonic current, and restricting the amount of harmonic current that can be generated [7-11].

As a result, there is a need for a reduction in line current harmonics necessitating the need for Power Factor Correction (PFC) and harmonic reduction circuits [13-17]. Improvements in power factor and harmonic distortion can be achieved by modifying the input stage of the diode rectifier filter capacitor circuit. Several Power Factor Correction (PFC) topologies are conceived [12].

As the underlying cause of low power factor and high circulating currents created by switched mode power supplies is the discontinuous input-filter charging current, the solution lies in introducing elements to increase the rectifier's conduction angle [18-23]. These are namely the passive and active power factor correction, passive or active filtering in the network and lastly accepting a non-sinusoidal voltage/current in the system. Passive solutions can be used to achieve this objective for low power applications. With a filter inductor connected in series with the input circuit, the current conduction angle of the single-phase full-wave rectifier is increased leading to a higher power factor of about 0.8 and lower input current distortion [24-25]. With smaller values of inductance, these achievements are degraded. However, the large size and weight of these elements, in addition to their inability to achieve unity power factor or lower current distortion significantly, make passive power factor correction more suitable at lower power levels. Active PFC solutions are a more suitable option for achieving near unity power factor and sinusoidal input current waveform with extremely low harmonic distortion. In these active solutions, a converter with switching frequencies higher than the AC line frequency is placed between the output of the diode bridge rectifier and the bulk capacitor [26].

The reactive elements of this converter are small, because their size depends on the converter switching frequency rather than the AC line frequency. The function of this converter is to make the load behave as an ideal resistive load and thus eliminate the generation of line current harmonics

II. BLOCK DIAGRAM

Fig 1 shows the closed loop block diagram using voltage follower method. The output voltages are regulated by the voltage control loop. The controller is chosen as pi type compensator and represented by the transfer function $g_c(s) = k_p$

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$(1+1/t_i\ s)$. Where k_p and t_i are proportional gain and integral time constant respectively. The output voltage is regulated using voltage error (v_{error}) obtained by comparing the measured actual output voltage (v_{actual}) and desired reference voltage (v_{ref}). The v_{error} is processed by the voltage pi-controller whose output is compared with the pwm modulator. Finally generates pulse width modulated gate pulses to the mosfet switch.

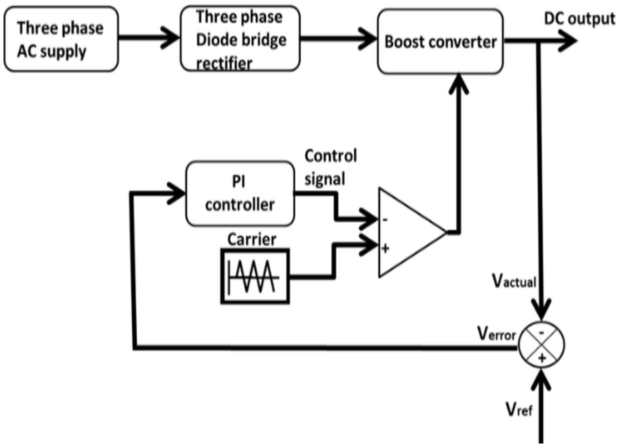

Fig. 1 Closed loop block diagram using voltage follower method

III.CIRCUIT DIAGRAM

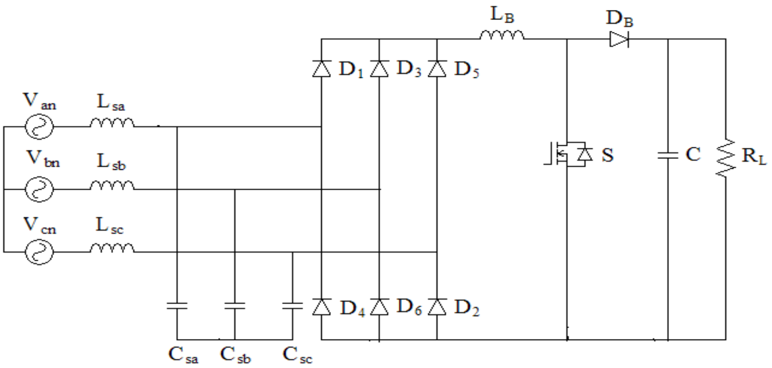

Fig 2 Circuit diagram of proposed work

Fig 2 shows the circuit diagram of three phase AC-DC boost converter. The converter basically consists of two stages:

1) a three-phase diode rectifier with capacitors C_{sa}, C_{sb} and C_{sc} connected to the input mains of each phase
2) The active output stage consisting of the boost-type single ended converter.

The active switching device of the output stage employs variable frequency control and operates in discontinuous-current mode. Only one boost inductor L_B is used. The converter has a pulsating input voltage during each switching period, with a peak voltage proportional to the input-line current, thereby, providing an average component of line current nearly sinusoidal and approximately proportional to the phase voltage. The input-line currents i_{sa}, i_{sb} and i_{sc} are filtered through the input inductors L_{sa}, L_{sb} and L_{sc}. A three-phase high-frequency single-switch discontinuous-inductor-current boost rectifier has been introduced. With a view to obtaining a low distortion in mains current and a high-power density, the converter is realized as a pulse-converter system with high-system pulse frequency, the filtering requirement is considerably reduced as compared to a line-commutated system. It is also possible to obtain low-harmonic rectification with capacitive type input. It is the case of the boost rectifier shown in Fig 2. The values of the input capacitors are chosen to be sufficiently small to operate the circuit in discontinuous voltage mode, and low-harmonic rectification is achieved by using a single-switching device Q**,** operating in discontinuous current mode. The operating mode consists of transferring energy from capacitors C_{sa},C_{sb} and C_{sc} to the inductor. To achieve this energy transfer L_B switch Q**,** is turned on and the capacitors are therefore discharged by the resonating switch current. As soon as the capacitor voltages are reduced to zero, all diodes of the bridge are conducting. The totality of the energy accumulated in L_B is transferred to the load through diode D_B when Q is turned off. Later, when the diode D_B turns off, the input capacitors are charged linearly by their respective phase currents isa, isb and i_{sc} until the switch Q is turned on again. The input-line currents i_{sa},i_{sb} and i_{sc} are filtered through the input-line inductors L_{sa},L_{sb} and $L_{sc.}$

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IV. DESIGN SPECIFICATIONS

Table 1 Design Specifications

Specifications	Rating
Input Voltage(V_{in})	20 V
Output Voltage(V_o)	50 V
Switching Frequency(f)	25 kHz
Load resistance(R_L)	50 Ω
Capacitance(C_B)	1200 µF
Inductance(L_B)	33 mH
Source inductance(L_{sa})	8 mH
Source capacitance(C_{sa})	1 µF

Table 1 shows the design specifications used in the converter.

V. SIMULATION OF THE SYSTEMS

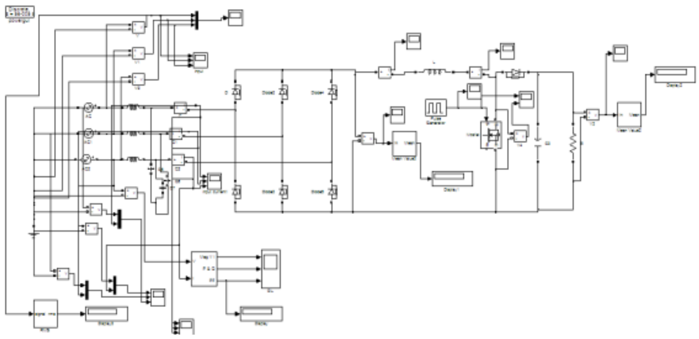

Fig. 3 Open Loop Simulated Circuit Diagram of the proposed converter

Fig 3 shows the simulated circuit diagram of three phase AC-DC boost converter with open loop control.

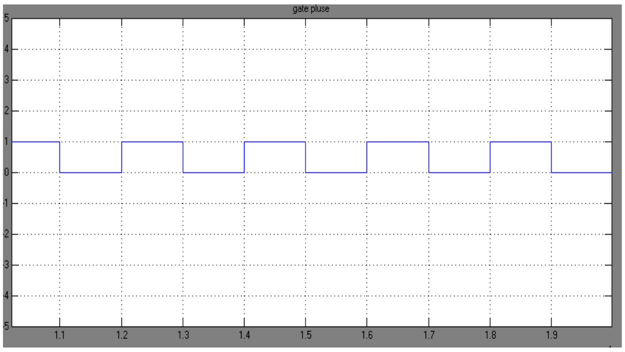

Fig 4 Gate Pulse

Fig 4 shows the gating pulse for the switch used in the open loop control of the proposed system.

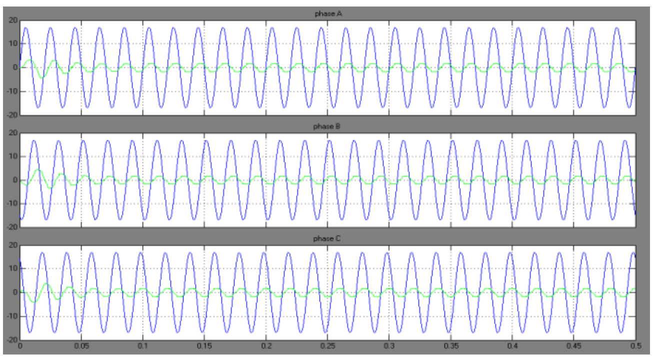

Fig. 5 Input voltage and input current waveform for open loop control

 DOI 10.17148/IJIREEICE.2018.6613

IJIREEICE

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Fig 5 shows the input voltage and input current waveform with open loop control. When the input AC voltage is rectified, the input current becomes non-linear. During open loop control of Boost PFC AC-DC converter, Power factor is improved to 0.856 and THD is reduced to 12.43% as shown in Fig 7. Fig 6 shows the output voltage waveforms is 49.5V

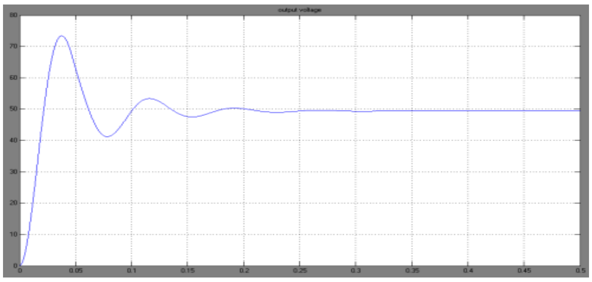

Fig 6 Output voltage waveform for open loop control

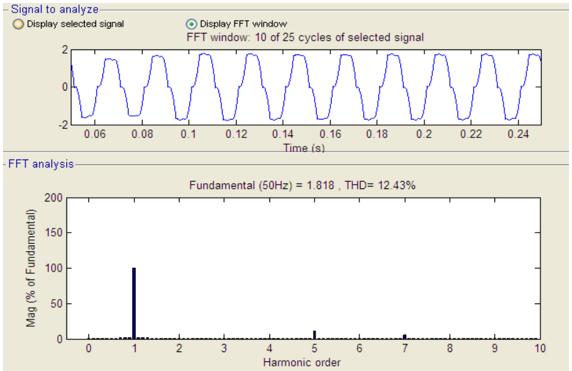

Fig 7 THD for open loop

Fig 7 shows the FFT analysis of total harmonic distortion with open loop control. By increasing load resistance, output voltage and THD are increased. But input power factor and efficiency are decreased. According to IEEE norms, harmonic should be less than 5%, which is not obtained in open loop control.

VI. CLOSED LOOP ANALYSIS

Closed loop control is a feedback control that deals with the behaviour of dynamical systems with inputs. The external input of a system is called the reference. When one or more output variables of a system need to follow a certain reference over time, a controller manipulates the inputs to a system to obtain the desired effect on the output of the system.

USING VOLTAGE FOLLOWER METHOD

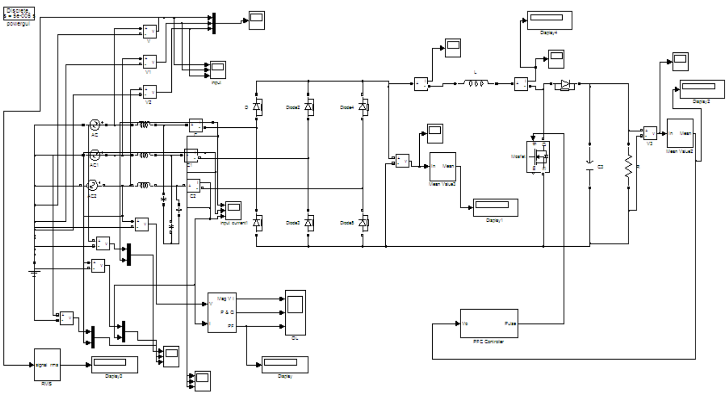

Fig 8 Closed Loop Simulated Circuit Diagram of the proposed converter using voltage follower method

Fig 8 shows the closed loop simulated circuit diagram of proposed converter using voltage follower method. In closed loop simulation, voltage follower method is used. The output DC Voltage is compared with reference voltage. Thereby the input power factor and THD are used.

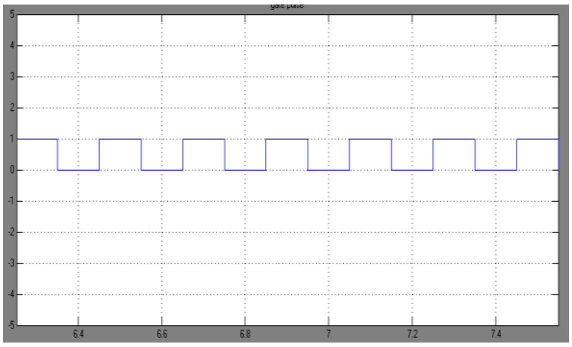

Fig 9 Gate Pulse

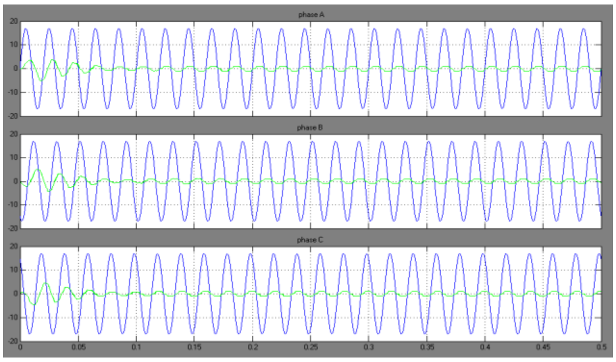

Fig 10 Input voltage and input current waveforms

Fig 9 shows the gating pulse for the switch used in the closed loop control of the proposed system using voltage follower method.Fig 10 shows the input voltage and input current waveforms. Input voltage and input current waveforms are in phase. Therefore input power factor is nearly closed to unity. Input current waveform is slightly distorted.

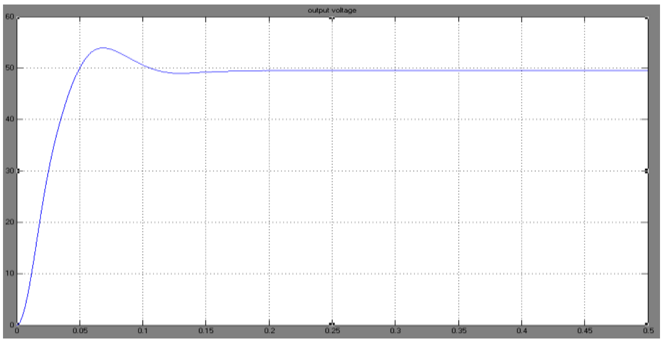

Fig 11 Output voltage waveform for the proposed converter

Fig 11 shows the output DC voltage is 49.7V Power factor is improved to 0.961 and THD is reduced to 22.41% as shown in Fig 12.

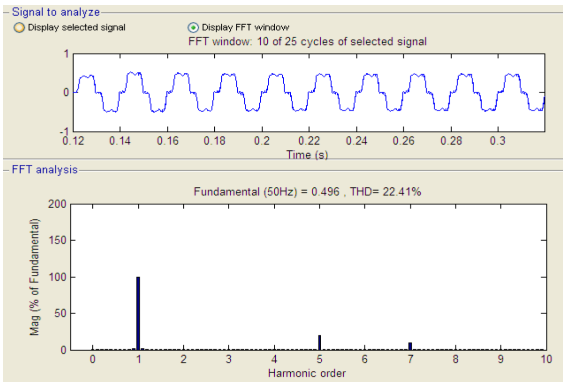

Fig 12 THD for closed loop

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Table 2 Comparison between closed loop and open loop simulation results for proposed converter

PARAMETER	OPEN LOOP	CLOSED LOOP
POWER FACTOR	0.856	0.901
THD %	12.43	7.70

Table 2 shows the comparison between the open loop and closed loop simulation results. In open loop, the power factor and THD obtained is 0.856 and 12.43% respectively. In closed loop, the THD is reduced to 7.70 % and the power factor is improved to 0.901 which is nearly equal to unity.

VII. HARDWARE RESULTS

(A) OPEN LOOP

Fig 13 Open Loop Hardware setup

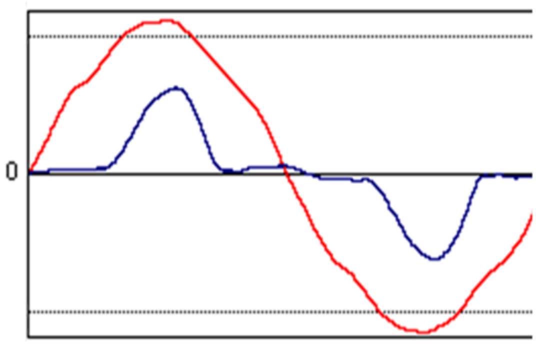

Fig 14 Input Voltage and Input Current in open loop mode

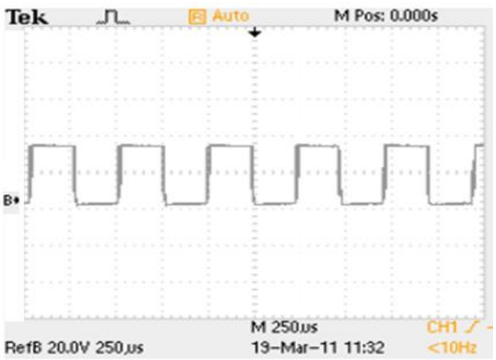

Fig 15 Pulse in open loop mode

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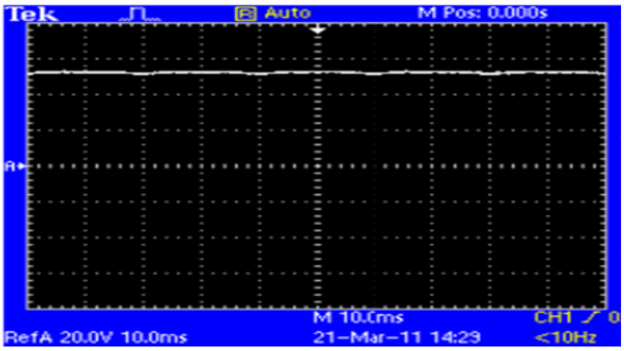

Fig 15 Output Voltage in open loop mode

Fig 15 shows DC output voltage of 48V. The power factor which is measured using power quality analyzer in open loop mode as 0.815 and fig 16 shows the THD which is obtained in open loop mode is 48.4%.

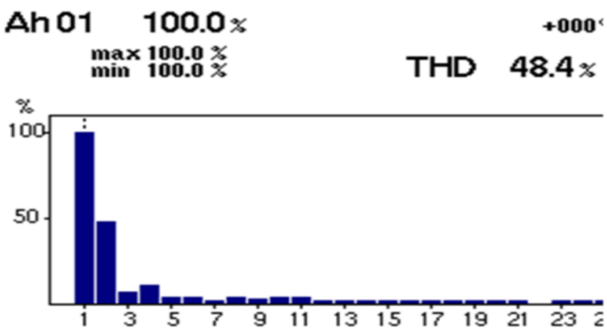

Fig 16 THD in open loop mode

(B)CLOSED LOOP

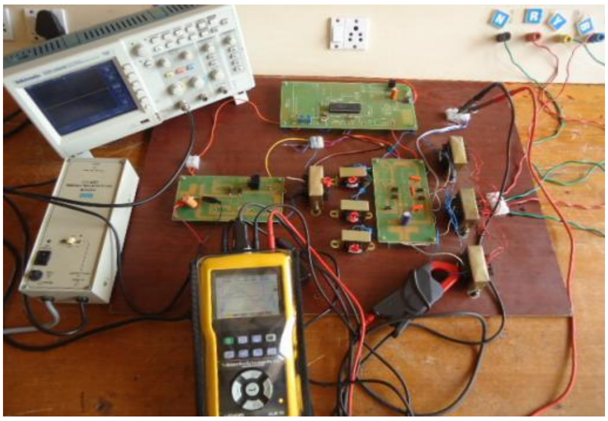
Fig 17 Closed Loop Hardware setup

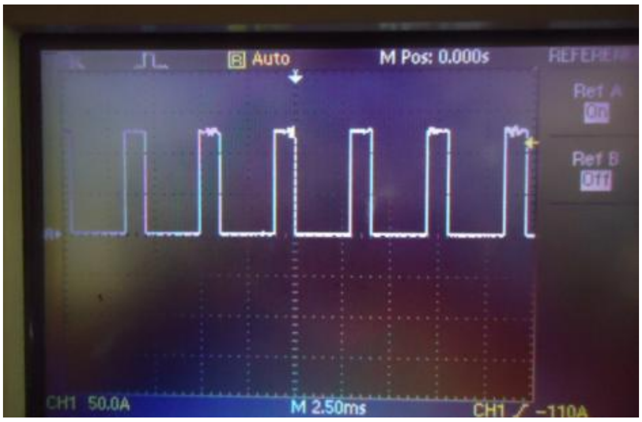

Fig 18 Pulse in Closed Loop model

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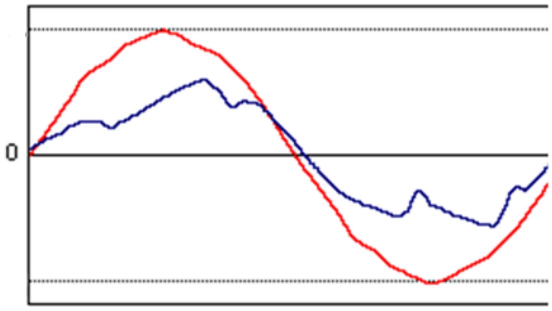

Fig 19 Input Voltage and Input Current in Closed Loop mode

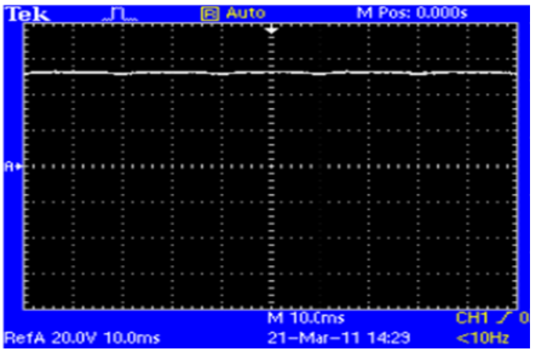

Fig 20 Output Voltage Closed Loop mode

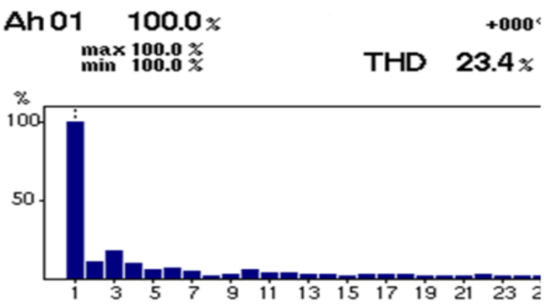

Fig 21 THD in Closed Loop mode

COMPARISON BETWEEN CLOSED LOOP AND OPEN LOOP HARDWARE RESULTS FOR PROPOSED CONVERTER

Table 3 Comparison between closed loop and open loop hardware results

PARAMETERS	OPEN LOOP	CLOSED LOOP
POWER FACTOR	0.815	0.961
THD %	48.4	23.4

From the above hardware results it is clearly evident that there is improvement in power factor and reduction in THD in closed loop mode.

VIII. CONCLUSION

A new single-switch three-phase AC-DC high-power-factor converter is presented. This converter is capable of drawing a high quality input –current waveform with high power factor and low THD. From the Simulation studies, it is clear that new single-switch 3 Phase AC-DC high power factor converter ascertain improved performance when compared with conventional topologies. Improvement in power factor and reduction in THD is witnessed with both the proposed converters with PFC. It is evident that, A new single-switch three Phase AC-DC high power factor converter since it has produced vast improvement in power factor and drastic reduction in THD.

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