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PFC Circuit for Wind Generator with PWM Controller

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ABSTRACT-The single-stage converters (SSC's) with power-factor-correction (PFC) feature is implemented in the wind generator is presented in this paper. The wind induction generator(IG) feeding an isolated load through the PWM controller with the power factor correction circuit. In this circuit, the power factor is improved by using an auxiliary winding coupled to the transformer of a cascade dc/dc flyback converter. The topology of this converter is derived by combining a boost circuit and a forward circuit in one power stage. To improve the performance of the ac–dc converter (i.e., good powerfactor correction, low total harmonic distortion (THD) and low dc bus voltage), two bulk storage capacitors are adopted. The output voltage and frequency of the wind generator can be varied according to random fluctuation of wind-speed variation.Due to its simplified power stage and control circuit, this converter presents a better efficiency, lower cost and higher reliability.

***Index Terms*— Single-stage converters (SSC's), Induction generator (IG),Total harmonic distortion (THD),Power-factor-correction (PFC), AC/DC converter,Input Current Sharper (ICS).**

I. INTRODUCTION

Power-Factor-Correction (PFC) techniques have become attractive since several regulations have been effected recently. Many PFC converters have been presented. They usually can be divided into two categories: the two-stage and single-stage approaches [1]. In order to reduce the cost, the single-stage approach, which integrates the PFC stage with a dc/dc converter into one stage (base).The additional discharge path in the PFC inductor and DC-bus voltage feedback effectively suppresses the DC-bus voltage and increases the overall efficiency [2]. Traditionally, to improve power factor of a given power electronic system, normally a power factor correction (PFC) circuit is designed and placed in front end of the system, which in turn interfaced with the load. This PFC circuit may be an independent unit followed by a dc–dc converter, or an inseparable part of circuit incorporated into the power supply of the load, namely two-stage PFC power supply and single-stage PFC power supply, respectively[3].

For high-power levels, the PFC stage is operated in the continuous-conduction mode (CCM), while the dicontinuous-conduction-mode (DCM) operation is commonly used at lower power levels due to a simpler control[4]. For single stage PFC rectifiers, the performance measures, such as efficiency, hold up time, component count, component voltage and current stress, input current quality, etc., are largely dependent of the circuit topology[5].

The performance of IG supplying various static loads using different control schemes are studied and analysed in various papers. An interleaved converter with a coupled winding is proposed to provide a lossless clamp. Moreover, the proposed converter design reduces the volume and weight of the magnetic material by almost half compared to existing boost-based single-stage PFC converters.

A common approach to improving the power factor is a two-stage approach. In this approach, an active power-factor-correction (PFC) stage, which is usually realized by a dc/dc converter, is adopted at the input of electronic equipment to force the line current tracking the line voltage. A PFC converter is adopted at the front-end to force the line current tracking the line voltage and another conventional DC/DC converter is cascaded after the PFC stage to obtain the desired tightly regulated output voltage[2].

The voltage across the DC-bus capacitor varies with the variation of the input voltage and the load, especially while the PFC part operates in discontinuous conduction mode (DCM) and the DC/DC part is in continuous conduction mode (CCM). The secondary winding is added in the PFC boost inductor, some input power is directly transferred to the output. In this paper, a review of the most interesting solutions for single phase and low power applications is carried out.

II. POWER FACTOR CORRECTION CIRCUIT

A single power stage with dual outputs produces both the desired DC output and a boosting supply in series with the input. In fig.1. the function of the circuit is illustrated. This circuit is original but the component count is high. Another way to realize single stage PFC is by cascading a boost ICS with a dc–dc converter using one switch.

Both pulse width modulation (PWM) and frequency modulation (FM) were applied in the control circuitry. In a single-stage approach, power-factor correction, isolation, and high-bandwidth control are performed in a single step, i.e., without creating an intermediate dc bus. Generally, these converters use an internal energy-storage capacitor to handle the differences between the varying instantaneous input power and a constant output power.

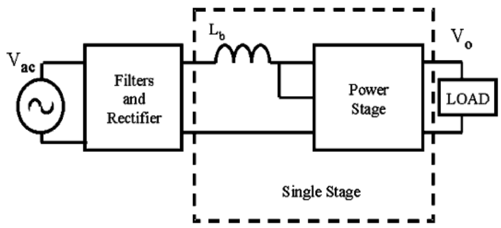

Fig. 1. General circuit diagram for single stage AC/DC PFC Converter.

In this family a boost circuit accompanied by a dc/dc converter was introduced to form the so-called single stage single-switch ac/dc converters. The family circuits have PFC function, as illustrated in Fig. 1. This concept successfully simplifies a conventional power-factor corrector by changing it from two stages to one stage. However, this concept employs a bulk inductor in the boost section, which occupies significant volume and weight.

A boost circuit accompanied by a dc/dc converter was introduced to form the so-called single-stage single-switch ac/dc converters. Single-stage PFC converters meet the regulatory requirements regarding the input current harmonics, but they do not improve the power factor and reduce the THD as much as their conventional two-stage counterpart. The power factor could be as low as 0.8, however, they still meet the regulation. In addition, although the single-stage scheme is especially attractive
in low cost and low power applications due to its simplified power stage and control circuit, major issues still exist, such as low efficiency and high as well as wide-range intermediate dc bus voltage stress.

This concept successfully simplifies a conventional power-factor corrector by changing it from two stages to one stage. The implemented values in simulation of power factor circuit is shown in Table I. Table II indicates the performance of the ac/dc converter. However, this concept employs a bulk inductor in the boost section. Moreover, the proposed converter design reduces the volume and weight of the magnetic material by almost half compared to existing boost-based single-stage PFC converters.

Furthermore, the voltage across the bulk capacitor can be reduced to a reasonable value by adjusting the turns ratio of the windings N_1 and N_3 . Therefore, this design can adapt to significant line voltage variation. Experimental results for a 60W converter at a constant switching frequency of 70 kHz are obtained to show the performance of the proposed converter.

III. QUASI ACTIVE PFC CIRCUIT

The proposed quasi-active PFC circuit is analyzed in this section. As shown in Fig. 2, the circuit comprised of a bridge rectifier, a boost inductor L_B , a bulk capacitor C_a in series with the auxiliary windings L_3, an intermediate dc-bus voltage capacitor C_B , and a discontinuous input current power load, such as flyback converter. The flyback transformer has three windings N_1, N_2 and N_3. The secondary winding $N_2 = 1$ is assumed. In the proposed PFC scheme, the dc/dc converter section offers a driving power with high-frequency pulsating source.

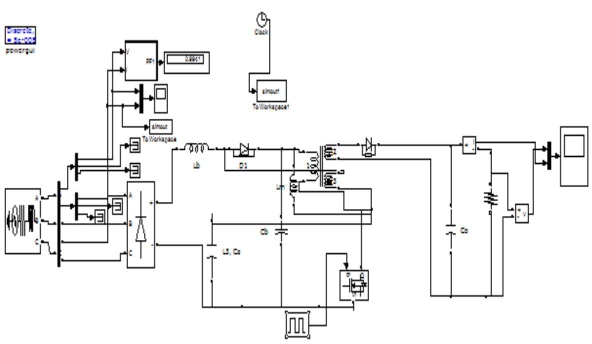

Fig. 2. Simulation diagram for Quasi –active power factor circuit

TABLE I

Technical data for the Quasi active power Factor Circuit

Transformer Turns Ratio:	N1 = 30,N2 = 10,N3 = 15
Magnetizing Inductor, Lm	200 µH
Energy Buffer, Lb	80 µH
Voltage capacitor, Cb	47 µF
Bulk Capacitor,Ca	22 MF
Capacitance,Co	470 MF
Input Voltage,Vin	230V
Line Voltage,Vrms	(100-240)V
Switching Frequency	100kHz

The capacitor voltage can be maintained below 450 V by properly designing the turns ratio $N_3/N_1$and the inductors ratio L_m/L_b .

TABLE II

Performance of the Circuit

Semiconductor	2 diodes, 1 switch, 1 bridge rectifier
Passive components	1 inductor,3 capacitors, 3- winding transformer
Switch current	$(N_3/N_1)\ I_{LB}+I_{Lm}$, where $N_3/N_1 <1$
Efficiency at full load	>90%
Capacitor voltage V_{CB} (for constant input voltage)	Controlled by the ratio L_m/L_B and the winding ratio N_3/N_1
THD of the input current	<10%

IV. WIND MODEL

The generation system is designed with IG. The block diagram of the wind model with PFC circuit is shown in Fig. 3. The stator winding terminals of the IG are connected to the load through the rectifier, DC link, PFC circuit, and inverter. The closed loop PWM signal generates proper PWM signals to switch the two power electronics devices of the Interleaved Boost Converter (IBC). The wind turbine rotates the IG. The IG generates power when the speed of the turbine is above the rated speed. The power generated from the IG is converted to DC with a diode bridge rectifier. The obtained DC voltage will not be in a pure DC signal. A filter circuit is used to filter out the ripple current and a pure DC voltage is obtained. This DC voltage is then boosted to the required DC level and then converted to phase AC signal with IGBT which is driven by PWM signal. To regulate the AC output voltage the IBC is controlled by close loop PWM signals. A load is connected at the output of the inverter.

Pulse-width modulation (PWM) is a very efficient way of providing intermediate amounts of electrical power between fully on and fully off. A simple power switch with a typical power source provides full power only when switched on.

The term duty cycle describes the proportion of on time to the regular interval or period of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Pulse-width modulation uses a rectangular pulse wave whose pulse width is modulated resulting in the variation of the average value of the waveform. If we consider a pulse waveform f(t) with a low value y_{min}, a high value y_{max} and a duty cycle D, the average value of the waveform is given by

$$\bar{y} = T\int_0^T f(t)dt$$

$$\bar{y} = \frac{1}{T}\left(\int_0^{DT} y_{max}\, dt + \int_{DT}^{T} y_{min}\, dt\right)$$

$$= \frac{D.T.y_{max} + T(1-D)y_{min}}{T}$$

$$\bar{y} = D.y_{max} + (1-D)y_{min}$$

The simplest way to generate a PWM signal is the interceptive method, which requires only a sawtooth or a triangle waveform and a comparator. When the value of the reference signal is more than the modulation waveform, the PWM signal is in the high state, otherwise it is in the low state.

V. Operation of Wind Model

In this the integrated single-stage power factor correction (PFC) converters usually use a boost converter to achieve PFC with discontinuous current mode (DCM) operation. Usually, the DCM operation gives a lower total harmonic distortion (THD) of the input current compared to the continuous current mode (CCM).

However, the CCM operation yields slightly higher efficiency compared to the DCM operation. In the DCM operation of the ICS inductor, low line-current harmonic distortions are achieved because of the inherent property of the DCM boost converter to draw a near sinusoidal current if its duty cycle is held relatively constant during a half line.

When the switch (SW) is turned on at $= t_1$, diodes D_1 and D_0 are OFF,then the value of i_m can be calculated.

$$i_m = \frac{V_{CB}}{L_m}(t_0 - t_1)$$

V_{CB} –DC Bus voltage

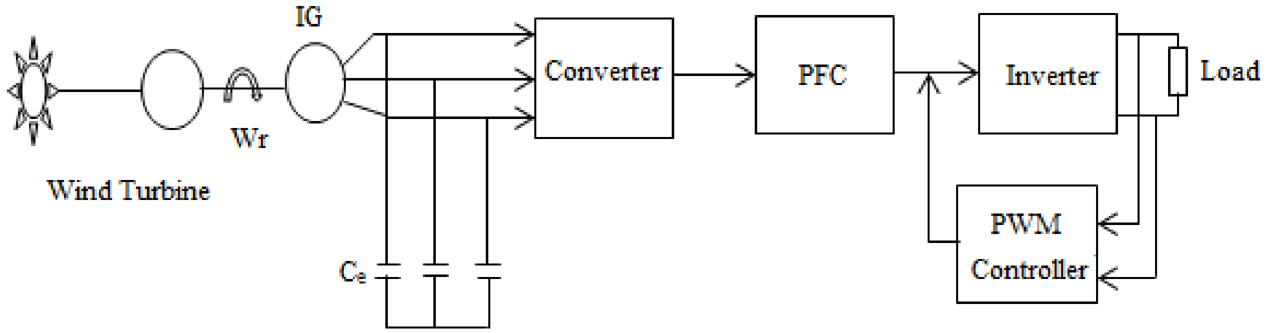

Fig. 3. Block Diagram of wind model

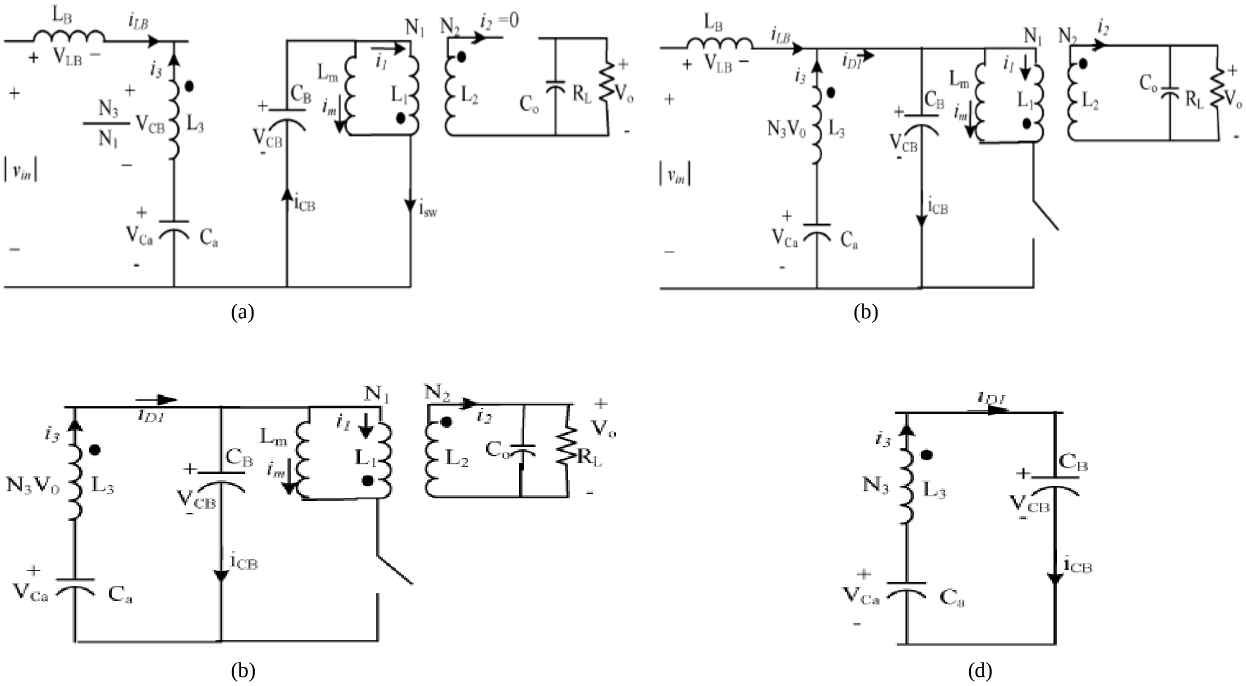

Fig. 4. Equivalent circuit operation of power factor correction circuit for the corresponding switching period. (a) At the switching period $(t_0 - t_1)$; (b) At the switching period $(t_1 - t_2)$; (c) At the switching period $(t_2 - t_3)$; (d) At the switching period $(t_3 - t_4)$;

A. Operation of Power Factor Correction Circuit

In the fig. 4(a),the diode D_1 is OFF, the input inductor L_B is charged by input voltage, therefore, the inductor current i_{LB} is linearly increased. On the other hand, D_0 is reversed biased and there is no current flow through the secondary winding.

$$i_{SW} = i_m + i_{LB}.$$

At $(t_1 - t_2)$ the switch is turned OFF at $t_1 = t_2$ output diode D_0 begins to be forward biased as shown in fig 5 (b). Therefore, the energy stored in the transformer magnetizing inductor is delivered to the load through the secondary winding. Similarly, the diode D_1 is also forward biased and the voltage across L_B now , $V_{in} - V_{CB}$.

Therefore, the current i_{LB} is linearly decreased to zero at $t = t_2$ (DCM operation), and the energy stored in L_B is delivered to the dc bus capacitor C_B. The capacitor (C_a) is also discharging its energy to the dc bus capacitor C_B and the current i_3 reverse its direction. Therefore, the capacitor current is given by

$$i_{D1} = i_{CB} = i_{LB} + i_3$$

In fig. 4(c).that is in the stage $(t_2 - t_3)$, the input inductor current i_{LB} reaches zero and the capacitor C_a continues to discharge its energy to the dc bus capacitor C_B.Therefore, $i_{D_1} = i_{CB} = i_3$. At $= t_3$, the magnetizing inductor releases all its energy to the load and the currents i_m and i_2 reach to zero level because a DCM operation is assumed.

In the stage 4,at $(t_3 - t_4)$ the currents i_m and i_2 reach to zero as shown in fig.5(d). Diode D_1 still forward biased, therefore, the capacitor C_a still releasing its energy to the dc bus capacitor C_B . This stage ends when the capacitor C_a is completely discharged.

The energy absorbed by the circuit from the source during a half switching cycle is given by

$$P_{in} = \frac{1}{\pi}\int_0^{\pi} V_m \sin(t)\, I_{in}\, dt$$

$$P_{in} = \frac{1}{\pi}\frac{V_m}{2L_B} d^2 T_S(A)\int_0^{\pi} \sin(t) B dt$$

Here,

$$A = \left[\left(1 + \frac{N_3}{N_1}\right)V_{CB} - V_{Ca}\right]$$

$$B = \frac{V_m \sin(t) + \frac{N_3}{N_1}V_{CB} - V_{Ca}}{V_{CB} - V_m \sin(t)}$$

The turns ratio N_3/N_1 and the dc bus voltage V_{CB} can be optimized in order to reduce the dead time and improve the quality of the input current.

Usually, the DCM operation gives a lower total harmonic distortion (THD) of the line current compared to the CCM operation. However, the CCM operation yields a slightly higher efficiency compared to the DCM operation. Regarding the power factor correction stage, the boost converter is widely used because of its advantages: grounded transistor, small input inductor, simplicity and high efficiency (around 95%). The main drawback is that the output voltage is higher than the peak input voltage, causing switching losses in the transistor and in the diode, due to its reverse recovery.

VI. Simulation Results

The wind model is simulated by using Matlab software.

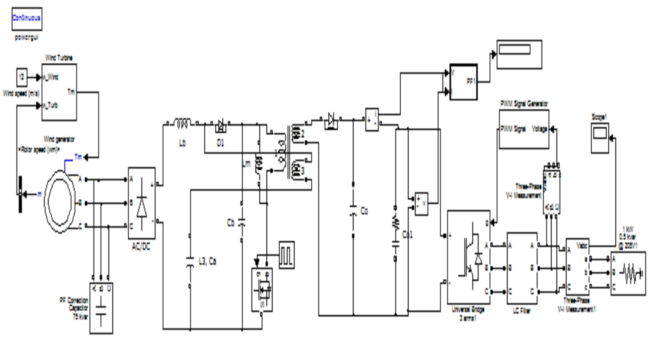

Fig. 5. Simulation diagram for the wind turbine.

The IG design is made with the calculated value of resistance, flux linkage of the stator and rotor windings and with the torque equation and the number of poles. The generated power is rectified. The generated power varies with the wind speed. The power converter converts the three phase AC to DC and then the filter circuit is used for obtaining smooth DC voltage across it.

The project module is simulated using MATLAB 7.7.0(R2008b). The simulation is executed under ode23tb (stiff/TR-BDF2) state which is used to fasten the execution speed and the Zero-crossing control is disabled. The solver method is set to fast. The voltage is measured at different points in the simulation circuit. The simulated output is shown below. The system is tested with different load and wind speed. The designed system generates AC power with asynchronous generator (215HP;400V50Hz).

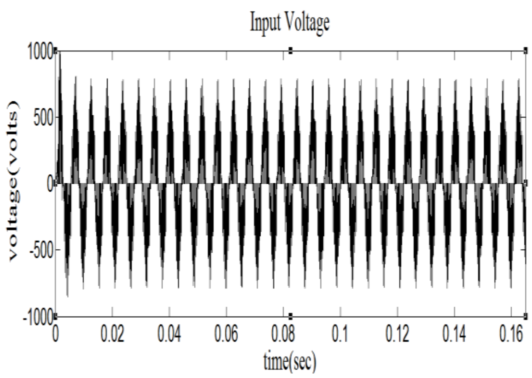

Fig. 6. Input Voltage for power factor circuit.

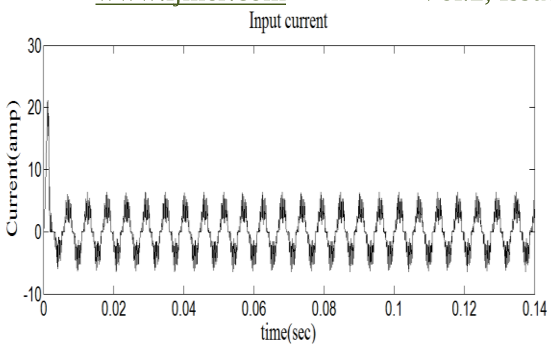

Fig. 7. Input Current for power factor circuit.

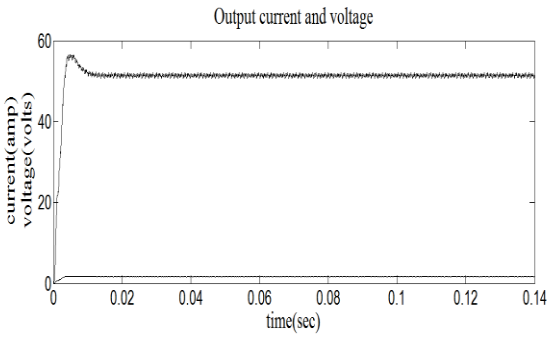

Fig. 8. Output Voltage and Current for power factor circuit.

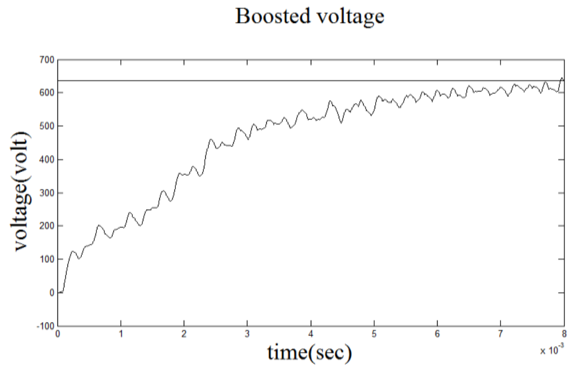

Fig. 9. Boosted voltage from PFC circuit.

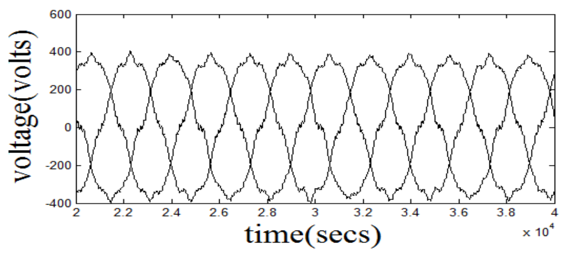

Fig. 10. Output Voltage of Wind model.

The turns ratio N_3/N_1 and the dc bus voltage VCB can be optimized in order to reduce the dead time and improve the quality of the input current. In the Fig. 6. the input current for the power factor circuit. Note that, in order to improve the visibility of the higher order harmonics, class A limits are scaled down by a factor of 5 (class A limits/5). The measured THD = 6.70% and the power factor is 0.994 for the closed loop wind power generation circuit.

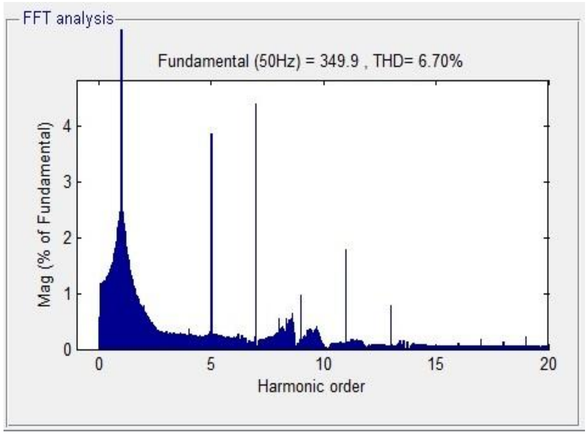

Fig. 11. THD for input current in the closed loop circuit

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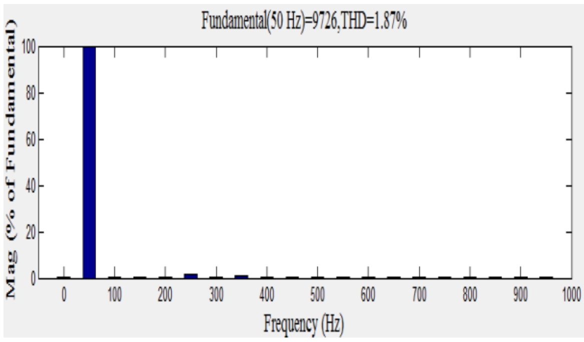

Fig. 12. THD for input current in open loop circuit.

VII. CONCLUSION

A ac/dc converter based on a quasi-active PFC scheme has been presented and simulated in this paper. The proposed method produces a current with low harmonic content to meet the standard specifications and the high efficiency. This circuit is based on adding an auxiliary winding to the transformer of a cascade dc/dc DCM flyback converter. The main advantage of the system is that the minimum wind speed is required for the power generation. The simulated results of output voltage shows the performance of the proposed wind model. The input inductor can operates in DCM to achieve lower THD and high power factor. By properly designing the converter components, the relation between efficiency and harmonic content can be established to obtain the proper regulation and efficiency as high as possible.

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BIOGRAPHIES

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