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# Improvement Power Factor by using Hybrid Fuzzy Logic Controller of Fly back PFC Converter Operating at the Light Load

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**Abstract—**this paper presents propose a duty-ratio feed-forward controller for flyback power factor correction (PFC) converters with PI and Hybrid Fuzzy Logic Controllers operating in discontinuous conduction mode (DCM). For PFC with PI and Hybrid Fuzzy Logic Controllers applications, the power factor (PF) of the input current must be high under most load conditions. To improve PF of the flyback converter with PI and Hybrid Fuzzy Logic Controllers even under light load, we propose a compensation method for input capacitor current. The proposed controller significantly improves the displacement factor as well as the distortion factor, and therefore flyback PFC converter can achieve the high power quality. Meanwhile, the output voltage of the PFC converter is well regulated. The derivation of the proposed method is presented and effectiveness of the proposed method is demonstrated in Simulates with a 100-W rated power circuit.

**Index Terms—Single-stage PFC, power factor improvement, total harmonic distortion, capacitor current, feed forward controller.**

## (I) Introduction

Power factorcorrection (PFC) is usually used to provide a sinusoidal input current. Hence, research of multiple-output ac/dc power converter with low cost and high power factor (PF) is important.In order to achieve a high PF and to accurately regulatethe output voltages or currents of a multiple-output ac/dc converter, a conventional multiple-output ac/dc power converterconsisting of two-stage power conversion is utilized, as shownin Fig. 1, where the PFC preregulator provides the dc busvoltage$V_{bus}$and parallel-connected dc-to-dc regulators are usedto regulate the output voltage or output current from $v_{bus}$.

The circuit configuration of the multiple-output ac/dc converter shown inFig. 1is complex and suffers from high cost, withmultiple inductors and controllers required [6], [7]. Moreover,the two-stage power conversion with PFC pre regulator and dc-to-dc converters suffers from lower efficiency and highervolume and cost. However, the single-stage PFC converter canachieve high PF and output current or voltage regulation at the same time [8], [9]. Hence, it has drawn more and more attention in recent years.A flyback PFC converter with multiple secondary windings is a typical single-stage multiple-output converter, whereonly one output can be well regulated. Multiple secondary windings in the transformer lead to cross-regulation due toleakage inductance, forward voltage drop of diodes, and seriesresistance of the windings [10]. Moreover, only voltage outputregulation can be achieved, while multiple current outputs arehard to regulate independently. In order to achieve a highlyaccurate regulation of multipleoutput converters, the magneticamplifier postregulator approach is applied in [11] and[12], butit still requires multiple inductors and windings A single-inductor multiple-output (SIMO) converter withonly one inductor benefits from significant overall cost saving,small size, and light weight, which make it as one of themost suitable and cost-effective solutions for multiple-outputpower supplies. SIMO dc/dc converters in mobile applicationhave been studied in recent years [13]–[17]. In some offlineapplications, such as LED lighting, single-stage PFC converters are preferred. A single-stage buck–boost PFC converterhas the advantage of low cost and high PF, which make itwidely applied in single-output nonapplications [18]. In this paper, a novel single-inductor dualoutput (SIDO) buck–boost PFC converter operating in criticalconduction mode (CRM) is proposed. Its control strategy and corresponding characteristics are analyzed. Independent regulation of each output can be achieved in this converter by multiplexing a single inductor. Compared with a conventional two-stage multiple-output converter, the proposed converter benefits from significant overall cost saving, small size, lightweight, and

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high power conversion efficiency due to singlestage power conversion. The proposed converter can also be easily extended to realize the SIMO buck–boost PFC converterto fulfill different systemrequirements.

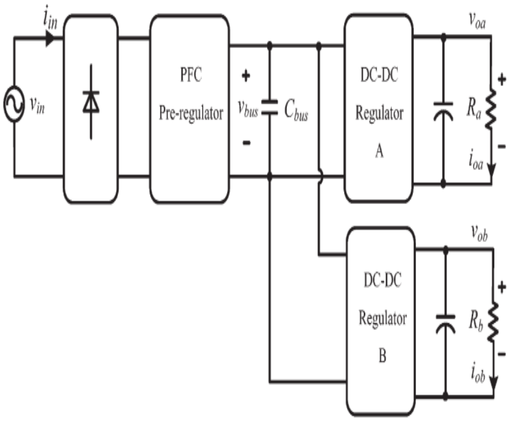


Fig. 1. Block diagram of a conventional multiple-output ac/dc power converter with a high PF.

### 3.2 Preliminaries and Problem Formulation

Single-stage flyback PFC converter (Fig. 2) consists of a diode bridge connected in series with a flyback converter and a large output capacitor. The flyback PFC converter is designed to operate in discontinuous conduction mode (DCM). It modulates the main switch S1 with an almost constant duty cycle Dconv at switching frequency fs. The objective of the PFC converter is to obtain an input current that is synchronized with the sinusoidal input voltage. Assuming lossless operation, the conventional duty-ratio feedforward controller Dconv can be obtained as [11]

$$D_{conv} = \frac{\sqrt{2P_o L_m f_s}}{V_{rms}} \tag{3.1}$$

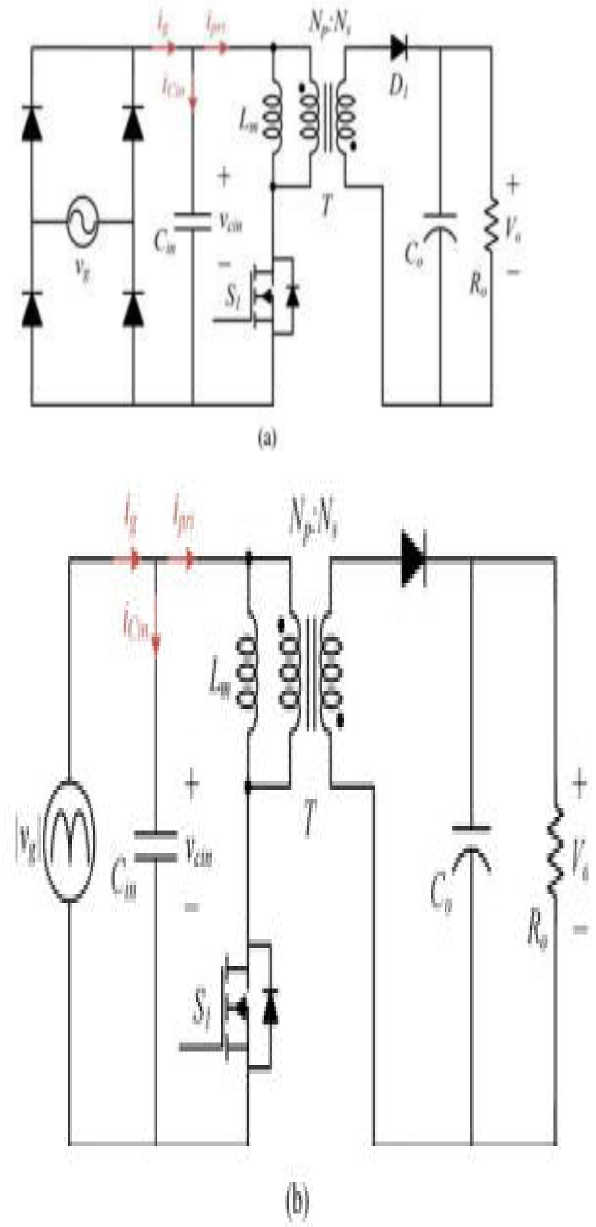


Fig. 2. Schematic diagram of the single-stage flyback PFC converter.(a) Schematic diagram. (b) Equivalent circuit.

where Po is a desired average power output, Lm is the magnetizing inductance seen from the primary winding, fs is the switching frequency, and Vrms is the root-meansquare of the input voltage. Then, the primary current can be represented as

$$i_{pri}(t) = \frac{D_{conv}^2 V_{rms} |\sin(2\pi f_L t)|}{\sqrt{2} L_m f_s} \tag{2}$$

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Where fL is the grid frequency. The total input current ig(t) is the sum of the primary current ipri(t) and the input capacitor current iCin(t)

$$(i_g(t) = i_{pri}(t) + i_{Cin}(t)). \quad (3)$$

The rectified grid voltage is applied to the input capacitor: vCin(t) = √2Vrms| sin(2πfLt)|, so

$$i_{Cin}(t) = C_{in}\frac{dv_{C_{in}}(t)}{dt} = \begin{cases} 2\sqrt{2}\pi f_L V_{rms} C_{in}\cos(2\pi f_L t) & \text{if } 0 < 2\pi f_L t < \pi \\ -2\sqrt{2}\pi f_L V_{rms} C_{in}\cos(2\pi f_L t) & \text{if } \pi < 2\pi f_L t < 2\pi \end{cases} \quad (4)$$

where Cin represents the input capacitance. Eq. (4) demonstrates that iCin increases as fL, Vrms or Cin increases, but that iCin is independent of Po. When the conventional nominal duty is used, iCin does not greatly affect the total input current in the heavy load condition, but iCin occupies a progressively larger portion of the total input current as load decreases, and thereby shifts and distorts the total input current (Fig. 2). To compensate the effect of the input capacitor current, a new duty-ratio feed-forward controller should be developed for flyback PFC converter.

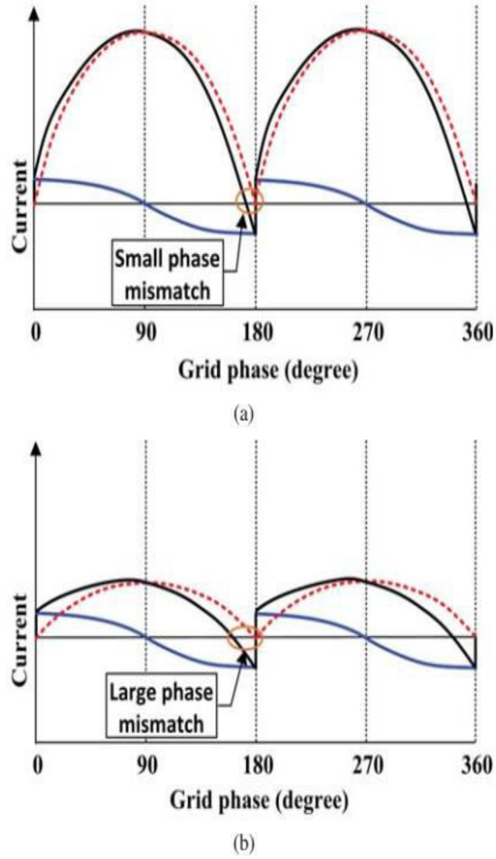


Fig. 3. Total input current (black solid line), primary current (red dashed line) and input capacitor current (blue solid line). (a) Under heavy load. (b) Under light load.

## 3 CONTROLLER DESIGN

The main control objective of the flyback PFC converter is to make the grid current become sinusoidal. The inner-loop current controller mainly controls the grid current. Also, flyback PFC converter should have the constant output voltage, which can be controlled by the outer loop controller. When the conventional duty cycle is used at the light load, the power factor decreases due to the effect of the input capacitor. To improve the displacement and distortion power factors, we propose a new duty-ratio feed-forward controller Dcomp for the flyback PFC converter.

The averaged input capacitor current Ts over a sampling period Ts. Here, we set the sampling period equal to the switching period. Then, we have

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$$\langle i_{Cin}(t)\rangle_{T_s} = \frac{\int_0^{T_s} i_{Cin}(\tau)d\tau}{T_s} = \frac{C_{in}}{T_s}(|v_{Cin}(T_s)| - |v_{C_{in}}(0)|). \tag{5}$$

In the discrete time domain, Eq. (5) can be expressed as

$$\langle i_{Cin}(t)\rangle_{T_s} = \frac{C_{in}}{T_s}(|v_{Cin}[k]| - |v_{Cin}[k-1] \tag{6}$$

where k is the discrete time index, vCin[k] is the present input capacitor voltage and vCin[k − 1] is the previouslysampled input capacitor voltage.

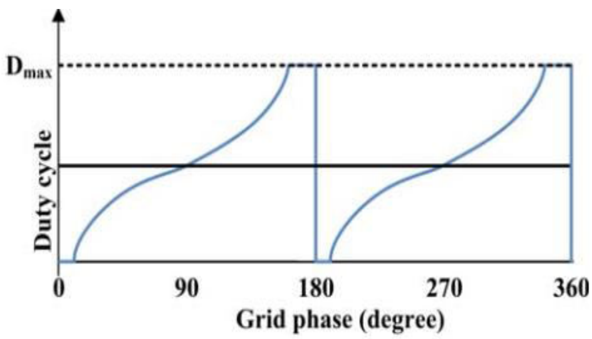


Fig. 4. Proposed feedforward duty cycle (Blue solid line) vs. conventional duty cycle (Black solid line).

The desired average grid current ig can be represented as

$$\langle i_g(t)\rangle_{T_s} = \frac{\sqrt{2}P_o}{V_{rms}}|\sin(2\pi f_L k T_s)|. \tag{7}$$

Then the compensated primary current should be

$$\langle i_{pri,comp}(t)\rangle_{T_s} = \langle i_g(t)\rangle_{T_s} - \langle i_{Cin}(t)\rangle_{T_s}. \tag{8}$$

Rearranging eq. (2) and using eq. (8), we have the compensated feed-forward duty-ratio

$$D_{comp}(t) = D_{conv}\sqrt{\frac{i_{pri,comp}(t)}{i_{pri}(t)}} \tag{9}$$

The PFC converter cannot generate the negative current due to hardware limitations. Thus, when the compensated current is negative, the control duty is set to zero. When the compensated current is positive, the control duty is set to D comp(t). Since the required control duty is excessively high near the end of every half cycle, the control duty is set to a maximum duty Dmax. Then, the resulting feed-forward duty-ratio becomes

$$D_{new}(t) = \begin{cases} 0 & \text{if } \langle i_{pri,comp}(t)\rangle_{T_s} < 0 \\ D_{comp}(t), & \text{if } \langle i_{pri,comp}(t)\rangle_{T_s} \geq 0 \\ D_{max}, & \text{if } D_{comp}(t) \geq D_{max} \end{cases} \tag{10}$$

When we use the new nominal duty for the fly back PFC converter (Fig. 3), the capacitor input current can be completely compensated, therefore unity PF can be achieved theoretically.

### (4) Hybrid fuzzy Logic controller

Fuzzy controllers demonstrate excellent performance in numerous applications such as industrial processes and flexible arm control.Mamdami's work introduced this control technology that Zadeh pioneered with his work in fuzzy sets. Unlike "two valued" logic, fuzzy set theory allows the degree of truth for a variable to exist somewhere in the range [0,1]. For example, if pressure is a linguistic variable that describes an input, then the terms low, medium, high and dangerous describe the fuzzy set for the pressure variable. If the universe of discourse for pressure is [0, 100], then low could be defined as "close to 10", "medium" is "around 40", and so on. For control applications, linguistic variables describe the control inputs for dynamic plants and rules define the relationships between the inputs. Thus, precise knowledge of a plant's transfer function is not necessary for design and implementation of the controller. The thrust of earlier efforts involved replacing humans in the control loop by describing the operators' actions in terms of linguistic rules.

There are two steps involved in the implementation of a fuzzy logic controller; fuzzification of inputs and determination of a "crisp output." Fuzzification involves dividing each input variable's universe of discourse into ranges called fuzzy subsets. A function applied across each range determines the membership of the variable's current value to the fuzzy subset. Linguistic rules express the relationship between input variables. Table I is an example of a matrix of rules to cover all possible combinations of fuzzy subsets for two input variables. In this case, each variable has seven subsets that gives a total of 49 rules. Defuzzification to determine the "crisp output", resolves the applicable rules into a single output value.

Table 1: PD Control Rule Matrix

| Change In Error \ Error | NB | NM | NS | ZO | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| PB | ZO | PS | PM | PB | PB | PB | PB |
| PM | NS | ZO | PS | PM | PB | PB | PB |
| PS | NM | NS | ZO | PS | PM | PB | PB |
| ZO | NB | NM | NS | ZO | PS | PB | PB |
| NS | NB | NB | NM | NS | ZO | PS | PM |
| NM | NB | NB | NB | NM | NS | ZO | PS |
| NB | NB | NB | NB | NB | NM | NS | ZO |

PID controllers are designed for linear systems and they provide a preferable cost/benefit ratio. However, the presences of nonlinear effects limit their performances. Fuzzy controllers are successful applied to non-linear system because of their knowledge based nonlinear structural characteristics. A FLC makes control decisions by its well-known fuzzy IF–THEN rules. FLCs can be classified into two major categories: the Mamdani type FLC that uses fuzzy numbers to make decisions and a Takagi– Segno (TS) type FLC that generates control actions by linear functions of the input variables. In the early years, most FLCs were designed by trial and error. Since the complexity of a FLC increases exponentially when it is be used to control complex systems. Hybridization of these two controller structures comes to one's mind immediately to exploit the beneficial sides of both categories. The two control structures are combined by a switch. In a fuzzy switching method between fuzzy controller and conventional PID controllers is used to achieve smooth control during switching. The motive to design a new hybrid fuzzy PID controller so that a further improved system response performance in both the transient and steady states can been achieved as compared to the system response obtained when either the classical PID or the fuzzy controller has been implemented.

Classical PID controller is the most popular control tool in many industrial applications because they can improve both the transient response and steady state error of the system at the same time. Moreover, it has simple architecture and conceivable physical intuition of its parameter. Traditionally, the parameters of a classical PID controller, i.e. KP, KI, and KD, are usually fixed during operation. Consequently, such a controller is inefficient for control a system while the system is disturbed by unknown facts, or the surrounding environment of the system is changed (Panichkun&Ngaechroenkul, 2000; Pratumsuwan et al, 2010). Fuzzy control is robust to the system with variation of system dynamics and the system of model free or the system which precise information is not required. It has been successfully used in the complex ill-defined process with better performance than that of a PID controller. Another important advance of fuzzy controller is a short rise time and a small overshoot (Aliyariet al, 2007; Panichkun&Ngaechroenkul, 2000). However, PID controller is better able to control and minimize the steady state error of the system. To enhance the controller performance, hybridization of these two controller structures comes to one mind immediately to exploit the beneficial sides of both categories, know as a hybrid of fuzzy and PID controller (Panichkun&Ngaechroenkul, 2000;Pratumsuwanetal, 2010).

Nevertheless, a hybrid of fuzzy and PID does not perform well when applied to the SEHS, because when the SEHS parameters changes will require new adjustment of the PID gains.

During the design of fuzzy based hybrid controller, the designer meets two key design challenges namely, optimization of existing fuzzy rule base and identification, estimation of new membership function or optimization of existing membership function. These issues play a vital role in controller design in real time. In real time

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controller hardware design there is memory and computational power constraints, so a designer needs to optimize these two design aspects.

Recent research into fuzzy control has applied classical techniques to stability analysis and design. The operation of a fuzzy controller behaves similar to a classical PD or PI controller. For a classical PD controller, the position and derivative gains remain constant for all values of input. However, for a fuzzy controller, the gains depend on the range where the control variables exist at any instant. The piecewise linearity of the fuzzy controller provides better system response than a classical controller. Also, since the operating point of the fuzzy controller is not fixed, it provides improved robustness to changes in the system parameters as compared to a classical controller.

Logically, it should be possible to divide the action of the PID controller into two separate control actions: PD controller for fastest response and PI controller for the elimination of the steady-state error. Obviously, the plant must be capable of being compensated by a PI controller. Figure 5 is the implementation of the proposed hybrid fuzzy PID control scheme. Similar to separate control rule tables for" coarse" and "fine" control, a PD controller provides the "coarse" control and the PI controller gives the "fine" control. The PI portion activates only when the PD portion reduces the error and change in error to where both are in the ZO fuzzy subset range. Therefore, at any instant, calculation of the control action involves only four control rules where as a three control variable controller (i.e. a typical PID) requires eight. If the three control variables of the hybrid controller contain seven subsets each, only a maximum of sixteen subsets would be checked to determine the applicable rules. The rule search first checks the two ZO subsets for the PD portion and then checks at most all fourteen of the PI portion subsets. For the hybrid fuzzy PID controller, the PD and PI portions are designed separately and logic controls when to switch between the two controllers. The logic switches to the PI portion when both change of error and error are in the ZO range. The PD portion must not be re-enabled until the error variable moves out of the ZO range, regardless of the change in error variable. The PI portion in the process of reaching steady-state obviously creates a change in error that might be out of the PD's ZO range and thus reactivate the PD portion.

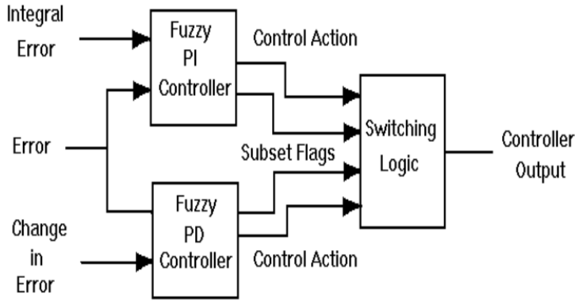



Figure 5 Hybrid PID Fuzzy Logic Controller

**5) MATLAB/SIMULATION RESULTS**

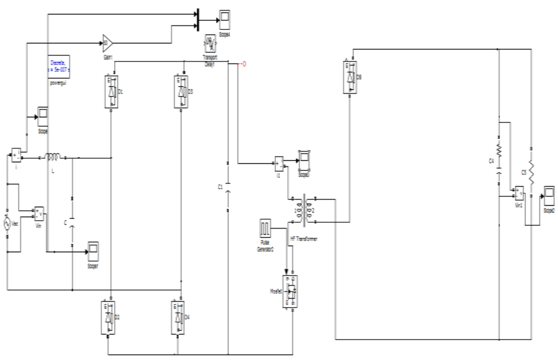
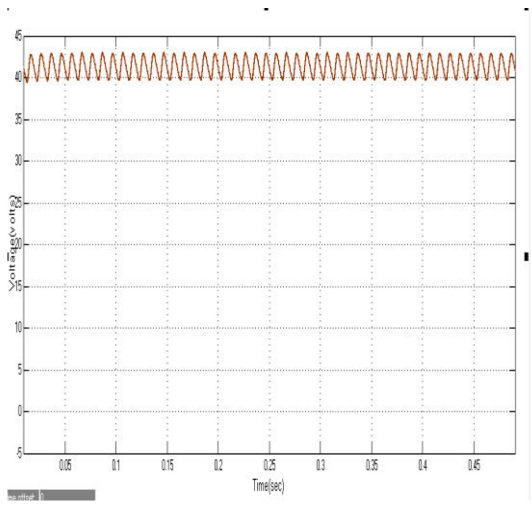


Fig 6 Simulink Diagram Of Proposed Converter




(a) Output Voltage

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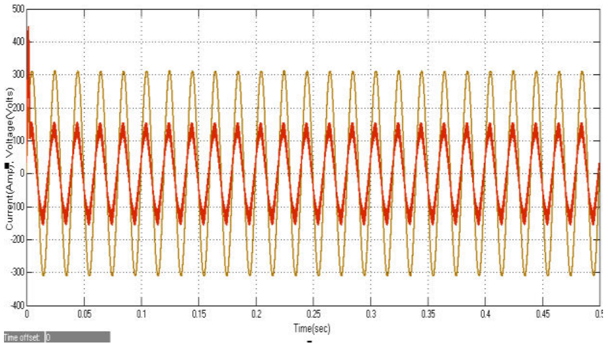
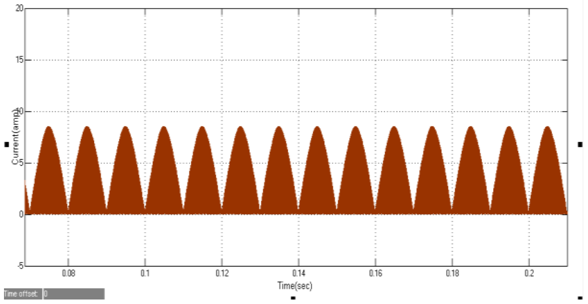
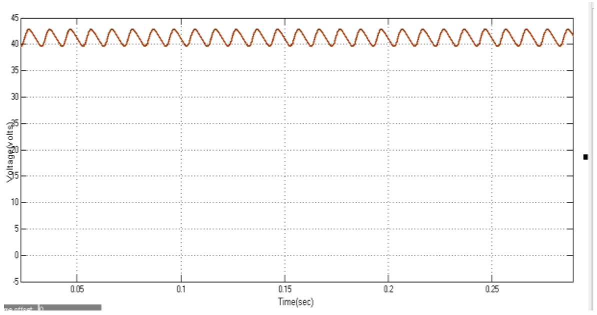


(b) Grid Voltage and Grid Current

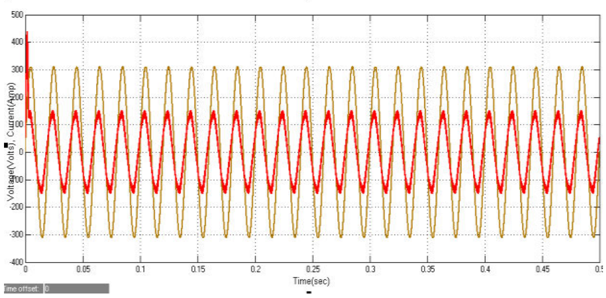


(c) primary current

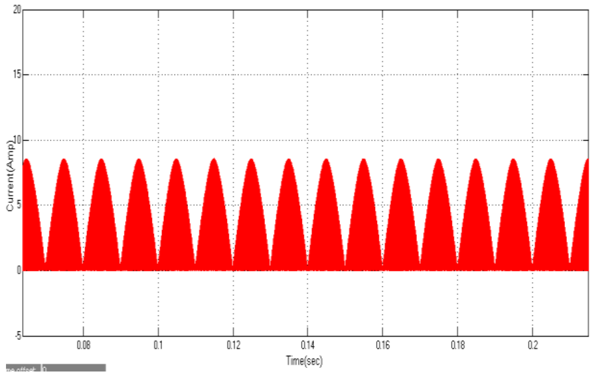
Fig. 7 Simulations waveforms under half load condition when the conventional nominal duty is used.;



(a) Output Voltage



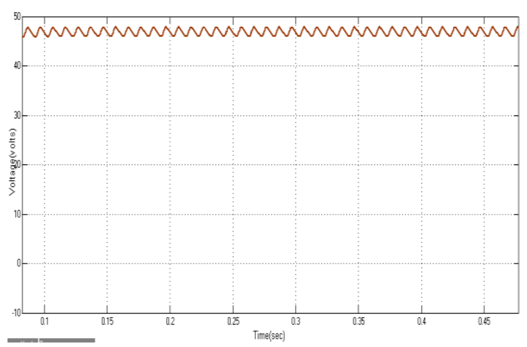
(b) Grid Voltage and Grid Current



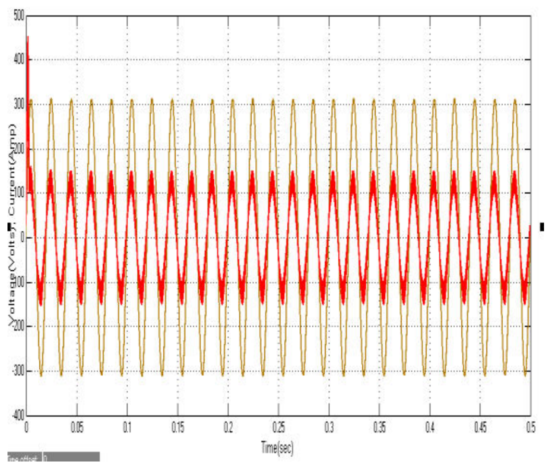
(c) primary current

Fig. 8 Simulations waveforms under half load condition when the proposed nominal duty is used.

When the conventional feed-forward controller was used, the input current was distorted and out of phase with the grid voltage due to the effect of the input capacitor current (Fig. 7). When the proposed feed forward controller was used, the input current was close to sinusoidal and in phase with the grid voltage (Fig. 8).



(a) Output Voltage



(b) Grid Voltage and Grid Current

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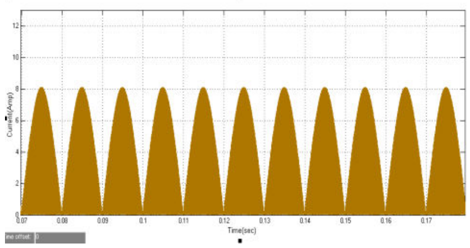
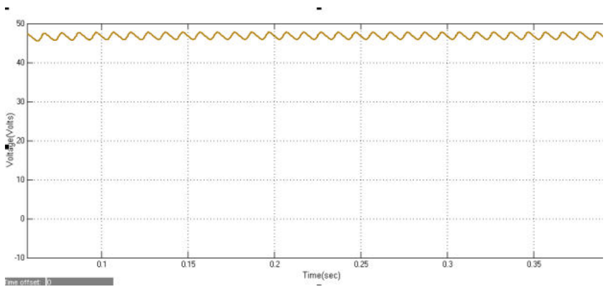
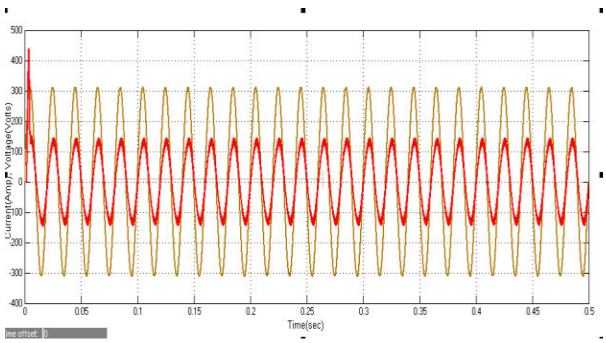


(c) primary current

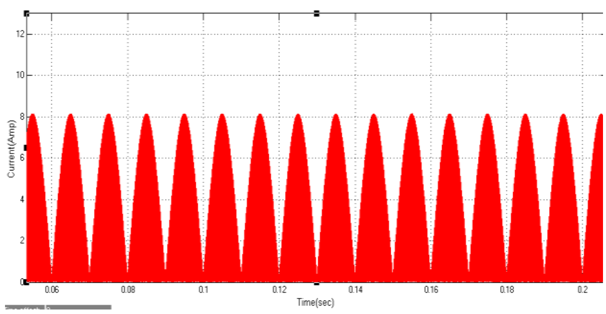
Fig. 9 Simulations waveforms under quarter load condition when the conventional nominal duty is used.



(a) Output Voltage



(b) Grid Voltage and Grid Current



(c) primary current

Fig. 10 Simulations waveforms under quarter load condition when the proposed nominal duty is used.

Moreover, the current distortion near the zero crossing point was diminished. At quarter load, when the conventional nominal duty was used, the input current was close to sinusoidal, but the phase discrepancy becomes greater than that under half load condition (Fig. 9). When the proposed controller was used, the input current was sinusoidal and in phase with grid voltage (Fig. 10)

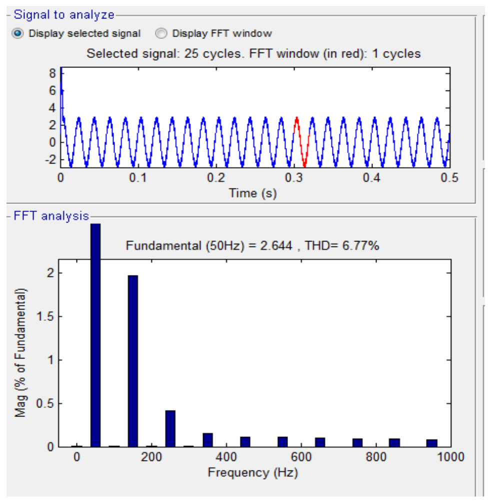



Fig. 11 Total Harmonic Distortion (THD) of PI Controller.

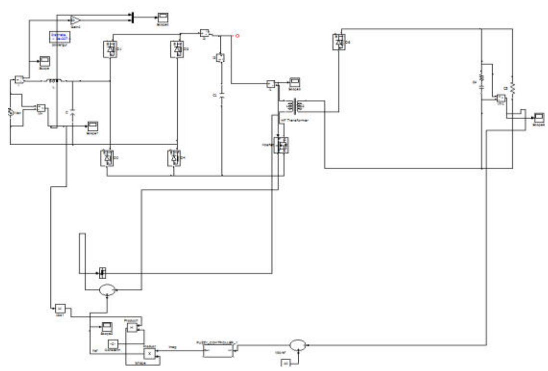


Fig 12 Simulink diagram of Hybrid Fuzzy Logic controller Proposed System

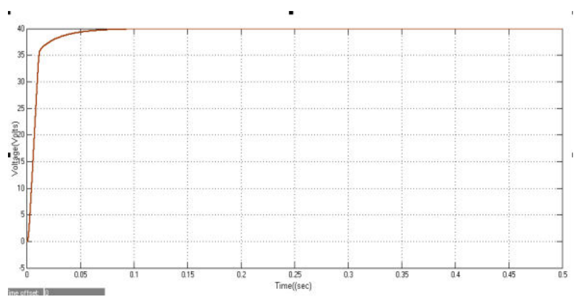


Fig. 13 Simulations Output Voltage waveforms under quarter load condition when the proposed nominal duty is used.

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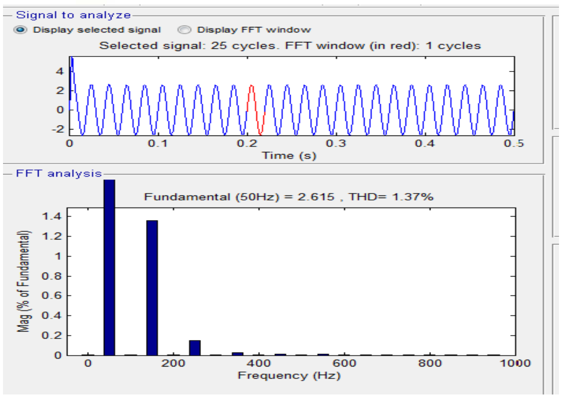


Fig. 14 Total Harmonic Distortion (THD) of Hybrid Fuzzy Logic Controller.

## (6) CONCLUSION

To improve the power factor under the light load, we propose a duty-ratio feed-forward controller for the fly back PFC converter with PI & Hybrid Fuzzy logic controllers. The fly back PFC converter PI & Hybrid Fuzzy logic controllers feature step-up/down ability, low cost, and high efficiency. However, it suffers from low power factor and total harmonic distortion under the light load due to the input capacitor effect. The proposed feed-forward PI & Hybrid Fuzzy logic controller aims at compensating the phase leaded current caused by the input capacitor. We describe the implementation of the controller, the required compensated current, and the controller structure in detail. We conducted Simulations with a 100-W prototype to verify the operation of the proposed feed-forward controller. The proposed feed forward PI & Hybrid Fuzzy logic controller significantly increased the power factor of the converter. Meanwhile, the output voltage of the PFC converter is well regulated.

## REFERENCES

[1] Limits for harmonic current emissions. IEC 61000-3- 2:2018, Dec. 2004.
[2] Environmental Protection Agency (EPA). "Energy star program requirements for single voltage external ac–dc and ac–ac power supplies," [Online]. Available: https://www.energystar.gov/ia/partners/product specs/programreqs/EPS Eligibility Criteria.pdf.
[3] J. J. Lee, J. M. Kwon, E. H. Kim, W. Y. Choi and B. H. Kwon, "Single-stage single-switch PFC flyback converter using a synchronous rectifier," IEEE Trans. on Ind. Electron., vol. 55, no. 3, pp. 1352-1365, Mar. 2008.
[4] H. Khalilian, H. Farzanehfard, E. Adib, and M. Esteki, "Analysis of a new single-stage soft-switching power-factor-correction LED driver with low DC-bus voltage," IEEE Trans. Ind. Electron., vol. 65, no. 5, pp. 3858-3865, May 2018.
[5] S. W. Lee and H. L. Do, "A single-switch AC–DC LED driver based on a boost-flyback PFC converter with lossless snubber," IEEE Trans. Power Electron., vol. 32, no. 2, pp. 1375-1384, Feb. 2017.
[6] K. S. Kim, J. M. Kwon, and B. H. Kwon, "Singleswitch single power-conversion PFC converter using regenerative snubber. IEEE Trans. Ind. Electron., vol. 65, no. 7, pp. 5436-5444, Jul. 2018.
[7] S. Y. Park, C. L. Chen, J. S. Lai, and S. R. Moon. "Admittance compensation in current loop control for a grid-tie LCL fuel cell inverter," IEEE Trans. Power Electron., vol. 23, no. 4, pp. 1716-1723, Jul. 2008.
[8] J. W. Kim and G. M. Moon, "Minimizing effect of input filter capacitor in a digital boundary conduction mode power factor corrector based on time-domain analysis," IEEE Trans. Power Electron., vol. 31, no. 5, pp. 3827-3836, May 2016.
[9] H. S. Youn, J. B. Lee, J. I. Baek, and G. W. Moon, "A digital phase leading filter current compensation (PLFCC) technique for CCM boost PFC converter to improve PF in high line voltage and light load conditions," IEEE Trans. Power Electron., vol. 31, no. 9, pp. 6596-6606, May 2016.
[10] O. A. Montes, S. Son, J. W. Kim, J. S. Lee and M. Kim, "Duty-ratio feed-forward controller design to minimize the capacitor effect of the flyback inverter under light load condition," IEEE Trans. Power Electron., vol. 33, no. 12, pp. 10979-10989, Dec. 2018.
[11] R. Erickson, M. Madigan and S. Singer, "Design of a simple high-power-factor rectifier based on the flyback converter," IEEE Applied Power Electronics Conference, Los Angeles, CA, USA, pp. 792-801, 1990.