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Fuzzy Controlled 1-Φ Integrated AC/DC PFC Converter

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Design and performance analysis of 1-Φ, single switch, isolate integrated AC/DC converter is presented in this work. In this proposed topology voltage across the bulk capacitor is low and having single switch, hence reduce in controller complexity and cost. Because of the robust and effective than conventional controllers, in this paper the fuzzy controller (FLC) is proposed to generate control signal to switch. The proposed converter has been implemented and evaluated using a Texas Instruments (TI) TMS320F2812. The proposed system is designed for input of (90–230 V, AC), 50 Hz, output of 48 V (DC) and operating at 100 kHz and verified experimentally & simulation at various load conditions. The designs and realizes digital (TMS320F2812) fuzzy controlled 1-Φ, single switch, integrated AC/DC converter meet the international regularity standards for class-C & D appliances.

Keywords: Bulk capcitor, Digital Signal Processor, Power Factor Correction, Simulation

Introduction

Due to increase in use of power electronic based AC/DC converters to supply electric power for various applications, more attention has been paid on increase in power factor (PF) by reducing harmonic content in the input current drawn from supply mains. In lately years, 1-ɸ, AC/DC switch-mode converters have been progressively using in various engineering owing to features of lighter components with compact size and more efficiency. With rapid growth of switching converters introduces highly non sinusoidal input currents into the supply system, which not only reduces the input power factor also infuses a substantial quantity of harmonic content into the supply mains. The manufacturers of power converters have to maintain the stipulated power quality levels to nullify EMI effects for this purpose various organizations set different standards such as IEC-61000-3-2. In the literature two methods of PFC techniques have been implemented namely passive and active PFC techniques.

PFC Techniques

The passive PFC technique is simple to implement but high power factor can't be achieve, so this technique is not suitable for the present trends of harmonic regulations. Active PFC cell is deployed at the front-end to track the source current with the source voltage. This technique can be developed using either the two stage approach or the single-stage approach.[1]

In two stage active PFC contains source current shaping converter followed by DC–DC converter. Controlling of two converters are done independently to obtain sinusoidal input current wave and fast load voltage regulation. This method can obtain high power factor, lower harmonics in source current. This is not applicable for low power application due to it's high cost. Hence a one-stage design is proposed, which is capable of producing step up and step down operation. The performance of single stage PFC rectifiers, measured in terms of efficiency, number of components, voltage rating of components, current stress, and quality of input current.[2–5] These performance measures are dependent on circuit topology, such as conventional Buck-Boost converter; two switch Buck-Boost converter, Buck-Boost-Buck converter and integrated Buck-Fly back converter topology.[4]

Literature reveals that 1-ɸ, single switch integrated converter improves the system reliability even with reduced number of switches as well as the ability to operate at low and medium power applications. In this paper, integrated buck-Flyback converter (IBFC) is considered as an integrated converter. IBFC offers certain advantages like freedom from the use of center taped transformer and allowing either only buck or flyback inductor current whichever is greater but not sum of both like other integrated converters.[6–8]

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To obtain the fast dynamics of the converter, a control loop has been used. Commonly used control techniques are PI based voltage and current control. However these techniques entail a better understanding about the system and better tuning in-order to obtain desired performance. These controllers' design is simple and implementation can be done easily. Performance of controller depends on the behavior of parasitic elements, load and input variations of the system/, which makes the control parameters selection in any operating condition becomes difficult. Intelligent controller doesn't require system's precise mathematical model. It can also tackle nonlinearity in the system. Among the several intelligent controllers, Fuzzy controller is known for its good precision, ease of integration with system and speed in processing hence, a completely novel approach is designed by fuzzy logic approach. FLC is a non-linear type of controller; it is designed based on experience on the system behavior but not on the accurate system's mathematical model like linear controllers.[9,10]

Now days, digital signal processor based control is being extensively used in many electrical applications because of advantages like easier parameter adjustment, simple realization of various control schemes, reduced component count, reduced cost, more robustness, and high immunity to noise.[11,12]

In this paper, a fuzzy controller based integrated converter is proposed and real time implementation has been done using a TMS320F2812 digital signal processor (DSP) board.

Experimental Details

Converter Design

Integration of converters means, integrating the PFC stage with power control (PC) stage which are operating at same switching frequency and duty cycle. The aim of integrating the power stages is to decrease count of switches and their driver schemes and improvement in system reliability. Integration of buck and flyback converter has been accomplished as in Fig. 1(a). Buck circuit consists of Lb, Dc, Da, SW1, Cb, Vp and Flyback circuit consists of Cb, SW1, 1:m, Db, Da, Dd, Co. SW1 is common switch for both circuits.

In this IBFC, flyback converter followed with buck converter by sharing common single control switch SW1. Fly back converter fed from output of the buck converter. Performance analysis of the proposed IBFC can be done with the help of the low frequency equivalent circuit shown in Fig. 1(b). Design Parameters of the proposed IBFC are shown in Table 1.

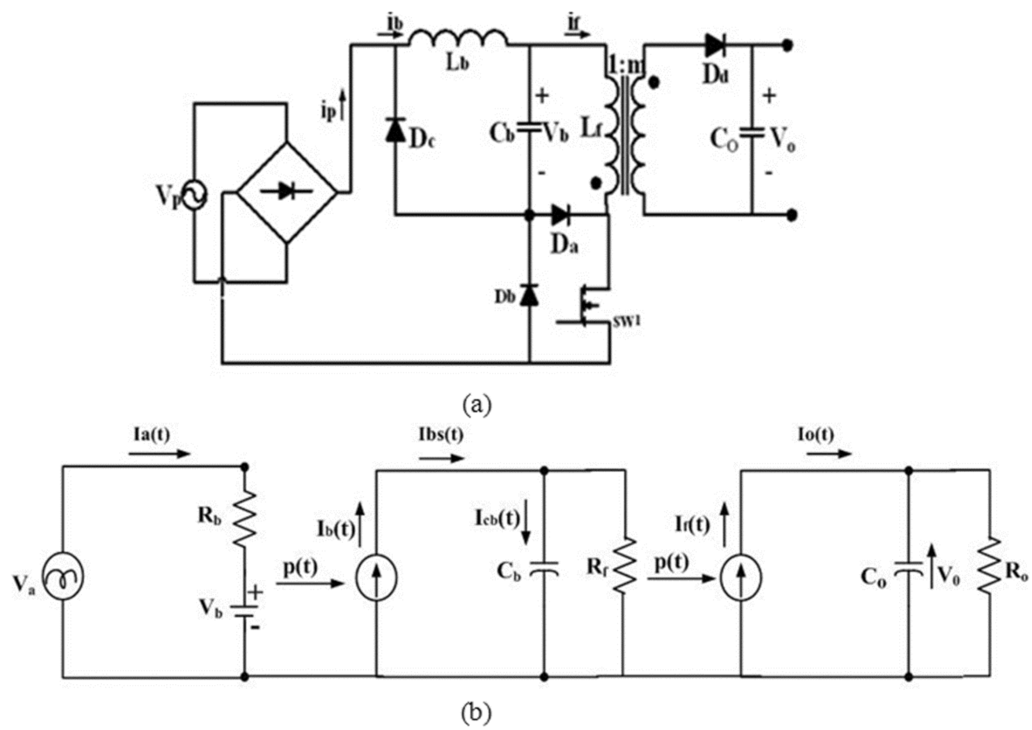


Fig. 1 — (a) Circuit Model of IBFC; (b) Low frequency model of integrated isolated converter

Table 1 — Component values

Parameter	Symbol	Specification
Input voltage	Va	90-230 V
Output voltage	Vo	48V
Output power	p	100 W
Conduction period	θ	1200
Switching frequency	fs	100 KHz

Inductor of buck converter (L_{bu}) can be calculated from Eq. (1).

$$L_{bu} = \frac{D^2}{P_{in}} \frac{T_s}{T_r} \int_{t_1}^{t_2} (V_a(t)(V_a(t) - V_b))dt$$

$$t_1 = \frac{T_r}{2\pi} a\sin(\frac{V_b}{V_a}) \text{ And } t_2 = \frac{T_r}{2} - t_1 \quad \dots (1)$$

Where t_1 and t_2 are the conduction duration instants of the buck mode as given, Output capacitor and bus capacitor vales are calculated from Eq. (2)

$$C_0 = \frac{1}{\Delta V_{ohf}} \int_{t_3}^{t_4} (i_{C_0}(t))dt \quad \dots (2)$$

Where $i_{Cb}(t)$ is bus capacitor current as in Eq. (3) and ΔV_b is the bus voltages ripple.

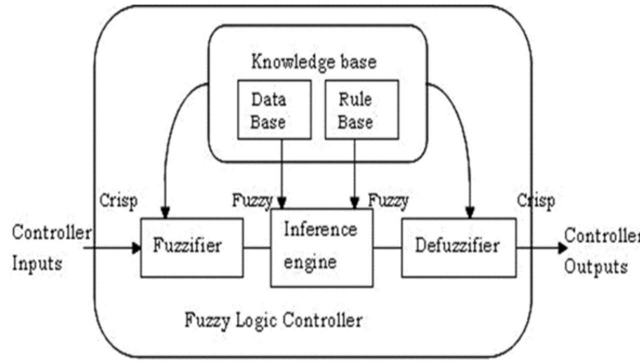
$$i_{C_b}(t) = i_{L_b}(t) - I_{L_p}(t) \quad \dots (3)$$

DSP based Fuzzy Logic Controller

Converter output voltage is regulated with FLC by mamdani type fuzzy inference systems. The error between reference voltage and converter output voltage and its change are the inputs to FLC. The output of FLC is the duty cycle control of converter. The FLC and its components are shown in Fig. 2(a).

FLC, with the support of knowledge and experience of expert it improves the performance of the system. Applying intelligent control techniques for problem related to uncertainty makes use of IF-THEN rules to define the rapport among the inputs and outputs. Simulation is carried out to check the performance of the design and if the design is not up to the mark, modifications are made to tune the limits of the controller by changing the fuzzy rules and the procedure is repeated for better results.

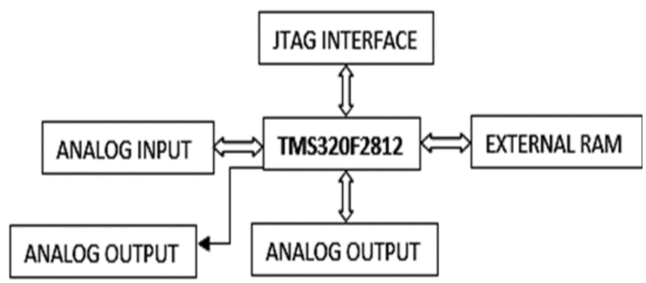
Several steps intricate in the design of fuzzy controllers, Measures the estimation of information factors and plays out a scale mapping that exchanges the scope of estimations of information factors into the comparing universes of talk and afterward plays out the capacity of fuzzification, which changes over information into appropriate phonetic qualities that might be seen as names of fluffy sets. Scale mapping, which changes over the scope of estimations of yield factors into relating universes of talk, at that point changes the fluffy control activities to persistent (fresh) signals, which can be connected to the physical plant.



(a)

CE \ E	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

(b)



(c)

Fig. 2 — (a) FLC and components; (b) FLC Rule Base; (c) General Hardware block diagram

FLC consists of following components: Fuzzifier converts crisp data into fuzzy data; Knowledge base contains data base & fuzzy rule set; Inference engine deduce the fuzzy control action from the knowledge base and simulating a human decision process. Defuzzification yields crisp value from fuzzy action.

Proposed system having 7*7 rules is shown in Fig. 2(b). It has seven variables named as N1, N2, N3, Z, P1, P2, P3. Triangular shapes are used as a membership function and center of gravity method is used for defuzzification process.

Microcontrollers based FLCs for power converters have been implemented, but because of having high sampling frequency control DSPs are used. In this paper fuzzy controllers have been implemented using TMS320F2812 DSP, which is a 32-bit processor and operates at 150MHz. Because of using triangular membership function there is a reduction in computation time, hence in this paper fuzzy membership functions are triangular.

The process of a digital converter is alike to its analog counter. The digital converter contains the recompense network, fault amp, slant recompense, and PWM generator which are working in the discrete time domain. This application describes the use of a Texas Instruments TMS320F2812 DSP processor.

The duty is to initially set 100%, but tripped using the cycle-by-cycle trip feature of the processor. The yield voltage of the converter is connected to a resistive "inspecting divider" arrangement that is associated with ADC. The voltage is tested and changed over to an advanced esteem. An advanced reference (REF) is subtracted from the computerized esteem and the mistake esteem will be utilized as a contribution to the computerized controller. This structures into the mistake intensifier and remuneration system of the simple identical.

The output of the controller is multiplied by a gain term K, which scales the output of the controller to a digital value apt for use with the Digital Analog Converter (DAC) of the comparator module.

The general hardware structure is shown in Fig. 2(c). Output of converter is sampled by A/D converter, which gives the digital value to the fuzzy controller. The controller process the data to produce a PWM signal to the control switch SW_1 of the converter.

Results and Discussion

Simulation Results

The proposed fuzzy controlled integrated AC / DC converter is developed in MATLAB / Simulink software. The simulation model of the proposed converter is shown in Fig. 3(a). In the observed simulation results the input voltage and current waveforms at rated value of the supply (230 V) and at rated load of 100 W are in phase. The power-factor of the converter at this voltage is 0.982 and THD of current signal is 13.23%, which is observed from current harmonic spectra. The output voltage waveform at the load terminals of the converter in the rage of 90 V – 230 V and load of 100 W, which maintains regulated voltage of 48 V with fewer ripples and the load current waveform, which maintains at 2.1 A to suit full load of 100 W.

Experimental Results

Experimental setup has been implemented to validate the simulation results; through it the performance of the proposed fuzzy integrated AC/DC converter is analyzed. The source voltage and current waveforms, Load current and voltage waveforms, and harmonics content of the source current are observed. The experimental setup of proposed fuzzy integrated AC / DC converter with controller is shown in Fig. 3 (b). The experimental result of line current is shown in Fig. 3(c), which is in-phase with supply voltage of 230 V. Corresponding measured power factor is 0.973 with % THD of 16.348 and source current follows the source voltage. Load current and voltage waveform, maintains regulated voltage of 48 V and 2.1 A of load current. The graphs between voltage and power factor, voltage and % THD respectively are depicted in Fig. 3(d) and Fig. 3 (e). It is observed that at lower voltage (90 V) power factor is low (0.925) and THD content is high (22.07%), whereas at high voltage (230 V) power factor has a significant increase and is found to be 0.982 with a decreased THD content (13.23%).

Comparison of simulation and experimental results are tabulated in Table 2, from that it can be concluded that, proposed DSP based integrated AC / DC converter operating at low voltage (90 V) gives low power factor and high % current THD and it increases to 0.982 in simulation and 0.973 in experimental trial at a voltage (230V) and the corresponding THD is 13.23% in simulation and 16.348% experimental condition at full load of 100 W.

From the experimental and simulation results shown in Fig. 3, it is clear that the propose fuzzy controlled integrated AC / DC converter implemented through DSP is most suitable for the low / medium / high voltage operations

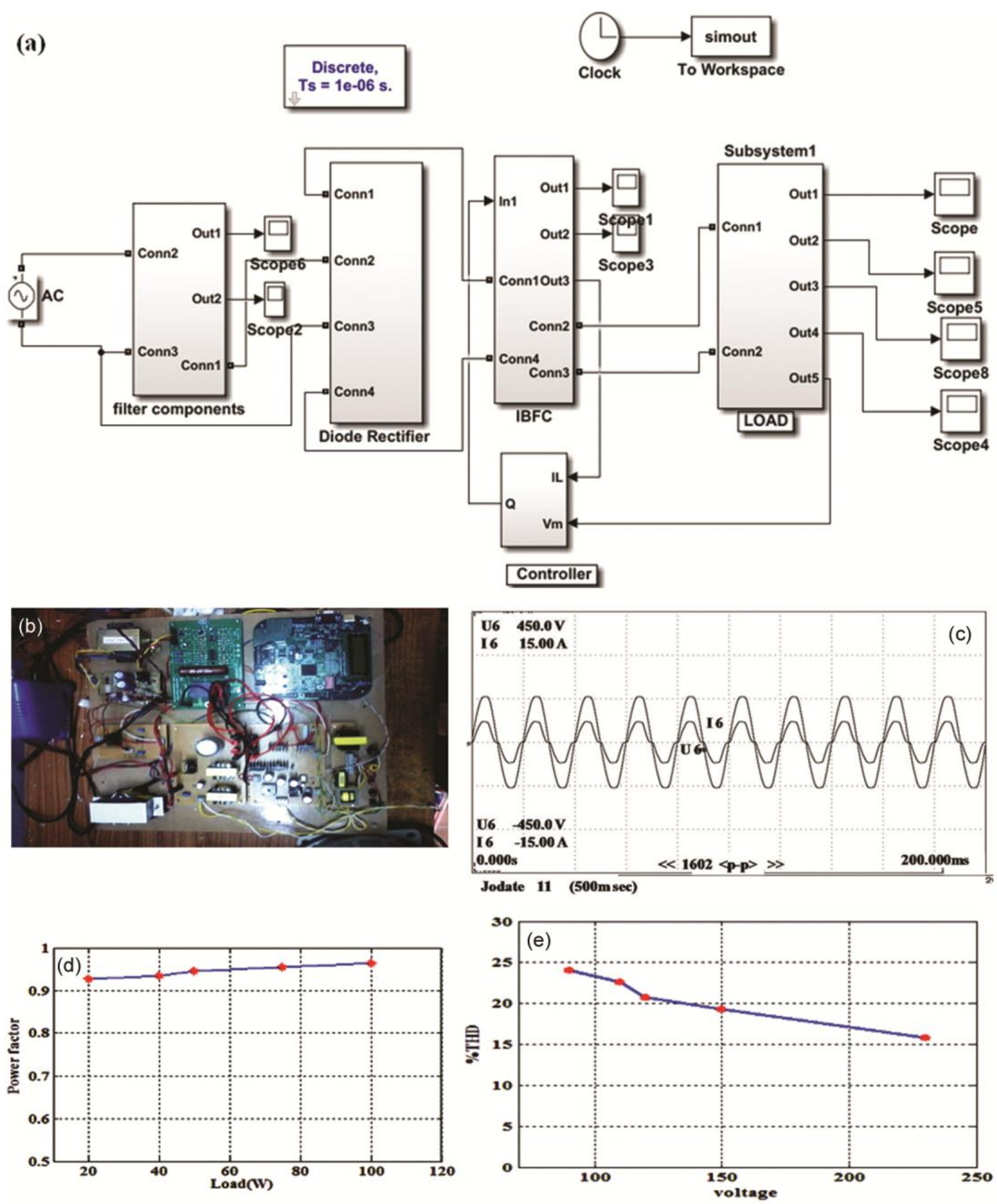


Fig. 3 — (a) Simulink Diagram of Integrated AC/DC PFC Converter; (b) Proto type of implemented DSP based Fuzzy Controlled IBFC; (c) Experimental waveforms of supply voltage & Current (230 V & full load); (d) Plot between line voltage and power factor; (e) Plot between line voltage and % THD

Table 2 — Simulation & Experimental results at different source voltages at full load

Simulation Results			Experimental Results		
Voltage	PF	THD (%)	Voltage	PF	THD (%)
90	0.925	22.07	90	0.901	23.782
110	0.938	20.12	110	0.92	22.468
150	0.964	15.58	150	0.952	18.413
230	0.982	13.23	230	0.973	16.348

Conclusions

Design and implementation of DSP TMS320F2812 based fuzzy controlled 1-Φ, single switch, integrated converter for PFC has been presented. Simulation and experimental results are presented, from hardware, it has been observed that the power factor of the converter is 0.973 and % THD is 16.348% at full load which is meeting the international regulations (IEC-61000-3-2) to class-D devices and regulated load voltage is 48 V has been achieved. Voltage across C_0 is 150 V at less load condition which is low.

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