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A Fuzzy Controlled Three -Level Isolated Single Stage PFC Converter

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ABSTRACT: A fuzzy controlled three-level isolated single-stage PFC ac/dc converter is proposed for low power applications. The proposed converter exhibits high PF with less number of switches/diodes, operated at constant duty ratio. An inductor and a diode bridge are added to the conventional three-level isolated dc/dc converter, with a modified switching scheme and fuzzy based controller. The input current ripple frequency is twice of the switching frequency contributing to using smaller PFC inductor. Moreover, output current and voltage ripples are very less. A high PF is achieved by this topology. Fuzzy controller is used which has the advantage of fast response.

KEYWORDS: Power Factor Correction (PFC), single-stage power factor correction (SSPFC), single stage full bridge (SSFB), zero current switching (ZCS), ac/dc converters.

I. INTRODUCTION

For full capacity utilization of transmission lines and grid quality, ac/dc converters should operate at high power factor and less harmonic distortion. Conventional methods for improving PF are to include passive and capacitive filters. However, these filters are heavy and bulky. Two stage PFC converters have been proposed in [1] [2]. However, they are larger and have more components. To reduce the number of components, single stage PFC converters have been proposed [3]-[5]. These converters have reduced number of components but they suffer from excessive voltage and current stresses on the switches.

In this paper, a fuzzy controlled three-level isolated single stage converter is proposed. This topology has minimum number of switches. It is an integrated version of a boost PFC converter and a three-level dc/dc converter. No additional components are used. A modified switching scheme is used. A high PF is achieved by this topology. Output voltage regulation is achieved by a fuzzy controller.

II. LITERATURE SURVEY

In year 2001, Richard Morrison, and Michael G. Egan [1] presented a modulation strategy for a power factor corrected, isolated ac/dc converter, which is derived from the integration of a non isolated, two switch buck-boost ac/dc converter with an isolated dual active bridge dc/dc converter (2SBBDAB). Crest factors of the currents in the switching devices of the converter are minimized by this scheme and the input switch is turned on at zero current and the zero-voltage. Moreover, the converter has higher line voltage surge immunity than that of the conventional design. However, this converter have more components and larger size and switching losses are also high.

In 2014, Haoyu Wang and Serkan Dusmez [2] proposed a two-stage onboard battery charger for plug-in electric vehicles (PEVs). An interleaved boost topology is employed in the first stage. Power factor correction is done in this stage. In the second stage, a full-bridge LLC-based multi-resonant converter is adopted for dc/dc conversion and for galvanic isolation. A good voltage regulation at light load condition is achieved by this converter. This converter employs zero-voltage switching (ZVS) over wide load ranges, and it operates at high PF and low THD. However, this method is expensive and the constant switching losses are also high.

In 2010, Hao Ma and et.al [3] proposed a new single-stage power factor correction (SSPFC) converter for the adapter applications. It is composed of a flyback converter, a feedback winding and a front-end input current shaper.

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Operations of the converter are performed in a single-stage. A high efficiency and good power factor is achieved by this circuit. Furthermore, the feedback winding is connected to the input through only two diodes, which results in low conduction losses. It is a cost-effective approach to reduce the number of switches.

In year 2008, Jiann-Fuh Chen and et.al [4] proposed a single-stage current-fed boost PFC converter with zero current switching (ZCS) for high voltage applications. A variable frequency control scheme is employed in this topology. For a current-fed single stage full bridge (SSFB) converter there is no dc bus capacitor on the primary side of the transformer. Therefore, the dc bus voltage is subjected to excessive overshoots and ringing and the output voltage contains high amplitude second-order harmonic

Pritam Das and et.al proposed a voltage-fed PWM ac–dc single-stage full-bridge converter in the year 2013 [5]. Voltage-fed SSFB converters do not exhibit the drawbacks of current-fed single stage full bridge (SSFB) converters, where a large capacitor is located on the primary side dc bus. This converter can operate with excellent input power factor.

Mohammed S. Agamy and Praveen K. Jain in the year 2009 [6] proposed a three-level resonant single-stage power factor correction converter. This converter integrates the operation of the boost power factor preregulator and a three-level resonant dc/dc converter. The dc-bus voltage and input current are regulated by means of duty cycle control of the boost part of the converter and the output voltage is regulated by controlling the switching frequency of the resonant converter. This provides a well regulated output voltage, high power factor, high efficiency, and control of the dc bus voltage to a desired range even at very light loading. This converter is suitable for both discontinuous and continuous input current This converter alleviate most of the drawbacks associated with SSFB converters, while reducing the voltage stress on the switches. However, this topology is bulky and can be further integrated.

Mehdi Narimani and Gerry Moschopoulos proposed a three level integrated AC/DC converter in the year 2014 [7]. This converter is an integrated version of a boost PFC ac-dc converter and three level integrated dc-dc converter. This is a single stage and fully integrated converter. This converter operates at high PF and high efficiency. However, two auxiliary diodes are included in the converter to enable a freewheeling path for primary side current when the energy in the leakage inductance is transferred to the bottom capacitor and to prevent input current to flow through the midpoint of split dc bus capacitors. A third auxiliary diode which operates as a boost PFC diode is also added. Even though this converter alleviates most of the problems mentioned earlier, it can be further integrated to remove the three auxiliary diodes.

III. PROPOSED CONVERTER

A fuzzy controlled three level isolated single stage PFC converter is an integrated version of a boost PFC ac/dc converter and a three level dc/dc converter.

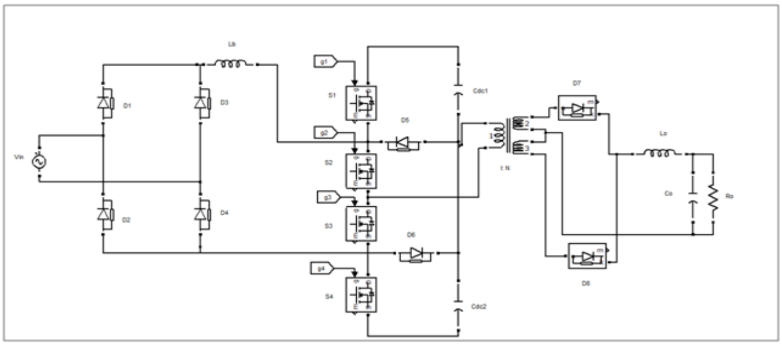

Fig. 3.1 Fuzzy controlled three-level isolated single stage PFC converter

Fig. 3.1 shows the topology of proposed converter. S_1, S_2, S_3 and S_4 are the four switches. D_1, D_2, D_3 and D_4 are the rectifying diodes. There are six modes of operation for the converter.

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Mode 1: S_1 and S_2 are ON. The upper capacitor, C_{dc1} discharges to the load by applying $-V_{dc}/2$ to the primary side of the transformer. D_8 conducts at the secondary side of the transformer. Output inductor voltage is $V_{Lo}=V_{dc}/2N-V_o$.

Mode 2: S_3 is turned ON, while S_2 remains ON. The primary current freewheels and zero voltage is applied across the primary side of the transformer. V_{in} is applied across input inductor, and input current increases linearly storing energy in the inductor.

Mode 3: S_2 is turned OFF, S_4 is turned ON, while S_3 is kept ON. The energy stored in the input inductor is transferred to the dc-link capacitors. $-V_{dc}/2$ is applied across the primary side of the transformer.

Mode 4: C_{dc2} discharges over to the load and $V_{dc}/2$ is applied across the primary side of the transformer. The voltage across the output inductor is $V_{Lo}=V_{dc}/2N-V_o$.

Mode 5: S_2 is turned ON. The energy from the input is stored in the inductor. Operation is similar to Mode 2. Here primary side current freewheel through D_6**.**

Mode 6: S_3 is turned OFF. S_1 is turned ON and S_2 remains ON. Operation is similar to Mode 3. Input inductor energy is transferred to dc-link capacitors and $-V_{dc}/2$ is applied across primary side of transformer. Output current commutated from D_7 to D_8.

The switching scheme and associated waveforms are shown in the Fig. 3.2. Here the converter is explained based on input current as discontinuous.

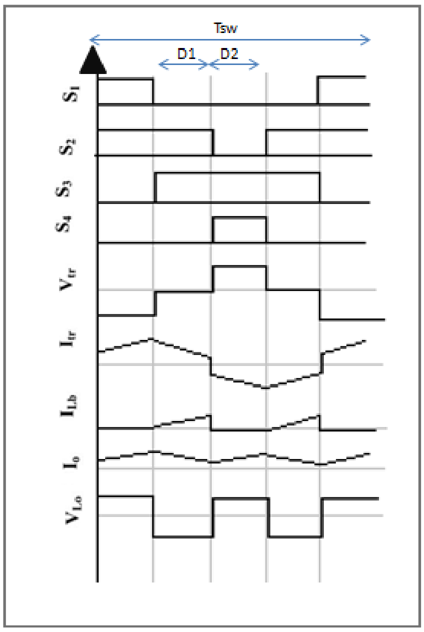

Fig. 3.2 Switching sequences S_1-S_4, primary side transformer voltage and current, input inductor current, output inductor current and voltage

The pulses for S_3 are complement to S_1 and pulses for S_4 are complement to S_2. D_1 represents half of the overlapping period of S_1 and S_2. D_2 represents the duty ratio of S_4. The duty ratios of S_1 and S_3 should be greater than 50% to enable overlapping of their ON time

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IV. DESIGN CONSIDERATION

1 Input inductor (L_b): In DCM operation, the transferred power is a function of the dc-link voltage, duty ratio and the input inductor. Equation for input inductor is given below.

$$L_b = D_1^2 V_m^2 \Big/ \pi f_s P_0 \quad \times \int_0^{\pi} \frac{\sin wt^2}{1 - V_m \frac{\sin wt}{V_{dc}}} d(wt) \quad (1)$$

V_m, f_s, P_0 are peak input voltage, switching frequency and output power respectively.

2. Output inductor (L_0): Output inductor current can be discontinuous or continuous depending upon the design. Here output inductor value is designed to make current continuous.

$$L_0 \geq V_0^2 (.5 - D_2) T_{SW} \Big/ 2 \times P_x \quad (2)$$

P_x represents the minimum power at which the output current become continuous.

3.Turns ratio of transformer (N):

$$D_2 = \frac{NV_0}{V_{dc}} \quad (3)$$

V_0, V_{dc} is the output voltage and dc-link voltage.

V. FUZZY LOGIC CONTROLLER

A fuzzy logic controller is easy to design and it is simple. Response obtained by fuzzy logic controller is more superior to response obtained by other controllers. In this paper, we use Mamdani style fuzzy interface system. Here we have two input variables and one output variable.

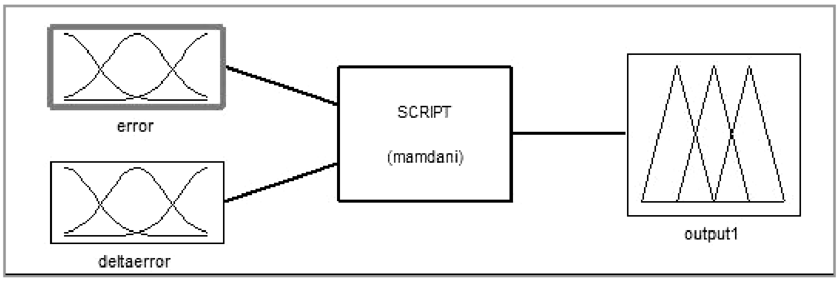

Fig. 5.1 Variables of fuzzy controller

Fig. 5.1 shows the input and output variables. Error and deltaerror are the input variables and output1 is the output variable.

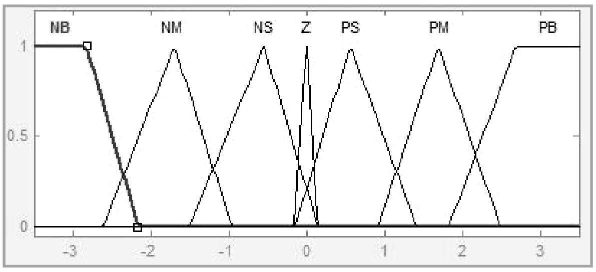

Fig. 5.2 Membership functions of the variable error.

There are seven membership functions for the input variable error. Fig. 5.2 shows the membership functions of input variable error.

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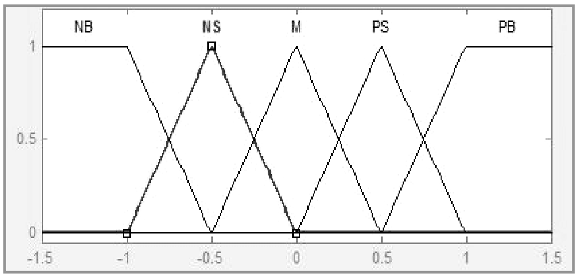

Fig. 5.3 Membership functions of the variable deltaerror

There are five membership functions for the input variable deltaerror. Fig. 5.3 shows the membership functions of input variable deltaerror.

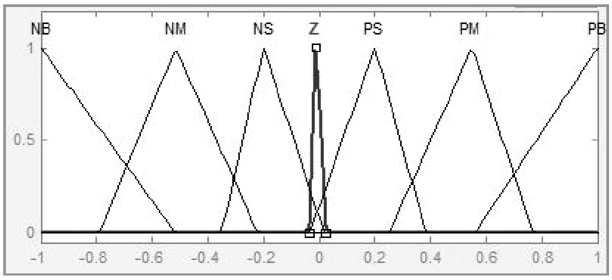

Fig. 5.4 Membership functions of output variable

There are seven membership functions for the output variable. Fig. 5.4 shows the membership functions of output variable.

In this paper, eleven rules are used to control the output variable. The priorities for all the rules are set to one.

Rule 1: If error is (Z) then output1 is (Z).
Rule 2: If error is (PS) then output1 is (PS).
Rule 3: If error is (PM) then output1 is (PM).
Rule 4: If error is (PB) then output1 is (PB).
Rule 5: If error is (NM) then output1 is (NM).
Rule 6: If error is (NB) then output1 is (NB).
Rule 7: If error is (NS) then output1 is (NS).
Rule 8: If error is (PS) and deltaerror is (PS) then output1 is (PS).
Rule 9: If error is (PS) and deltaerror is (PB) then output1 is (PM).
Rule 10: If error is (NS) and deltaerror is (NS) then output1 is (NS).
Rule 11: If error is (NS) and deltaerror is (NB) then output1 is (NM).

VI. RESULTS AND DISCUSSIONS

A 500W/48 V prototype is simulated. Input voltage is 90 Vrms, 60 Hz ac, switching frequency is 125 KHz.

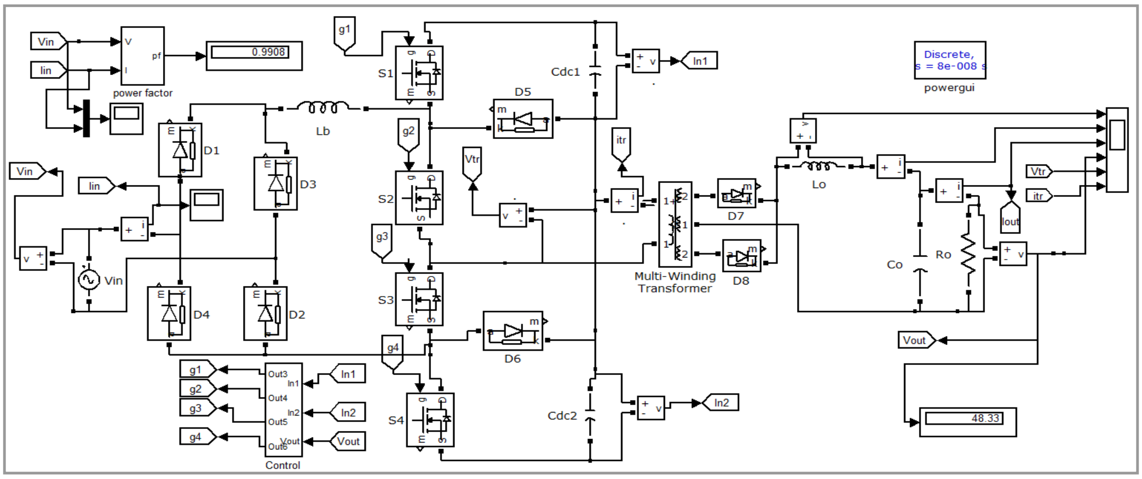

Fig. 6.1 SIMULINK/MATLAB model of the proposed converter

Fig. 6.1 shows, the MATLAB/SIMULINK model of proposed converter. Value for input and output inductor is 27 μH, and the value of dc-link capacitors are chosen as 470μ, and output capacitor value is $100\mu F$.

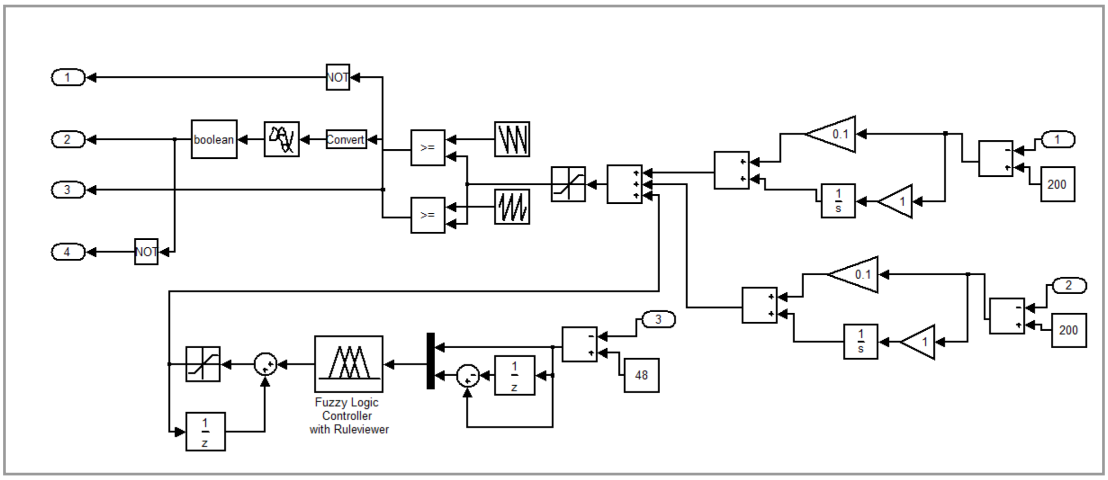

Fig. 6.2 Control Scheme.

Fig. 6.2 shows the control scheme of the proposed converter. Reference voltage across the dc-link capacitors are chosen as 200V, and the output voltage reference is chosen as 48V. Voltage regulation is controlled by Fuzzy controller and dc-link capacitor voltage balancing is done by using PI controllers. 180° phase-shifted carrier waves are used for modulating the switches S_1, S_3 and S_2, S_4

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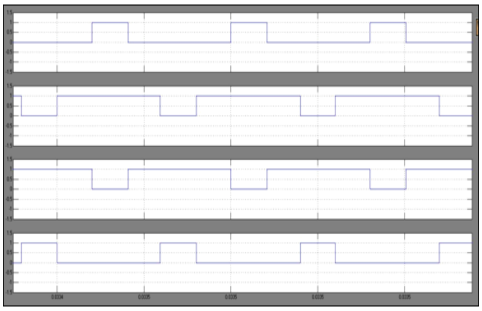

Fig. 6.3 Gate signals for switches S_1, S_2, S_3, and S_4

Switching pattern is shown in fig. 6.3. Switching signals of switches S_1 and S_3, S_2 and S_4 are complement to each other

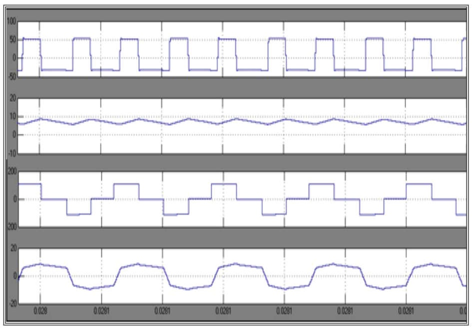

Fig. 6.4 Output inductor voltage and current, primary side transformer voltage and current

Output inductor voltage, output inductor current, primary side transformer voltage, primary side transformer current waveforms are shown in fig. 6.4. S_4, S_3 and S_1, S_2 are switched simultaneously to apply $V_{dc}/2$ and $-V_{dc}/2$ to the primary side of transformer. When switches S_2 and S_3 are switched ON simultaneously, zero voltage is applied across the primary side of transformer.

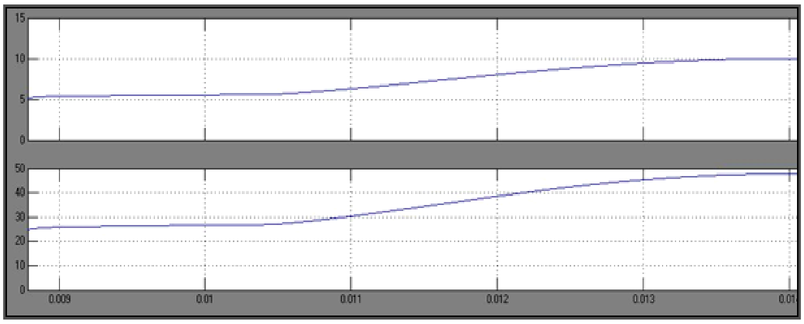

Fig. 6.5 Output current and voltage

Fig. 6.5 shows output current and voltage waveforms. Output voltage is approaching 48 V at steady state and the ripples are minimal. Output current is reaching 10 A at steady state .

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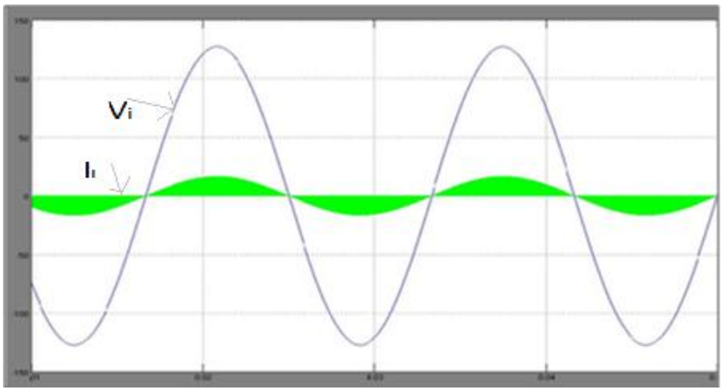

Fig. 6.6 Input voltage and current

Fig. 6.6 shows the input voltage and current waveforms. From the alignment of input voltage and input current waveforms, it is clear that the PF is high and the current wave is sinusoidal.

VII. CONCLUSION

A fuzzy controlled three-level isolated single stage PFC converter is designed and simulated in MATLAB/SIMULINK. A 500W/48V prototype is simulated. A high PF of .99 and output voltage regulation (48 V) is achieved. A sinusoidal input current wave shape is also obtained. The response of the converter is faster. Output voltage and current ripples are minimum. The controller uses minimum number of components compared to other PF converters

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