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Drive Applications of Fuzzy Logic Controlled Interleaved Boost Converter for Maximum Power Point Tracking in Solar PV

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***Abstract*— *The improvement in the efficiency, a reduced ripple and reduction in the passive elements is proposed in this project through the interleaved boost converter. The interleaved boost converter operates multiple phase approach, is used for the power factor control applications. The proposed converter is used to extract the power output from the solar panel with reduced ripple losses and greater efficiency thereby obtaining the maximum power from the solar panel. The control of the current with energy saving method is obtained with the efficiency of 95%. The converter operation is controlled by the fuzzy logic controller to operate the switches with the finest and reduced power loss constrains. The proposed method is mathematically modeled and the results are analysed. A similar prototype model is designed and the results are compared with the theoretical values.*

***Keywords*— Boost converter, current ripples, fuzzy logic controller (FLC), maximum power point tracking, solar photovoltaic.**

I. INTRODUCTION

The years of research in solar power applications have reached to a greater extent in the field of power generation and utilization. Problems caused due to non-renewable resources are being explained for years which introduced the renewable energy resources using wind, solar, tidal, water as its major source of power generation. The influence of these renewable resources requires a higher power generation compared to the non-renewable resources. This is being a major problem for years, in comparison to the existing non-renewable energy units. In developed counties, the problem is solved by introducing the advanced control units for the renewable energy resources to compete the production capacity of the non-renewable energy resources. However the research and developments have a challenging environment in producing high power generation units using renewable energy. The use of the solar is widely seen in many applications. However the power conversion from the renewable energy is the challenging task. It is well known that the power extraction from the renewable energy is not possible for 100% extraction. This challenging task over years has developed various power electronics techniques to extract the maximum power from the renewable source. In solar, the solar panels require the maximum power point tracing system (MPPT) to obtain the maximum power. In conventional methods the MPPT is performed using the DC-DC converter through the controllers. This DC-DC converter is operated both in buck and boost operation to obtain the wide range of voltage values. There are various methods to obtaining the maximum power from the solar energy. Each method has its own significance. The solar energy form the solar power is converted to electrical form using the solar PV panel. The solar radiations are not the constant source so the output of the solar panel is also variable [5]. The power constancy is obtained by using the DC-DC converters. The different DC-DC converters are the buck, boost and cuk converters are used based on the application requirements. The implementation of cuk converter for the power constancy which is also referred to maximum power tracking method is used in direct control of power extraction [2]. The MPPT techniques have various advantages which is discussed and compared and the significance are studied [3]. The implementation of boost converter is more common among the MPPT technique. The boost converter output is comparatively efficient however; the extraction of power from the panel is considerable limited [4]. In some applications it is necessary to have the buck and the boost converter to obtain the various level of the power output, but the cost of two converters in a single system is not much efficient for the power generation [6]. Further discussions have turned another new method of MPPT for the lower power solar PV panels [7]. In the proposed method, the MPPT involved uses the boost converter which is controlled using the fuzzy logic controller. This fuzzy logic controller efficiently controls the boost converter operation in obtaining the maximum power from the solar PV panel.

II. MODELING OF SOLAR PV PANEL

The solar PV can be modeled [1] by a current source acting as the PV panel current (Ipv) connected to the parallel diode. The equivalent structure implies the photo-diode operation producing the current (I). The combination of the series resistance (Rs) and the parallel resistance (Rp) refers to the solar array consisting of the solar cells connected in series and parallel combination. The modeling of the PV cells describes the I-V characteristics of an ideal PV cell. The equivalent circuit of the PV cell is shown in Figure 1.

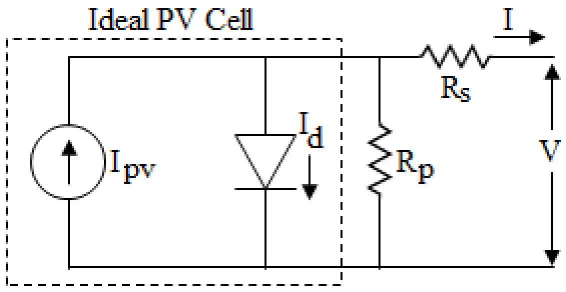

Fig.1: Equivalent circuit of PV Cell

The output of the current from the PV cells is given as,

$$I = I_{pv,cell} - I_d \quad (1)$$

Where,

$$I_d = I_{0,cell}[\exp\left(\frac{qV}{akT}\right) - 1] \quad (2)$$

Therefore,

$$I = I_{pv,cell} - I_{0,cell}[\exp\left(\frac{qV}{akT}\right) - 1] \quad (3)$$

Where,

$I_{pv,cell}$is the current generated by the incident light (it is directly proportional to the Sun irradiation),

I_d is the Shockley diode equation,

$I_{0,cell}$is the reverse saturation or leakage current of the diode,

q is the electron charge (1.60217646 × 10−19 C),

*k*is the Boltzmann constant (1.3806503 × 10−23 J/K),

T (in Kelvin) is the temperature of the *p*–*n* junction, and

*a*is the diode ideality constant.

The figure 2 shows the origination of the I – V curve for the equation (2.2). Practical arrays are composed of several connected PV cells and the observation of the PV array requires the inclusion of additional parameters to the basic equation.

Hence,

$$I = I_{pv} - I_0 \left[\exp\left(\frac{V+R_s l}{V_t \alpha}\right) - 1\right] - \frac{V+R_s l}{R_p} \quad (4)$$

Where,

V = N_skT/q is the thermal voltage of the array with N_s cells connected in series.

The output voltage is increased by increasing the number of the series cells because the voltage gets added up in series combination. Similarly, the current is increased on parallel connection of the solar cells as the current gets added up in parallel combination under same direction. If the array is composed of N_p parallel connections of cells the photovoltaic and saturated currents may be written as,

$I_{pv} = I_{pv,cell} * N_p$, and

$I_0 = I_{0,cell} * N_p$.

These equations originate the I-V curve in figure 2.

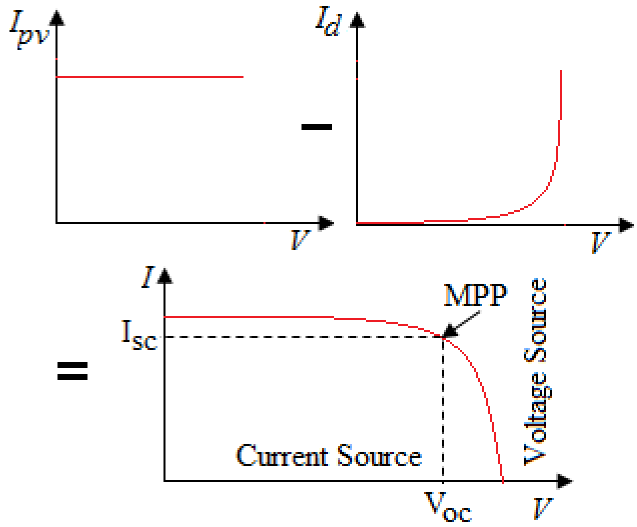

Fig.2: Origin of I-V equation of an Ideal PV cell curve of a practical PV module and Characteristic I-V curve of a practical PV module

The mathematical modeling equations of the PV panel are modeled using suitable equations programmed in the MATALB. This simulation is done for standard test condition (STC) when temperature is 35°C and Irradiation is 3000 W/m^2. The modeling is done for a 500W solar panel.

TABLE I

PARAMETERS OF THE PV PANEL – TATA BP1235

Open Circuit Voltage V_{oc}	500 V
Short circuit Current I_{sc}	10.9 A
Maximum Voltage V_m	487.5V
Maximum Current I_m	10.35A

III. MODELING OF MPPT USING INTERLEAVED BOOST CONVERTER

DC-DC Converters are prominently used to obtain the Maximum Power output from the PV panel. The conventional DC-DC are operated both in buck and boost condition. The optimized output value is set such that if the output from the panel when comparatively less to that

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of the desired out is boosted and when comparatively greater than the desired output it is bucked. This double operation minimizes the output level due to the frequent operation of the converter both in buck and boost operation. In the proposed method, an interleaved boost converter is used to reduce the current ripple and the increase the efficiency for any output obtained from the panel at the input side. This can be done by selecting the duty cycle of the converter such that the voltage is boosted to a constant value. This can be performed using a controller to convert feedback signals to a desired output pulse for the converter. In this proposed technique fuzzy logic controller is used to select the desired duty cycle. Due to this the limitation in the linear voltage output is eliminated. The switching losses are reduced as the converter operates only in boost condition. The figure 3 shows that interleaved boost converter for the MPPT technique. The circuit diagram consists of the Solar PV Panel connected to the proposed converter. The output of the panel is controlled by the proposed converter. The converter produces a constant boosted output for the load by eliminating the ripples. The stepped voltage can be used for DC and AC drives.

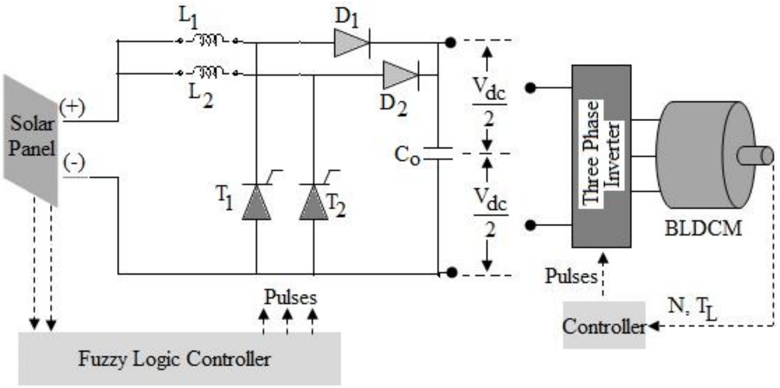


Fig.3: MPPT Based Interleaved Boost Converter Model

The inductor in the boost converter possibly produces the ripples in the input current. This can be minimized with two-phase interleaved boost converter. The interleaved boost converter has its high power density and fast dynamic response by operating at 180° out of phase. This causes the ripple currents to cancel out.

Two Phase Interleaved Boost Converter

The two phase interleaved boost converter consists of two channels composed of an inductor, thyristor switch and diode in each channels. The inductor L_1, thyristor switch T_1 and the diode D_1 forms the first channel and the inductor L_2, thyristor switch T_2 and the diode D_2 forms the second channel. The thysistor interleaved design of the gating signal at T_1 and T_2 produce identical phase shift of 180° each. The current is branched to L_1 and L_2 respectively.

Mode I During the mode I, the thyristor T_1 is ON and T_2 is OFF. The input voltage V_{in} linearly charges the inductor L_1 through the current i_{L1}. The diode D_1 is reverse biased and the energy is transferred to the load. The operational mode circuit diagram is shown in the figure 4 (a).

Mode II The figure 4(b) shows the mode II operation. In this the thyristor T_1 is turned OFF and T_2 is turned ON. The current i_{L2} flowing through the inductor L_2 linearly charges it. Thus the energy is transferred from the inductor to the output.

Transfer Function of Interleaved Boost Converter

Considering the mode II operation, the voltage equation is given as,

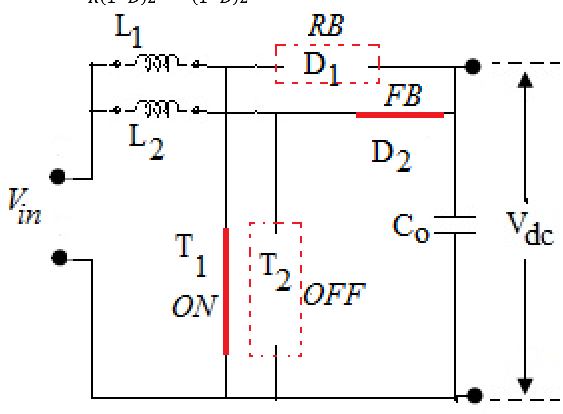
$$V_{in} = L_2 \frac{di_2}{dt} \quad (4)$$

$$V_{in} = L_1 \frac{di_2}{dt} + \frac{1}{C}\int (i_2 - i_3)\, dt \quad (5)$$

$$0 = \frac{1}{C}\int (i_3 - i_2)\, dt + Ri_3 \quad (6)$$

From the above equations, we get the transfer function as,

$$T_f = \frac{Vs/(1-D)2.[(1-S).(L/R(1-D)2)}{S.\frac{L}{R(1-D)2} + S^2\frac{LC}{(1-D)2} + 1}] \quad (7)$$



(a) Mode I

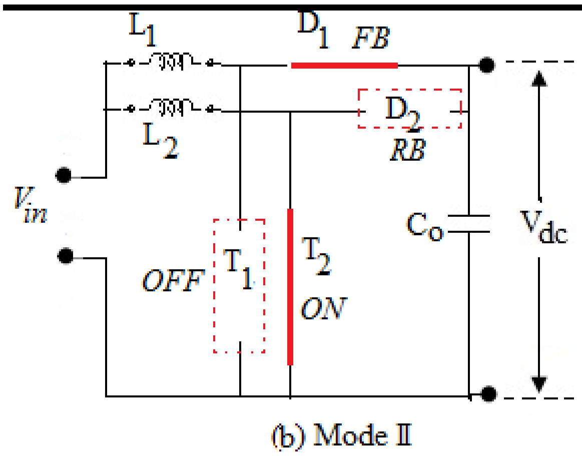


Fig.4: Models of Operation of Interleaved boost converter

IV. MODELING OF FUZZY LOGIC CONTROLLER

The maximum power point tracking is a technique that involves the voltage and current peak values. This electrical method applied, tracks the power which is maximum available with respect to the temperature and radiations of the solar. This method of tracking the power is more efficient compared to that of the mechanical tracking which requires additional power to the drives operating the panels. This control technique can be implemented using the fuzzy controller which is comparatively more efficient in MPPT technique. The functional block diagram of the fuzzy logic based MPPT system is shown in the figure 5.

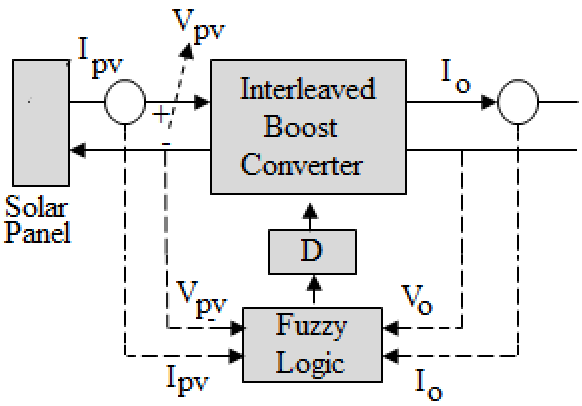


Fig.5: Fuzzy Logic Controller - Modeling

TABLE III
FUZZY RULE TABLE

ΔVpv/ΔPpv	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NS	NS	NS	Z	Z
Z	Z	Z	Z	PS	PS
PS	Z	Z	PS	PS	PS
PB	Z	PS	PB	PB	PB

V. SIMULATION MODELING AND RESULTS

The proposed system is mathematically modeled in MATLAB. The solar panel is modeled using the equivalent circuit programmed in MATLAB. The output of the solar panel is tracked by the maximum power point tracker using interleaved boost DC-DC converter controlled by fuzzy logic controller. The figure 6 shows the power generated from the solar panel and the power tracked using various techniques. The solar power obtained in the panel is subjected to the solar irradiation and the temperature. The solar energy converted is tracked using a reference voltage. By using conventional DC-DC converter operating both in buck and boost operation the output voltage is constant but limited to the maximum values. In proposed method, the high DC-DC converter acts only as a boost converter, thereby stepping up the voltage to maximum value. This enables the maximum power output under any input conditions. Also, the interleaved connection eliminates the ripple in the current and increases the efficiency of the output.

The power developed in the PV panel is connected to the proposed converter for tracking the maximum power. This input voltage is controlled effectively by the fuzzy logic controller (FLC).

The voltage output var7iations are compared between the conventional and the proposed converters. It is seen that the proposed converter the ripple is very much reduced when compared to that of the conventional converter. Moreover, the proposed converter output ripple is negligible both at theoretical and practical cases. The figure 7 shows the effectiveness of the output voltage.

The output from the interleaved boost converter is fed to a three phase inverter. The input to the three phase inverter is divided into two dc voltages (+$\frac{V_{dc}}{2}$ and -$\frac{V_{dc}}{2}$). The input is inverted using space vector PWM technique to obtain maximum inverted output. Though the inverter operation provides buck operation, the strategic control by SVPWM inverts the voltage with minimum losses. The voltage output simulated is shown in the figure 8. The voltage output from the inverter is used to power the input to the BLDC motor. The speed of the BLDC motor is sensed using the hall sensor and it is fedback to the SVPM controlled with the error signal. The error signal is corrected and it is converted into gate signal to the power converter.

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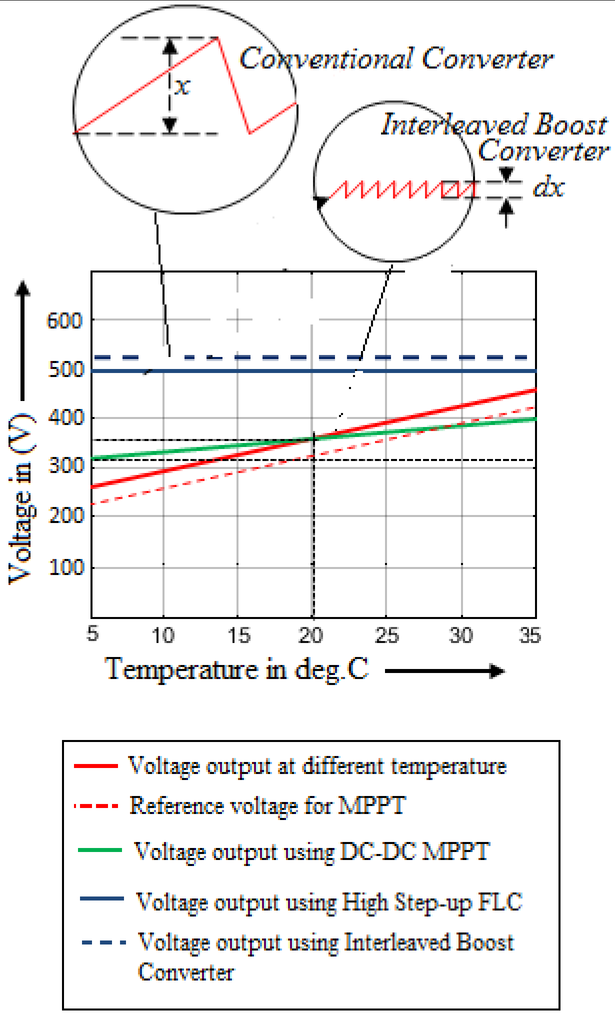

Fig.6: Voltage generated by solar panel using proposed MPPT

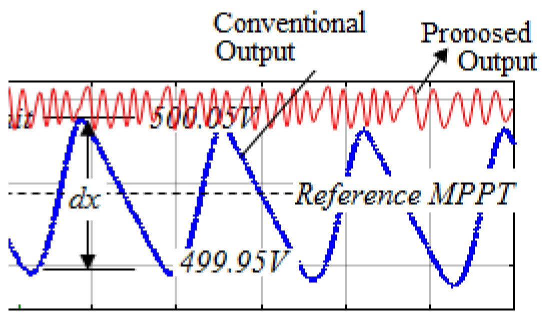

Fig.7: Effective voltage output of the proposed converter

The output from the interleaved boost converter is fed to a three phase inverter. The input to the three phase inverter is divided into two dc voltages (+$\frac{V_{dc}}{2}$ and -$\frac{V_{dc}}{2}$). The input is inverted using space vector PWM technique to obtain maximum inverted output. Though the inverter operation provides buck operation, the strategic control by SVPWM inverts the voltage with minimum losses. The voltage output simulated is shown in the figure 8. The voltage output from the inverter is used to power the input to the BLDC motor. The speed of the BLDC motor is sensed using the hall sensor and it is fedback to the SVPM controlled with the error signal. The error signal is corrected and it is converted into gate signal to the power converter.

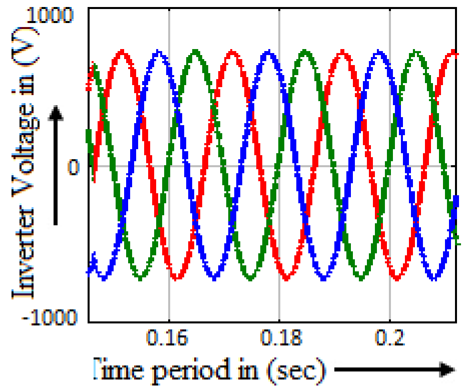

Figure 8 Three phase inverter output

VI. HARDWARE MODEL AND RESULTS

The prototype model of the proposed method is developed for a 1kW solar panel. The solar panel is regulated using fuzzy logic controlled to track the maximum power using interleaved boost converter. The proposed converter acts as the MPPT controller to track the solar power.

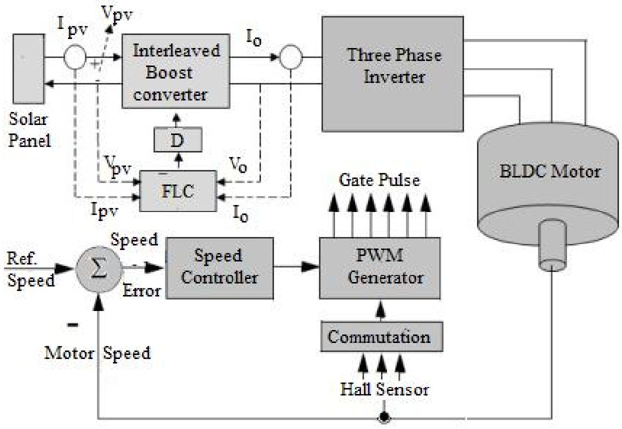

Fig.9: Hardware Prototype Model

The SVM is programmed using ATMEL 32-bit AVR Microcontroller using six channels. The AVR32UC3 is widely used in the speed control of BLDC motor. The hardware model is modeled in the laboratory for a closed loop speed control of the BLDC motor. The figure 9 shows the hardware model of the proposed system. The figure 10 (a) shows the DC output obtained from the solar panel through the interleaved boost converter. The DC voltage of 473V is obtained from a 1kW panel. The voltage obtained is inverted using three phase inverter controlled using space vector pulse width modulation. The inverted output voltage is shown in the figure 10 (b). The inverted three phase output obtained is 438V.

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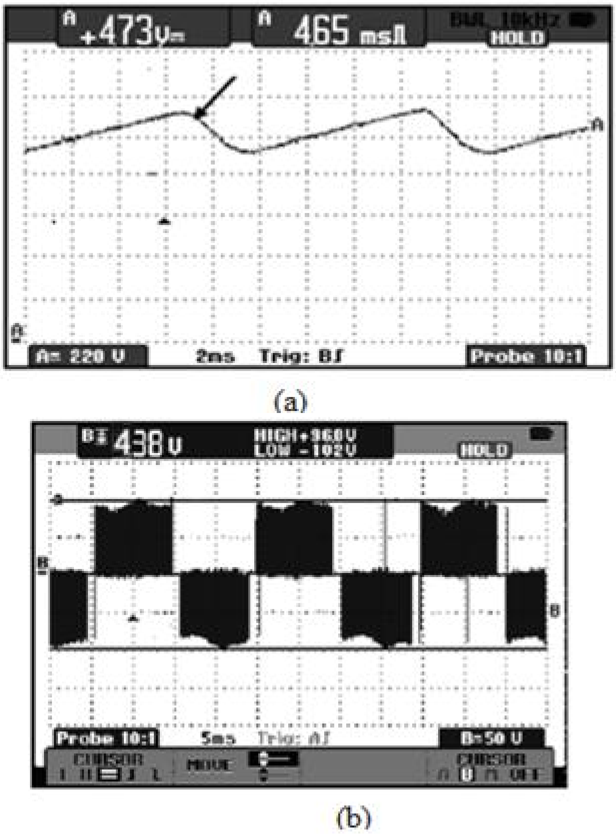

Fig.10: (a) Interleaved boost converter output (b) Inverter output

VII. CONCLUSION

The proposed interleaved converter is modeled mathematically for the MPPT Control of the solar panel. The proposed model increased the efficiency compared t that of the conventional model. This can be verified by the figure 6 and 7, which shows the output ripple very much negligible for the proposed compared to that of the conventional converters. The proposed method is suitable for high power drive application in industries eliminating the harmonic properties.

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