INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH IN ENGINEERING AND MANAGEMENT (IJSREM)
VOLUME: 06 ISSUE: 03 | MARCH - 2022 ISSN: 2582-3930

Performance Analysis of Direct Single-Phase AC-AC Converter with Novel Switching Strategy

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***Abstract*—Recently, direct-type ac-ac converters have attracted considerable attention for voltage magnitude variation due to the reduced number of component requirements. This paper introduces a direct single-phase ac-ac converter with a novel switching strategy for UPF and non-UPF load. The suggested converter's circuit configuration uses six power MOSFETs and two inductors at high switching frequency to reduce the size. The proposed switching strategy reduces the losses of semiconductor devices with a safe commutation. The performance analysis of the proposed converter has been carried out for high power quality operation with almost unity PF at the i/p and low THD at the output for 400W resistive and inductive loads. The simulations have been carried out on MATLAB-2019b.**

Keywords—AC-AC Converter, buck, switching strategy, UPF, and Non-UPF load.

I. INTRODUCTION

Many industrial applications need ac to an ac power supply like variable speed drives, ac to ac regulators, etc. In industry, there is the issue of satisfying the true power quality demand of direct ac-ac conversion by definitive and energetic converters. In generally, used ac-ac converters are three types: indirect-converters [1]-[2], direct-converters [3]-[4], and matrix-converters [5]-[6]. The application of matrix converters is suitable where the magnitude of the voltage changeable with frequency and indirect converters can be used only for ac voltage magnitude regulations. These power conversions are done in two-stage, using bully dc-link capacitors and inductor with a large source filter, which impact high loss, less accuracy, less power density, and high cost. Therefore, most attractive are direct type converters because it is easy to perform power conversion with a small number of devices archiving single-stage.

These days, PWM converters based on MOSFETs or insulated gate bipolar transistors (IGBTs) have recently gained a lot of attention due to various their complexity and prospective ability to achieve high efficiency, power quality, and reliability. In [7] the concept of switching cells is isolated for HFT isolation. In [8] the series connection of MOSFETs and a diode produces a switching cell structure, without causing damage to switch devices by three topologies can be formed by coupled inductors withstand all dead-time with overlap-time in this configuration. The proposed converters successfully offer a highly efficient with valuable power quality indices. They get better results in [9]-[10], the main goal of reducing size of an element with modifying the design of inductors, that is coupled. This aim is approximately obtained, However, the extra current circulating losses in these circuits may occur, on the other hand, have remained. As a result, separately inductor-based alternatives were developed in [11]-[12]. During each operation mode, multiple semiconductors are conducted simultaneously in the converter topology shown in [11], while [12] demands more inductors than any other prior design topology. In [13] proposes a better direct ac-ac converter that utilizes only two separate inductors while maintaining the same number of semiconductors as [12]. This circuit allows MOSFETs to be used without having to a disturbance about reverse recovery or switch diode losses, allowing for high-frequency and efficiency switching. However, it is constant usually necessitates the use of more semiconductors, using four power diodes and power MOSFETs, as well as two engaging cores, potentially increasing the converter's size and expense. Because at the same time, a large majority of semiconductors are conducting, the requirement for bulky i/p and o/p filters reduces efficiency and increases the overall size of the circuit. In [14] the proposed converters to give ac to ac conversion with a wide range of voltage gain, use various Z-source networks and bidirectional switches to provide an energy storage system. These converters are primarily affected by high voltage and current loads, as well as the requirements for more components, through which the power losses increase. Two novel ac-to-ac converters are generated in [15], including series z-source cells to the primary circuit design described in [13]. In comparison to [13], the modified switching technique presented in [15], allows conducting semiconductors for a reduction in each mode. The presented converters in [16], have a smaller number of components, but can only function as a buck converter that can shoot through an i/p voltage source. Considering their advantages, both converters tend to conduct harmonic waveform with low-quality indices from the source. The proposed converter a variable frequency single phase ac-ac converter [17], that works shows increased power quality towards the source. The converter given in [17] has some advantages, including fewer semiconductor ratings, a big number of operating high-frequency semiconductors, as well as high efficiency. There is voltage control, if necessary, it has significantly larger power losses than standard ac voltage regulators. This converter presented [18], which designs a buck-boost converter using the same switching cell

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structures. The passive component and the cost of extra semiconductors allow the converter to change the polarity of the output voltage. This converter uses two inductors and only six power MOSFETs with the capability to unity power factor for UPF and Non-UPF load.

The proposed converter without the hazard of the i/p voltage source shooting through the converter as a voltage buck converter can be used ac-ac converter. All the MOSFETs are guarded by their switch diodes for the safe commutation reducing the losses and reverse recovery difficulty. As a result, when decreasing the shape(size) of passive elements, the set a higher value of switching frequency(f_{sw}). Compared to competitors, the circuit layout of the offered converter is done on purpose to minimize the need for an isolated supply of gate drives. Furthermore, in presented converter, two inductors are connected in a common magnetic core to reduce the extra space and this proposed converter requires less capacitance and inductance than other converters. Smaller i/p and output filtering components result in fewer losses than previous successful competitors, during each process, there are reduced semiconductors in the current path. Moreover, this converter provides improved power quality operation with almost unity pf at the i/p and less o/p voltage THD at the output for 400-W resistive and inductive loads. The simulations have been carried out on MATLAB-2019b Considering mostly inductive and resistive load.

II. PROPOSED AC-AC CONVERTER

A. *Circuit-Analysis*

In-circuit analysis of direct single-phase AC to AC converter with novel switching strategy is diagrammatically presented Fig. 1, This converter is designed from the existing effective AC to AC converters already shown in [15]and [17] as well as the inverters and rectifiers shown in [19] and [20]. In simple words, a proposed AC-AC converter is designed by properly rearranging their capacitors, semiconductors and improving their switching techniques. Decrease the shape(size) of passive elements and increase the switching frequency, proposed-converter uses six MOSFETs. In general, there are two types of loads: UPF or Non-UPF.

Resistive mainly used for UPF load and inductive are used for non-UPF load. Power MOSFETs are used for both UPF and non-UPF loads. Does not require the replacement of any device. The load connection shown in Fig. 1, proposed-converter buck version is obtained by connecting the load between nodes P and Q. In this buck converter, only three isolated gate drives are required circuits depicted in Fig. 1. In each half-cycle of the i/p voltage, two inductors M_1 and M_2 act independently in the proposed converters. Then, to reduce the number of components on a common EE core, it can be integrated on its side parts [21]. Furthermore, two capacitors C_P and C_Q are used in the circuit depicted in Fig. 1 to give a channel for the i/p current. Then, the reason for the improvement in the wave quality of the output load is that inductors discharge their energy into the o/p load. Furthermore, these capacitors are used in conjunction with L_S to smooth out switching harmonics on the source and another load side.

B. *Switching-Strategy*

For the proposed converter, a basic switching strategy is presented in Fig. 2, Here, M_1 and M_2 receive the same high-frequency PWM signal, while M_3 and M_4 do not receive their logic. In half-cycle does not control the basic PWM's rational

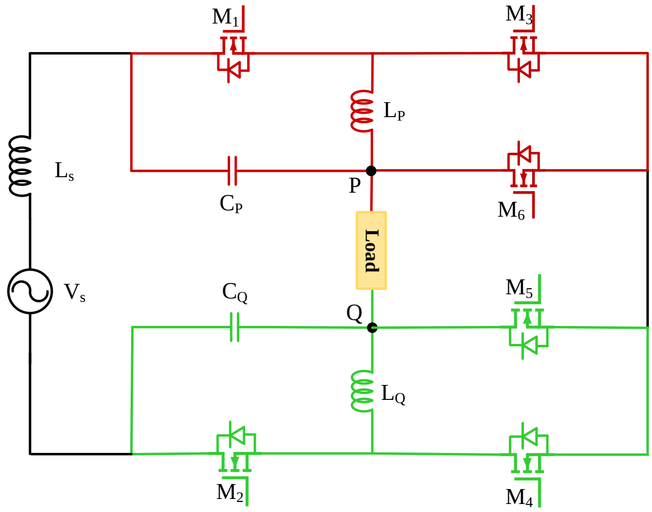

Fig.1. Proposed single-phase AC-AC Buck Converter

is as follows, goes to gates M_5 and M_6 for the -ive and +ive half-cycles of the i/p voltage, respectively. As a result, the proposed converter in two modes operates after every half-cycle of the i/p voltage.

1) *Positive Half-Cycle I/p Voltage:*

A) Mode-1: Switch M_1 operates in the operational mode, in Fig. 3(i), and M_2 switch diode is also operated. The inductor L_P is charged by C_P and the source. In addition, Fig. 3(i) as illustrated, the i/p current travels back to the i/p source through the path formed using the inductor L_Q and the switch diode of M_2. And voltage equations of mode-I shown in Fig. 3(i) can be written using the circuit generated as seen in Fig. 1.

$$V_{LP} = V_{CP}; \quad V_{LQ} = 0 \tag{1}$$

$$\left\{ \begin{array}{ll} V_{CP}^{Buck} & = V_S - V_O \\ V_{CQ} & = 0 \end{array} \right\} \tag{2}$$

V_S and V_o are i/p voltage and o/p voltages, respectively

B) Mode-2: The inductor L_P releases the energy it has accumulated into o/p load-through M_5, M_3, as indicated in

Fig. 3(ii). At same time, the source (C_P) capacitor is recharged, and the i/p current is routed through L_Q and the M_2 switch diode. For this mode of operation, the voltages that go through the inductors are computed as follows:

$$V_{LP} = V_0; \qquad V_{LQ} = 0 \tag{3}$$

The voltage increase of the suggested converters can be calculated by applying a volt second balance to the inductors across voltage equations (1) and (3) as follows:

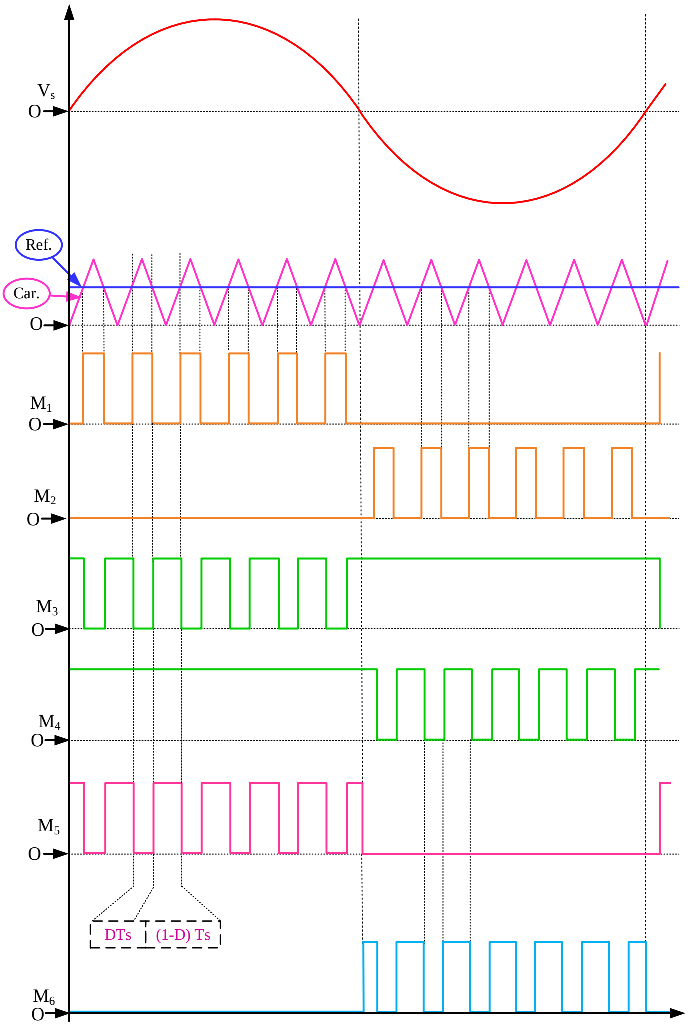

Fig. 2. Generation of Firing Scheme

$$\frac{V_0^{Buck}}{V_S} = D \tag{4}$$

From equation (4), it is concluded that a buck converter easily connects the nodes P, Q of the circuit shown in Fig. 1.

It should be observed that the M_2 switch diode continually conducts the +ive half cycle of i/p current during the entire +ive half cycle of i/p voltage and then blocks it then the current is zero. At the same time, a waveform that is quasi-continuous causes a high-quality change. Because during each mode of operation for flow, a path is supplied of i/p current, additionally to the source current, Fig. 3(i) and (ii), that the buck converter's load voltage to supply the o/p load during both operations modes also has a quasi-continuous wave. The output filter allows the size of the capacitors to be reduced.

2) Negative Half-Cycle I/p Voltage: Just as the +ive half cycle, shown in Fig. 3(iii) and (iv) is equivalent circuits are used to the first modes and second respectively, the operating principles of the proposed converters are analyzed with the same approach during the negative half.

III. COMPONENT PARAMETERS DESIGN

The power converter's size is mostly determined by the passive components. They are primarily designed with maximum tolerated ripples in current and voltage consideration. Furthermore, by Erikson and Maximovich [22], The maximal stored energy of inductors (L) and capacitors (C) is proportional to their volume, that is:-

$$\left\{ \begin{array}{lcl} W_L^{ind.} & = & \frac{1}{2} L\left(I_L^{\max}\right)^2 \\ W_C^{cap.} & = & \frac{1}{2} C\left(V_C^{\max}\right)^2 \end{array} \right\} \tag{5}$$

When feeding a UPF load with the proposed converters, the inductors L_P and L_Q can be calculated ripple α% of max.^{m} current as follows:

$$L_{P,Q}^{Buck} = (1-D)D^2 \times \frac{V_{S-(rms)}^2}{\alpha\% f_{SW} P_o} \tag{6}$$

and the capacitors C_P and C_Q can be calculated ripple β%of max.^{m} voltage as well as-

$$C_{P,Q}^{Buck} = \frac{P_o}{\beta\% f_{SW} V_{S-(rms)}^2} \tag{7}$$

(f_{sw}) switching frequency and (P_o) o/p power is respectively. Furthermore, the maximum voltages of capacitors and maximum currents of inductors are calculated by neglecting the voltage and current waveforms.

$$I^{\max}(L_{P,Q}^{Buck}) = \sqrt{2} I_{o-(\mathrm{rms})} \tag{8}$$

$$V^{\max}(C_{P,Q}^{Buck}) = \sqrt{2}(1-D)\mathrm{V}_{s-(rms)} \tag{9}$$

The maximum stored energy of inductors and capacitors can be obtained by putting (6) – (9) into (5).

$$W(\mathrm{L}_{total}^{Buck}) = \sum_{i=1}^{2} W_{L_i}^{Buck} = (1-D)^3 \times W_B \tag{10}$$

$$W(C_{total}^{\ Buck}) = \sum_{i=1}^{2} W_{C_i}^{\ Buck} = (1-D)^2 \times W_B \qquad (11)$$

where,

$$W_B = \frac{2P_o}{(\alpha or \beta)\% f_{sw}} \qquad (12)$$

To correctly determine their needed ratings, calculate peak voltages and currents values of proposed converters are also computed as (13), respectively.

$$\left\{ \begin{array}{lcl} V_{M_1-M_4-(pk)}^{\ Buck} & = & \sqrt{2}V_{s-(rms)} \\ V_{M_5-M_6-(pk)}^{\ Buck} & = & \sqrt{2}V_{o-(rms)} \\ I_{M_1-M_6-(pk)}^{\ Buck} & = & \sqrt{2}I_{o-(rms)} \end{array} \right\} \qquad (13)$$

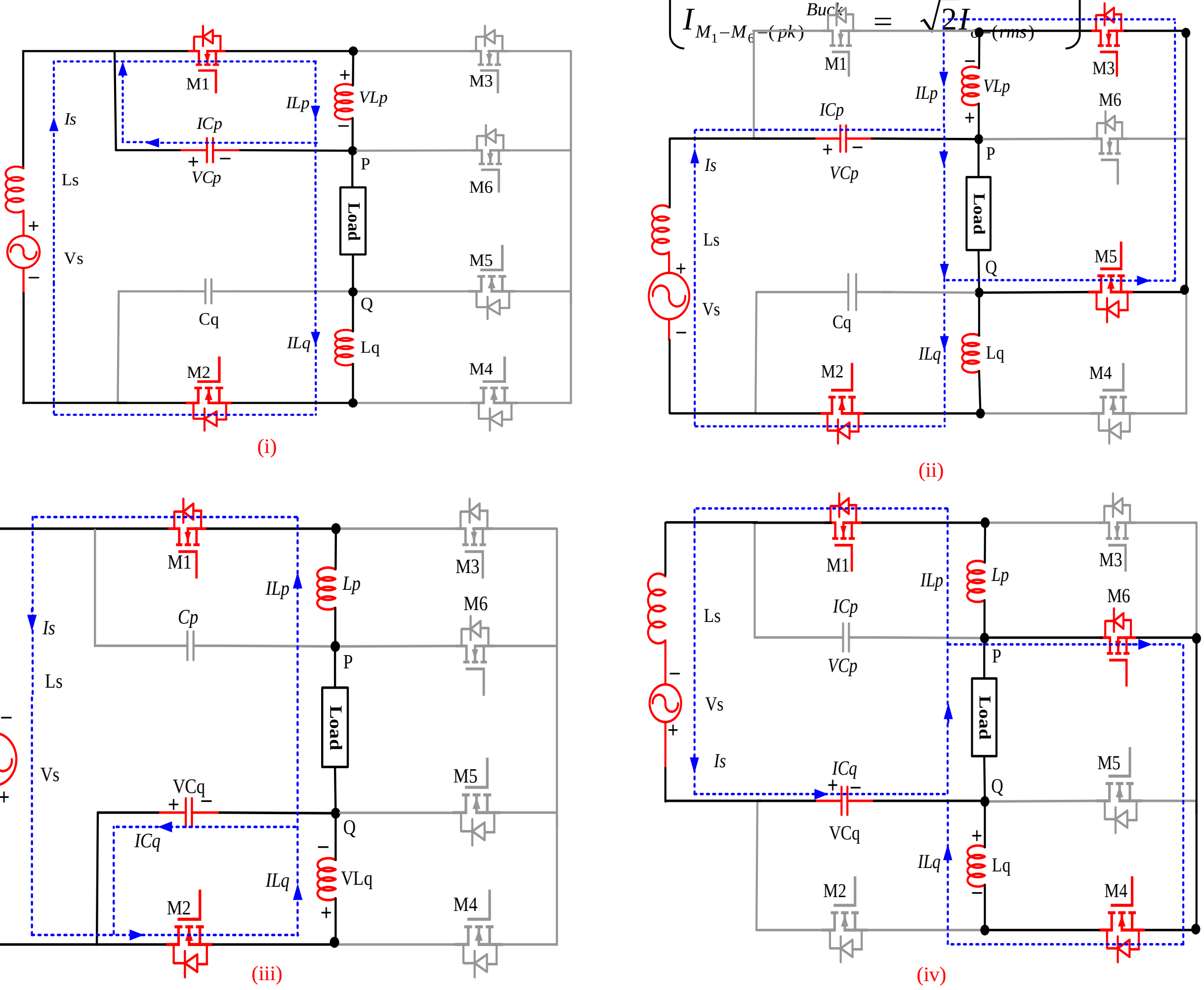

Fig. 3. The operation mode of the proposed ac-ac converter. (i) Mode 1 and (ii) Mode 2 during +ive half-cycle i/p voltage. (iii) Mode 1and (iv) Mode 2 during -ive half-cycle i/p voltage.

IV. COMPONENTS PARAMETERS

TABLE-I

Parameters		Values
O/p power, P_O		400W
O/p voltage, V_O		110Vrms/50Hz
	UPF: R_o	60Ω
	non-UPF: R_o & L_o	60Ω & 1mH
I/p voltage, V_S		72~ 210Vrms/50Hz
Switching frequency, f_{SW}		10KHz
Inductor, L_P=L_Q, L_S		450mH, 1mH

Capacitor, $C_P = C_Q$, C_O	1μF, 20μF

V. SIMULATION AND RESULT

For proposed converter, a 400-W simulation is created to validate properties as shown (Fig. 4), Consequently, the value of o/p voltage is supposed to be constant at 110 Vrms when proposed converter i/p voltage varies from 72 to 210 Vrms, then, can be easily confirmed voltage buck. Furthermore, performed with two load: both load UPF and non - UPF partially inductive loads with 60-Ω resistors. In addition, the offered converters are designed to have a continuous drive mode. Fig. 5(i) and Fig. 5(ii) is presented peak value of switches, capacitors, and inductors of voltage and current with i/p and o/p voltages and currents waveform are measured (assuming a resistive load and inductive load), when set as duty cycles are D_{buck} = 0.55 the proposed is buck converters, respectively, applied 210 Vrms at i/p to provide 110 Vrms at o/p. The voltages across the switches M_1 and M_2, as well as the currents flowing through the inductors. In second (II) section already presented inductive currents are sinusoidal 50 Hz waveforms with every switch operating throughout half ac cycle. The peak values calculated of voltages in capacitors and switches (8), (9), (13), are matching with theoretical. The component parameters are shown in Table-I.

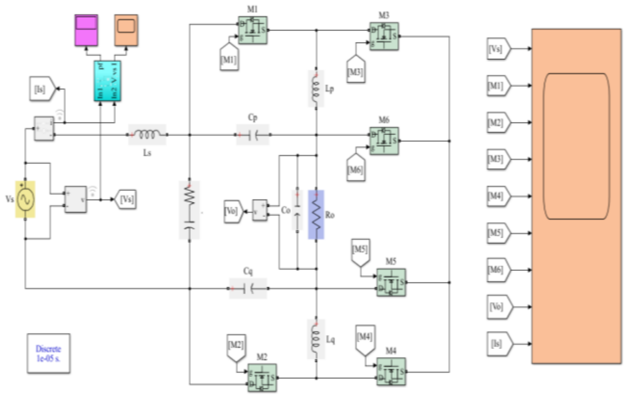

Fig. 4

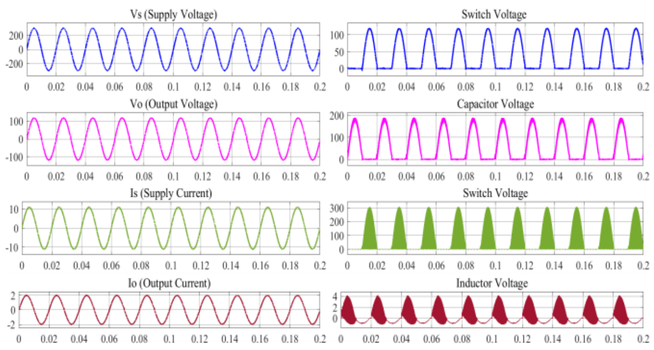

Fig. 5(i)

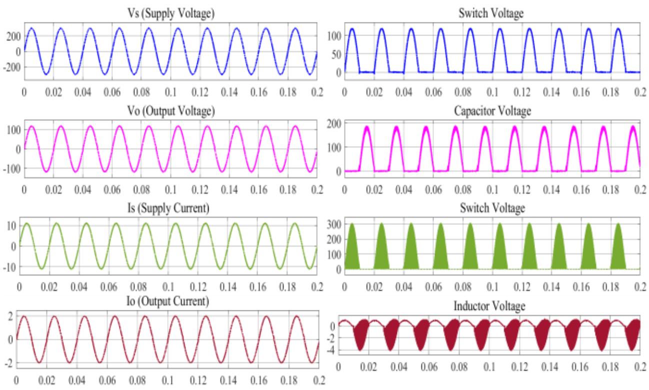

Fig. 5(ii)

As a result, shown in Figs. 6(i), 6(ii), 6(iii) and 6(iv). The proposed buck converter for resistive load i/p current (I_S) and output voltage (V_O) total harmonic distortion (THD) is shown in Fig. 6(i) and 6(ii). For inductive load i/p current (I_S) and output voltage (V_O) total harmonic distortion is shown in Fig. 6(iii) and 6(iv). Table-II shows in quality factors for the buck converter Improved power factor quality shown for resistive load 97% and inductive load 98.4%.

VI. QUALITY FACTOR AT BUCK CONVERTER

TABLE-II

Quality Factor	Power Factor, pf		Total Harmonic Distortion (THD)	
Converter	***Buck Converter***		***Buck Converter***	
Loads	R	RL	R	RL
Operating Mode	G = 0.55	G = 0.55	G = 0.55	G = 0.55
I/p Current (I_s)	0.970	0.984	0.56%	0.56%
O/p Voltage (V_o)	----	-----	0.71%	0.72%

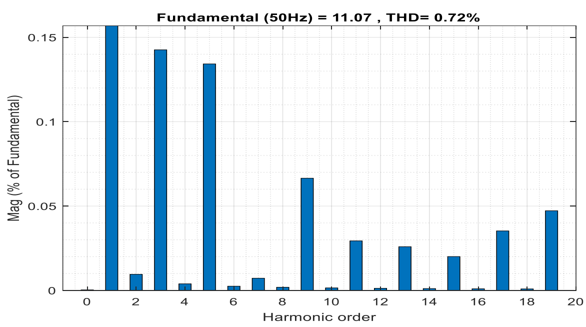

Fig. 6(i)

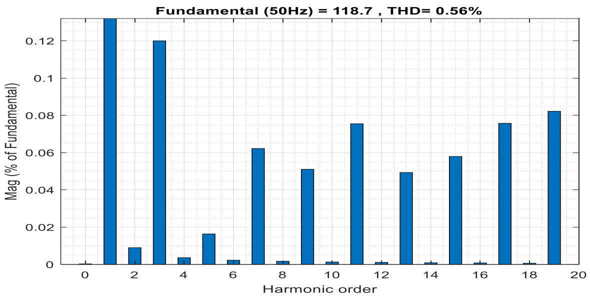

Fig. 6(ii)

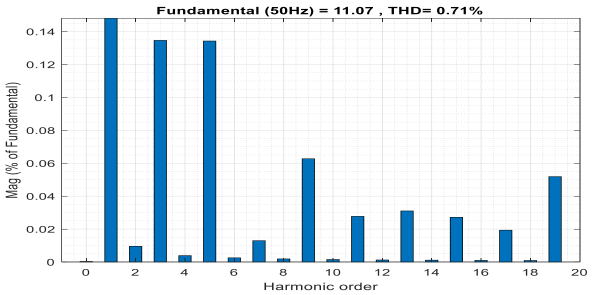

Fig. 6(iii)

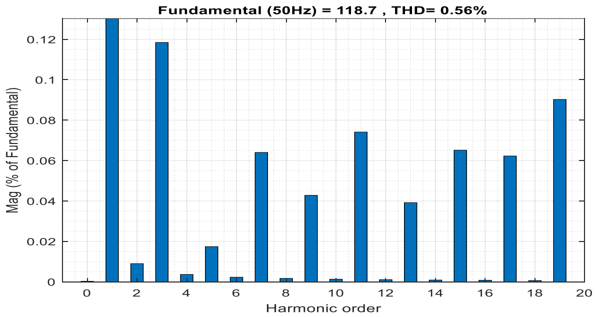

Fig. 6(iv)

VII. CONCLUSION

In this paper direct single phase ac- to -ac converter with a novel switching strategy. The performance has been analyzed for UPF and non-UPF loads. The proposed converter uses six power MOSFETs and two inductors at a high switching frequency. It is observed that the shape(size) of the converter is decreased and minimizes high frequency and conduction losses of semiconductor devices. The developed switching strategy also provides a safe commutation. The direct single-phase ac-ac converter is simulated for 400W resistive and inductive loads. It is found that the converter operates with high power quality operation and almost unity power factor. The power factor obtained for UPF and Non-UPF load is 0.97 and 0.98 respectively. The THD for i/p current and output voltage is 0.56 % and 0.71% respectively for UPF load and 0.56% and 0.72% for the non-UPF load. The simulations have been carried out on MATLAB-2019b.

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