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Modeling and Analyzing of a New Simple Structure for DC-AC Converter using Two Unidirectional Switches

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ABSTRACT

Reducing in size and number of active elements has been an important consideration in designing of the converters. There have been several attempts to achieve a better structure for inverters having less THD. In this paper, a novel structure has been proposed for DC-DC converters utilizing two switches to decrease the number of active elements. By the use of a simple switching method, the DC input voltage is divided into three voltages with different frequencies and amplitudes which have the frequency of zero (DC voltage), fundamental frequency, and switching frequency. To obtain an AC sinusoidal output, DC and switching frequency is eliminated by using two filters. Comparing to a conventional full bridge inverters, this structure reduces two active elements. In this proposed method, the total harmonic distortion (THD) has been greatly decreased and the efficiency is improved. Simulations have been carried out and the obtained results confirm the mentioned goals.
KEYWORDS- SPWM inverter; Unidirectional Switches; DC-AC converter, Total harmonic Distortion (THD).

NOMENCLATURE

$f_{control}$	frequency of control voltage,
$f_{triangular}$	frequency of triangular signal,
R_f	number of samples per each period,
R_a	amplitude ratio,
L_s	series inductance of filter,
C_s	series capacitance of filter,
$V_i(t)$	input voltage,
$V_o(t)$	output voltage,
C	circuit capacitance,
L_1 and L_2	circuit inductances,
R	circuit resistance.

1- INTRODUCTION

The main objective of static power converters is to convert a DC output voltage of a power supply to an AC voltage. The AC voltageis required in adjustable speed drives (ASDs), uninterruptible power supplies (UPSs), static VAR compensators, flexible AC transmission systems (FACTS), and voltage compensators, etc. For sinusoidal AC outputs, the magnitude, frequency, and phase should be controllable. There are several specifications, which define the performance and efficiency of inverters. These factors have small size, simple control system, low voltage stress, low input current ripple, simplicity of circuit, minimizing of total harmonic distortion (THD), low cost, and desirable and controllable output voltage. Different switching methods for AC choppers are presented which each one have advantages and disadvantages. Many switching methods have been proposed to apply for power electronic converters. In order to reduce the harmonics in multi-level inverters, FA and LAFA algorithms were used in [1]. Specified harmonics were properly eliminated by this method. SHE-PWM switching method was suggested in [2] to be used in AC/AC converters. By employing this method a desirable number of harmonics can be chosen and eliminated. A sample AC chopper with two taps is suggested in [3], in which a series transformer was used to compensate the output voltage. The switching method in this paper was pulse width modulation (PWM). In [4], differences between conventional and electronic tap changers were studied. Some changes for conventional tap changer controller were suggested as well. Output voltage harmonic was studied for cyclo-converter in [5], which was changed by modulation index variations. A new extendable single-stage multi-input dc-dc/ac boost converter was proposed in [6] which comprises two bidirectional ports to interface output load and battery storage, and other unidirectional input ports to obtain powers from different input dc sources. In [7], a current source modular multilevel converter (MMC) is proposed which is used mainly in high voltage AC/DC power conversion applications such as HVDC and FACTS.

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However, in the multi-level inverters the added complexity of the circuit, and additional components, reduce both the overall efficiency and reliability of the system. They may also increase the overall cost of the power electronic interface. Moreover, there are different attempts to reduce losses of switches with soft-switching methods [8],but these methods add extra components to the circuits resulting in more complex converters. In this paper, a novel inverter has been proposed which eliminates some of these disadvantages. The proposed inverter has two switches which reduces energy losses and the cost. The inverter has only one simple control system which can be controlled by a simple microcontroller.

This paper is organized as follow: in Section 2, the circuit structure is presented. Modeling and numerical analysis is illustrated in Section 3. In Section 4, simulation results and diagrams are shown to verify all of the statement. Finally, conclusion is explained in Section 5.

2- THE CIRCUIT STRUCTURE

2.1-Inverter Circuit

The new inverter circuit is shown in Fig.1. The circuit consists of two inductors, two capacitors for filtering undesirable frequency components, and two switches with freewheeling diodes. The switches work together to convert the DC voltage to an AC desirable output voltage. The circuit is presented for both inductive and resistive loads. Two switches were considered to be ideal. It was assumed that the input DC source did have any resistance and it could supply the current without reducing the voltage value.

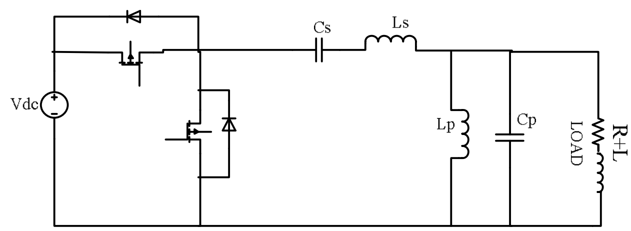
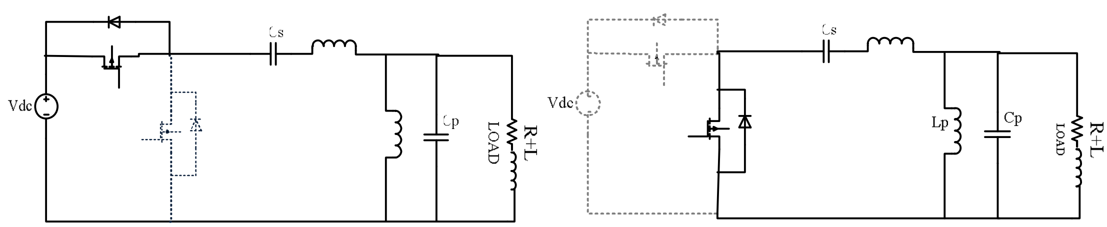


Fig.1: The structure of the proposed inverter

The circuit has only two modes, so it can be easily analyzed. The first and second modes are shown in the Fig.2a and Fig.2b, respectively, in which, current path is shown with the solid line.



(a) (b)

Fig.2: a) The current path of circuit for first mode, b) The current path of circuit for second mode

2.2- Method of Triggering the Gates

In this subsection, the method of switching is explained. In the simulation, gate pulse was modeled by comparing a triangular and a sinusoidal control signals as shown in Fig.3. The gate pulse was 5V when Eq. (1)was applied, and is 0v when Eq. (2)was applied.

$$\begin{cases} \text{Switch on} \Rightarrow \quad \text{if } V_{\text{control}} > V_{\text{triangular}} & (1) \\ \text{Switch off} \Rightarrow \quad \text{if } V_{\text{control}} < V_{\text{triangular}} & (2) \end{cases}$$

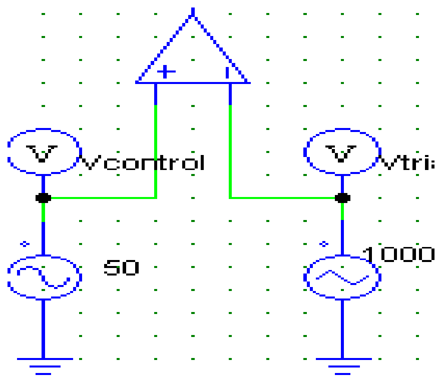


Fig.3: PWM by comparing of two signals

It is worth mentioning that, generally, one of the objectives of a pulse width modulation (PWM) technique is to create sequence of switching pulses that have same average voltage as a reference modulation signal. It can directly control the frequency of the output voltage. R_f can be obtained as Eq.(3).

$$R_f = \frac{f_{triangular}}{f_{control}} \qquad (3)$$

To get better view of this simulation, the frequency of triangular signal was selected to be 1 *kHz* and the frequency of control voltage (sinusoidal) was 50 *Hz*. Hence, based on Eqs. (3)-(4), the number of samples in each period is 20 and the frequency of the gate pulse was 1 *kHz*. One should add this clear point that, as switching frequency goes up, the size of filter and, consequently, the size of converter is reduced.

$$R_f = \frac{1\text{ kHz}}{50\text{ Hz}} = 20 \qquad (4)$$

By increasing the frequency of triangular voltage, the number of samples is increased that causes lower THD and also smaller filter. Fig. 4 shows the performance of the pulses and the way it cause sinusoidal output voltage. In this figure, three signals and output voltage are simultaneously shown. The parameters of the circuit were set in a way to give this voltage. The output voltage which is shown by black color isnot rated voltage and it is shown here to understand the concepts.

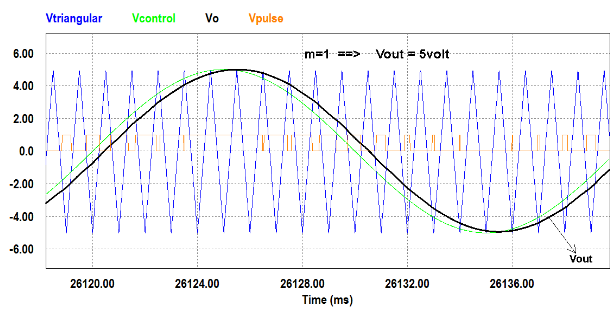
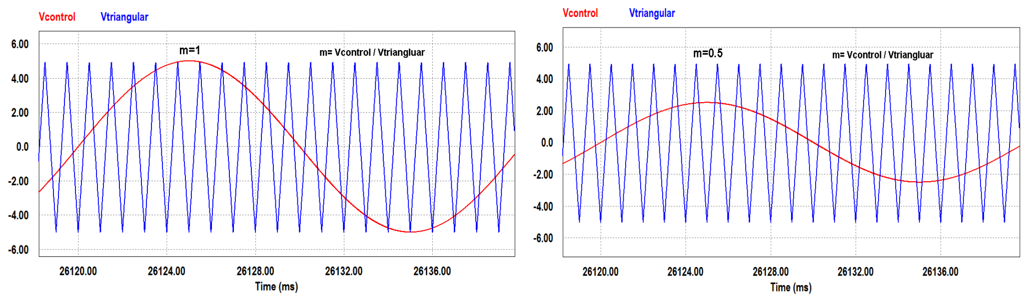


Fig.4: Three signal and output voltage for R_a=1 Ω,R_f=20 Ω, $f_{triangular}$= 1 kHz and $f_{control}$ = f_{Vout} = 50 Hz

To control the amplitude of the output voltage to a desirable value,$R_a$is defined by the Eq.(5).

$$R_a = \frac{V_{control}}{V_{triangular}} \qquad (5)$$

In this circuit for a rated output voltage,R_a was set to 1 to give rated output voltage. The value of R_a was not fixed at this value and it could be changed based on the users' desires. Therefore, the output voltage could be controlled from zero to the rated voltage. When *m*=0 the output voltage was zero and when *m*=1the output voltage was equal to desired value. Apparently, this converter cannot boost the input voltage and it is a drawback comparing with the inverters proposed in [9-10].Fig.5a and Fig.5b shows two different $R_a$for controlling of the output voltage amplitude.



(a) (b)

Fig.5: a) Control and triangular voltage for R_a=1, b) Control and triangular voltage for R_a=0.5

3- MODELING AND NUMERICAL ANALYSIS

As it was explained in the previous section the circuit has two independent modes. Based on the Fig. 2.a and Fig. 2.b these two modes can be shown as Fig.6a and Fig.6b. In the Fig.6a switch is on and it is ideally close. Consequently, the diode can be omitted and the switch can be substituted by a wire. In fact, in this figure the left part of the circuit, which consists of power supply, switch, and the diode, is changed by a DC voltage. In the second mode the switch is off and current flows through diode and the input voltage is zero.The circuit is shown in Fig.6b.

(a) (b)

Fig.6: a) The circuit layout in the first mode, b) The circuit layout in the second mode

It is obvious that, in the first mode, the input voltage is V_{dc} and in the second mode the input voltage is zero. These situations directly depend on the pulses which are assigned to the switch. A function for the signal gate pulses was defined to show the state of the switch is shown by Eq.(6).

$$\mathrm{PWM(t)} = \begin{cases} 1, & if \;\; \mathrm{V_{control}} > \mathrm{V_{triangular}} \\ 0, & if \;\; \mathrm{V_{control}} < \mathrm{V_{triangular}} \end{cases} \quad (6)$$

Because the states of the input voltage are directly based on the gate pulses, Eq. (7) is defined for input voltage as follow.

$$\mathrm{V_{in}(t)} = \begin{cases} \mathrm{V_{dc}}, & PWM(t) = 1 \\ 0, & \mathrm{PWM(t)} = 0 \end{cases} \quad (7)$$

By these statements, the circuit can be redrawn as Fig.7.

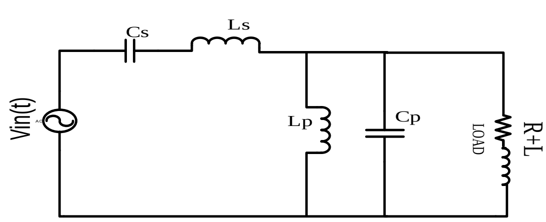
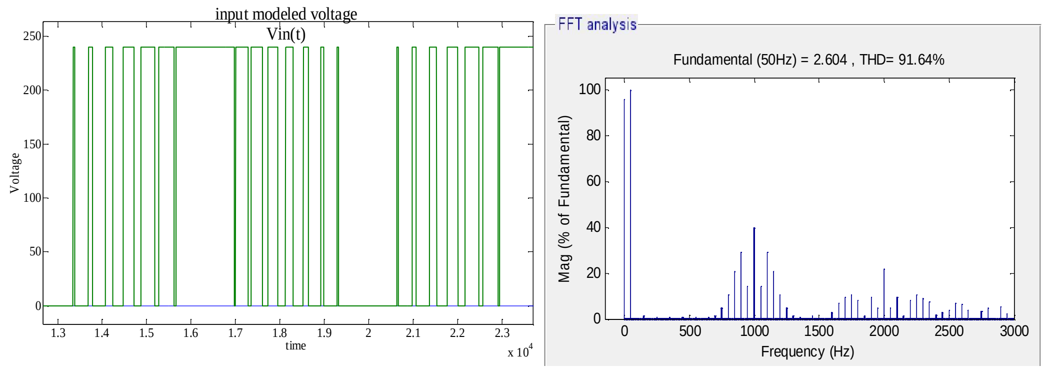


Fig.7: Circuit with the input modeled source as $V_{in}(t)$

The input voltage $V_{in}(t)$ is shown in Fig.8. In this figure the amplitude ratio, which is defined by Eq. (5), wasR_a=1.



(a) (b)

Fig.8: a) $V_{in}(t)$ forR_a=1, b) Fast Fourier transform (FFT) analysis of $V_{in}(t)$

As it is shown in Fig. 8b,$V_{in}(t)$consists of different harmonics. The biggest value is DC component and fundamental frequency which is 50 *Hz*. The amplitude is about 240*V*as shown Fig.8a. Other harmonics which are less than 1 *kHz* can be neglected because their amplitudes are so low. For substituting $V_{in}(t)$ with Fourier series, harmonics with high frequencies can be neglected because they can be removed with low pass filters. The DC part can be removed by a series filter including L_s and C_s, and the DC component does not pass through it. Therefore, the output voltage can be substituted by fundamental harmonic. The filter is shown in Fig. 9.

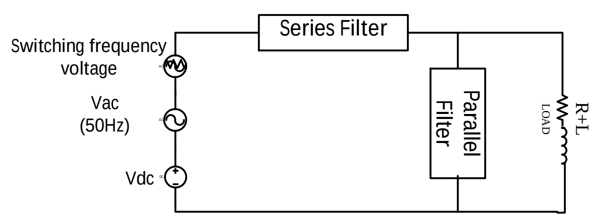


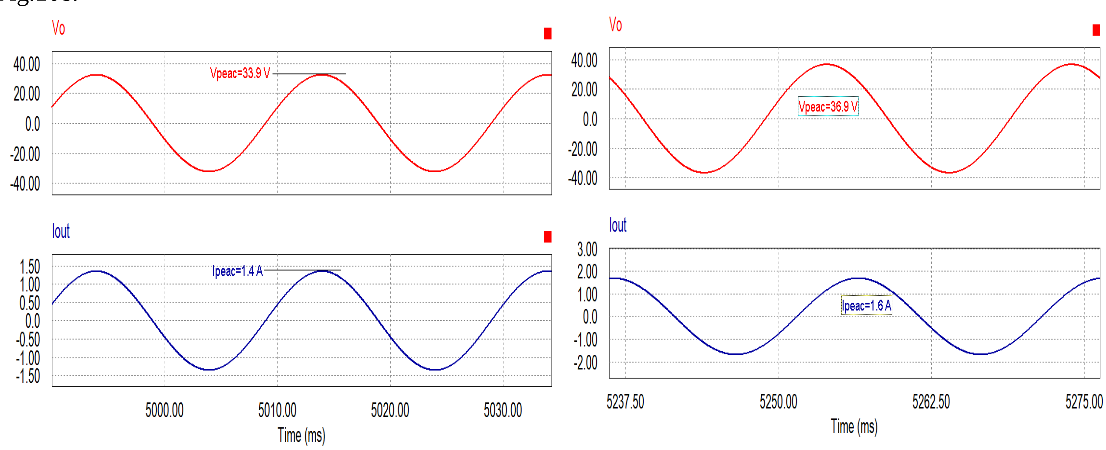
Fig. 9: Series filter including L_s and C

4- SIMULATION RESULTS AND DIAGRAMS

The results are shown in this section to confirm the numerical analysis. In order to set the output voltage at 24*V*, parameters of the circuit was selected as Eq.(8).

$$L_1 = 1e^{-3}\,H;\ L_2 = 3.4e^{-3}\,H;\ C = 14e^{-3}\,F;\ R = 24\ \Omega; \tag{8}$$

The output voltage and current for a resistive load and inductive load is shown, respectively, in the Fig.10a and Fig.10b.



(a)(b)

Fig.10:Output voltage and current of (a) resistive load (b) inductive load

This novel inverter was simulated for rated value and as it is shown in the Fig. 10.a and 10.b, the effective values of the voltage and current are almost 24 *V* and 1 *A*, respectively. The total harmonic distortion for output voltage and current was very small and could be neglected. The output apparent rated power was 24 *VA*. The output voltage could be easily set on lower or higher rated values by either changing parameters of the Eq.(8) or varying m_a properly. If the load current increased the output voltage would be decreased significantly. If the load current increased, with a simple feedback, m_a could be gone up to make the output voltage retain at the rated value. As it was defined in the Eq. (5) m_a goes up by increasing the control signal.

5- CONCLUSION

In this paper, a novel simple structure for DC-AC Converter has been proposed by using two unidirectional switches. A novel inverter circuit has been introduced and simulated in this paper which produces a sinusoidal output voltage with THD lower than 1%. This structure of the inverter, first, changes the DC voltage to three voltages bearing three different frequencies, and after filtering two of them, transfers the fundamental desired frequency. The inverter has been reduced in size because of reducing the number of components as well as decreasing the size of the filters. It does not need several individual control systems and utilizes only a simple control method. The frequency and amplitude of the output voltage can be easily controlled.

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The authors declare that they have no conflicts of interest in this research.

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