# Three-Stage-MPVD-Based DC-AC Converter Using Sinusoidal PWM Control

Y.-H. Chang [1], T.-Y. Luo[2]

[1,2]*Department of CSIE, Chaoyang University of Technology*
*168, Jifong E. Rd., Wufong Township ,Taichung County 41349, Taiwan (R.O.C.)*
[1]cyhfyc@cyut.edu.tw
[2]s9627638@cyut.edu.tw

***Abstract*—The main purposed of this paper is to propose a three-stage multiphase voltage doublers (MPVD)-based DC-AC converter by sinusoidal PWM (SPWM) control, and then it can provide step-up AC output for electroluminescent lamp (EL) drive. Since the MPVD is employed here, we can obtain 8 times the voltage of source just by the least number of 3 pumping capacitors. In order to have output regulation, SPWM control is need have. So we make AC output to be following the reference of voltage command. Finally, this MPVD-based DC-AC converter (inverter) is simulated via OrCAD and some cases discussed, including steady-state response and dynamic-state response for some variation.**

***Keywords*—multiphase voltage doublers (MPVD), Inverter, sinusoidal PWM (SPWM).**

## 1. INTRODUCTION

Due to development of science and technology, various kinds of mobile electronic products are more and more fashion, including PDA, notebook, cellular phone, digital camera, pager, e-book, etc. This kinds of products emphasize some excellent characteristics, for example, mobile convenience, integrated communication function, small volume, light weight and long-time power supply. All of mobile electronic products must have display screen, such as mobile phone, PDA and MP3 player, etc. And all kinds of products requirement is low power and high efficiency for power. Therefore, EL have some excellent characteristics, for example, small volume, light weight, no glimmered and long-time power supply that have extensively applied to backlight of the mobile electronic products now. The most importantly, the mobile electronic products always ask for the long running time of batteries. At present, the main sources of power supply is: single lithium ion battery (Li-ion, the standard voltage is form 3.0 V to 3.6 V), single nickel battery (Nickel, below 3.0 V) or the alkaline chemical battery (Alkaline, below 1.5 V), above-mentioned voltage source is unable to supply directly the EL device (Its supply voltage is 50 to 200Vp-p of DC voltage). For this reason, we design a step-up DC-AC power converter that can possess high-energy density, high conversion efficiency and small volume. It can improve the EL continuous work reliability, light-emitting efficiency and be using time, etc.

General speaking, the most popular step-up converters are classified as follows: (1) switched-capacitor boost converter, (2) LC Resonant boost converter. For dual-model control circuit, some scholars have proposed the concept according to DC-DC converter module and circuit [1] so that the power circuit can be better controlled and applied. Next we use single-phase full-bridge inverter to exchange DC voltage to AC voltage. Control system is to produce control signals for DC-DC converter and inverter switch need. The main purposed of this paper is to propose a three-stage MPVD-based DC-AC converter for EL drive.

## 2. CONFIGURATION OF MPVD-BASED DC-AC CONVERTER

The proposed circuit structure as shown in Fig.1. Because the capacity of battery for mobile electronic product isn't satisfactory, so it needs a conversion circuit to obtain an enough voltage for backlight circuit drive. The backlight operational effective voltage of EL is between 40 volt and 220 volt. Therefore, we proposed converter can

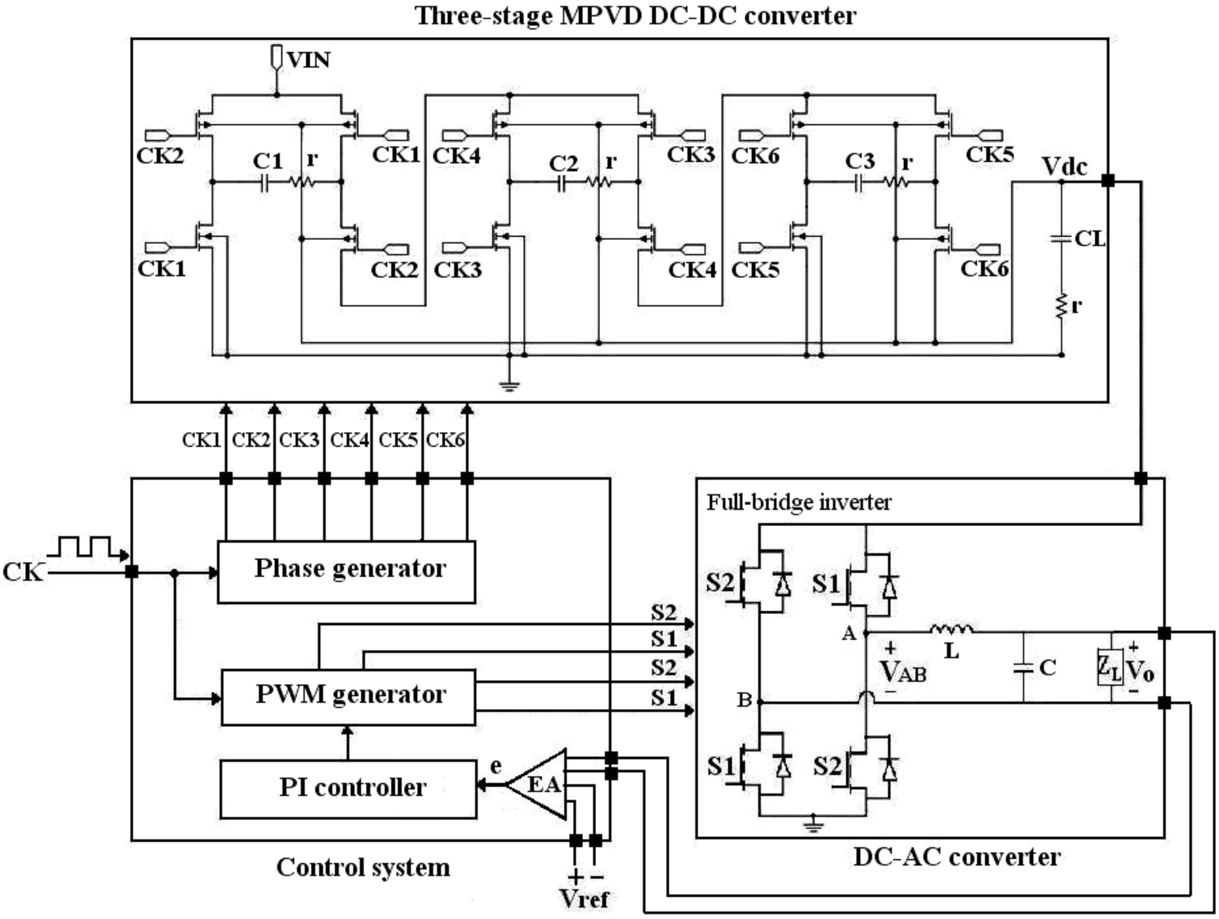


Fig.1 The proposed converter structure

supply enough AC voltage for EL drive need. The proposed converter structure can divide three parts, three-stage MPVD DC-DC converter, single-phase full-bridge inverter and control system. The MPVD DC-DC converter is to boost DC voltage, and the single-phase full-bridge inverter is to exchange DC voltage to AC voltage. Control system is used for converter switch turn-on or turn-off with voltage of output compensation.

## 2.1. Configuration of MPVD

Fig.2 shows a SC-based n-stages MPVD converter [2]. The most important advantage is that this circuit is able to step-up 2n times. The n sets of clock are required to control the switches of the step-up circuit. In the same step-up ratio, the switching capacitors required are the less (n+1 capacitors are required) and the voltage gain is the highest among all the switched-capacitor boost structures. This step-up power converter adopts the three-stage MPVD. The converter use MOSFET switched turn-on or turn-off, respectively, and it can periodically charge and discharge of the capacitors stage by stage. However, in order to enhance regulation capability the voltage of output, we purpose the improved circuit and it shown in Figure 2. We have used 12 MOSFET and control it on or off. This causes the capacitor C1, C2, C3 and CL in the circuit to charge and discharge and then voltage of output to be the same as eight times voltage of source. The three-stage MPVD-based boost converter requires 12 MOSFET and 4 capacitors. The MPVD output Vdc is provided for dc-ac converter as voltage of source.

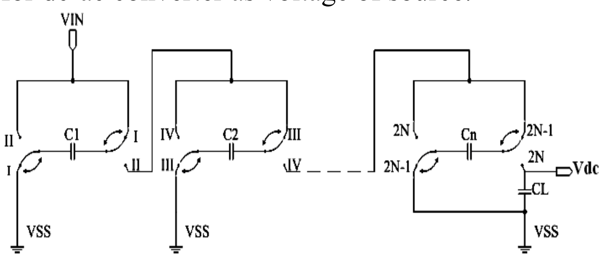


Fig.2 Multiphase voltage doublers

## 2.2. Configuration of DC-AC converter

The single-phase full-bridge DC-AC converter [3] is applied to exchange DC voltage to AC voltage. The inverter supply voltage is by DC-DC converter. The single-phase full-bridge inverter is consists of power stage (semiconductor switch MOSFET) and output stage (energy storage). The power stage of single-phase full-bridge DC-AC inverter main operation is employ SPWM to make four power switch on or off, and then the topological of circuit is changed that can regulate output of voltage wave. SPWM transforms DC voltage into pulse-width-modulation, and then the LC filter can filter out ripple components of high frequency switching cause an can supply a sinusoidal voltage to load. When the power switch MOSFET turn-on or turn-off in a wink, it will bring very large rush voltage. If the large rush voltage exceed power MOSFET safe operating area, and then the power MOSFET will be damaged. All of the above, the inverter need a buffer circuit (Turn-Off Snubber Circuit) [4] to reduce MOSFET switching loss, and decrease rush voltage in an instant of switching.

The output stage: Filter is consists of inductor L and capacitance C to complete low-pass filter, and its main function is to filter out ripple components of high frequency from power stage output. It can produce a low-frequency sine wave AC voltage. The design principle of LC filter by pulse-width-modulation can be knew that the higher switching frequency of system will make inverter to get the higher frequency of ripple, and then the filter's cut-off frequency *fo* will become large. If the cut-off frequency is large enough that filter can reduce value and volume of inductor L and capacitance C. The cut -off frequency *fo* of filter is

$$fo = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

## 2.3. Configuration of control system

The control system includes phase generator, PWM generator and PI controller. The phase generator with PWM generator is produce pulse waves for converter switch. In order to make DC-AC converter to get constant voltage of output under voltage variation, it needs a closed-loop circuit to control voltage of output. We use voltage-mode PI controller for voltage compensation circuit. The control circuit of voltage mode is uses voltage of output as feedback signal, when error signal pass through PI controller, and then the PWM generator will produce corresponding control signals for converter. So the converter voltage of output will be following voltage of reference. The proportion control (P) is a simple control method and it has a proportionate relationship between output and input signal. When system only a proportion control, and it will bring the steady-state error. Proportion control can be described as formula (2) with (3). In order to eliminate the steady state error, proportion control need to add integral control, and then value of output with integral value of input has a positive proportionate relationship. The relationship between integration with error value is concerned time, with time to go on that the integral value will be increased. So, even if the error value is very little, the integration will be increased with time to accumulate, and the output of controller will be increased, and it can make the steady state error be decreased until equal zero. Therefore, the PI controller cannot produce the steady state error, when system into steady state. PI controller formula can be described as (2) and (4) [5], and circuit is shown in Fig.3.

$$Gc(S) = \frac{Vo(S)}{Vi(S)} = KP + \frac{KI}{S} \quad (2)$$

$$KP = -\frac{R2}{R1} \quad (3)$$

$$KI = \frac{R2}{R1 \cdot C2} \quad (4)$$

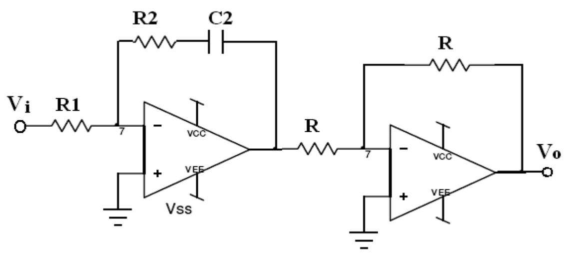


Fig.3 PI controller

## 3. OPERATIONAL PRINCIPLE OF MPVD-BASED DC-AC CONVERTER

### 3.1. Operation of three-stage MPVD

This step-up DC-DC converter circuit adopts three-stage MPVD that is using MOSFET switched turn on and turn off, respectively. Totally, eight phases of switching on or off are required to complete one working cycle. The eight phase equivalent circuit diagrams are shown in Figure 4(a) to Figure 4(d). The 12 power MOSFET is mainly used for controlling the connection or disconnection of the 4 capacitors C1, C2, C3 and CL. The internal resistance of the capacitors are also included in order to make results to be true.

The principle of MPVD is introduced below. The overall working cycle is divided into eight stages: (1) Phase 1, Phase 3, Phase 5 and Phase 7 as shown in Figure 4(a). When CK1 is turn-on and CK2-CK6 is turn-off. C1 is charged in series with source VIN, and the maximum voltage of C1 is fully charged to one time of VIN. (2) Phase 2 and Phase 6 are shown in Figure 4(b). When CK2 and CK3 are turn-on, and CK1 and CK4-CK6 are turn-off. C2 is connected in series with C1 and source VIN, and the maximum voltage of C2 is fully charged to twice of VIN. (3) Phase 4 is shown in Figure 4(c). When CK2, CK4 and CK5 are turn-on, and CK1, CK3 and CK6 are turn-off, C3 is connected in series with C2, C1 and source VIN, and the maximum voltage of C3 is fully charged to four times of VIN. (4) Phase 8 is shown in Figure 4(d). When CK2, CK4 and CK6 are turn-on, and CK1, CK3 and CK5 are turn-off, The output capacitor CL is connected in series with C3, C2, C1 and source VIN, and the maximum voltage of CL is fully charged to eight times of VIN.

The frequency of MPVD DC-DC step-up converter circuit is set to 10k Hz. The timing sequence diagram of CK1~CK6 is shown in Figure 4(e).

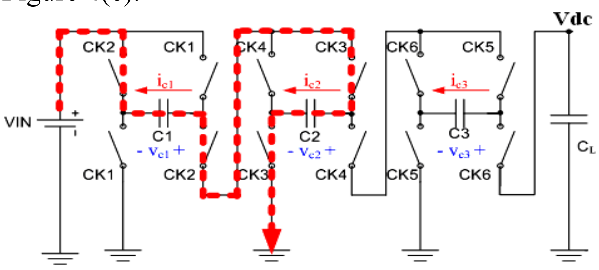


Fig.4 (a) Equivalent circuit for Phase 1, 3, 5 and 7

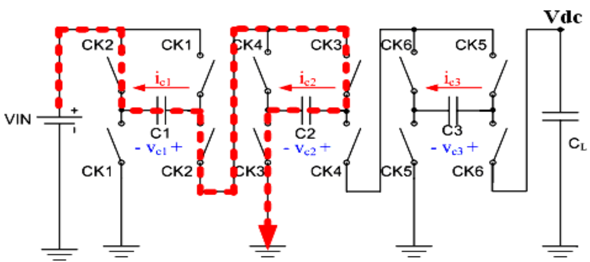


Fig.4 (b) Equivalent circuit for Phase 2 and 6

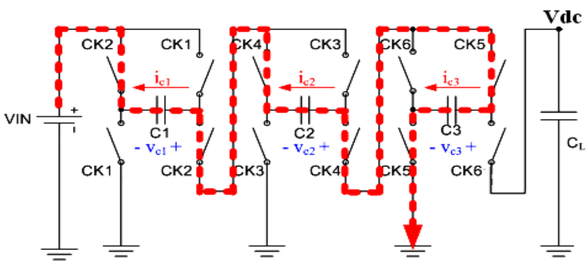


Fig.4 (c) Equivalent circuit for Phase 4

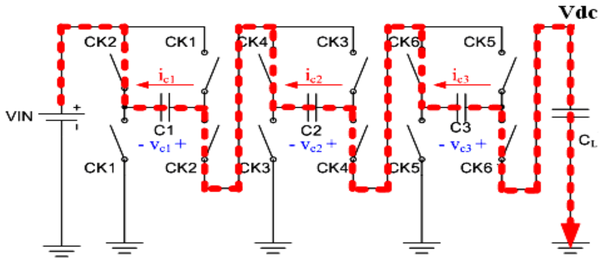


Fig.4 (d) Equivalent circuit for Phase 8

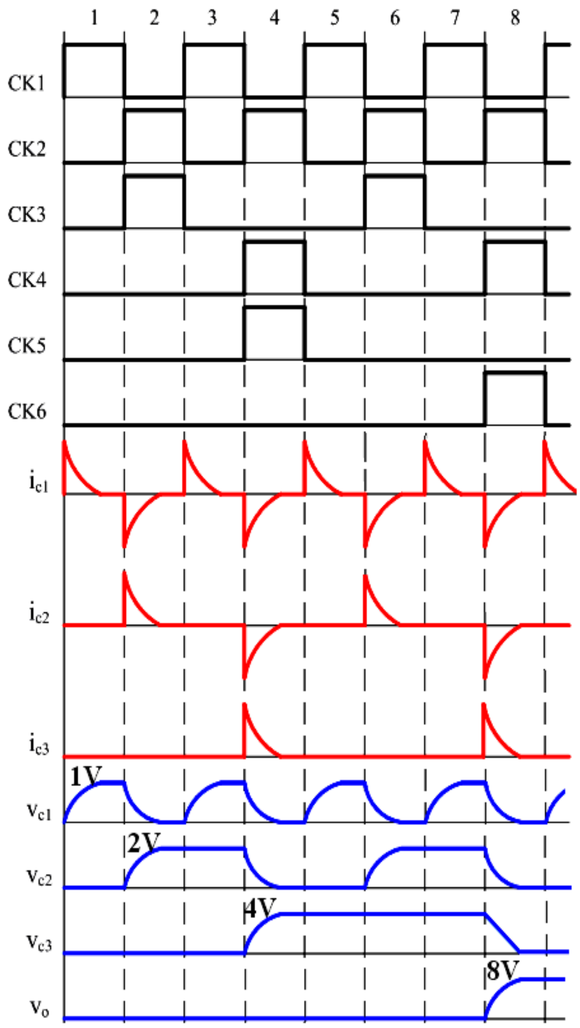


Fig.4 (e) Timing sequence of three-stage MPVD

## 3.2. Operation of single-phase full-bridge inverter

Fig. 5 shows is the single-phase full-bridge inverter, and general speaking, its source comes from an output of step-up DC-DC converter. Its basic operation as follows: In the positive-half-cycle, let MOSFET S2 and S3 turn on, and S1, S4 be off, and then the output Vo can obtain the positive voltage value. In the contrary, we can obtain negative output Vo, when the negative-half cycle is running.

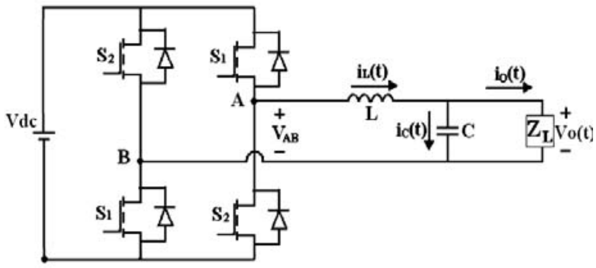


Fig.5 Single-phase full-bridge inverter

### 3.3. Operation of SPWM

Inverter is use the MOSFET turn on and turn off to reach exchange voltage and frequency. In all kinds of switching technology, SPWM is a common method. It can make circuit to get some characteristic such as constant voltage of output and low harmonic distortion, and moreover voltage of output with frequency can all be controlled [6]. Sinusoidal pulse width modulation is applied to full-bridge inverter and it can be finished by two methods, one is bipolar voltage switching and another is unipolar voltage switching. Figure 6 is unipolar voltage switching mode waveforms. The inverter switch control signal is produced via compare with ±Vcon and Vtri, namely A arm and B arm.

A arm:
When Vcon> Vtri, S3 on and $V_{AN}$ = Vdc
When Vcon< Vtri, S4 on and $V_{AN}$ = 0
B arm:
When -Vcon> Vtri, S1 turn-on and $V_{BN}$ = Vdc
When -Vcon< Vtri, S2 turn-off and $V_{BN}$ = 0

According to four power switch turn-on with turn-off, there are four kinds of combination for voltage of output, as the following shows:

(1)S3, S2 on, Vo = Vdc
(2)S4, S1 on, Vo =-Vdc
(3)S3, S1 on Vo = 0
(4)S4, S2 on, Vo = 0

Because voltage of output is among Vdc with zero or zero with -Vdc, so the way is called unipolar voltage switching (as shown in Fig.6). From this above explain, we can know that in the same switching frequency, harmonic components of unipolar switching voltage will arrive at a higher frequency. The voltage of output can get a better harmonic component, and it can make the filter's design become easier. Moreover, this mode can decrease volume and weight of filter, so we use unipolar switching for single-phase DC to AC converter that is very suitable.

## 4. EXAMPLE RESULTS

This proposed MPVD-based DC-AC converter can supply an AC voltage for EL drive. When the supply voltage of EL on the raise and its light will be step up; the EL have to increase its supply frequency and its light will be raised. So we regulate the converter's voltage of reference and frequency for circuit simulation. The circuit simulate soft is uses OrCAD, simulation results is divided into two parts, steady state response and dynamic state response respectively. The components used for simulation are shown in Table 1 and Table 2.

**A. Steady state simulation:**

Case I: First, we set circuit voltage of source 3.6V, voltage of output is 28V, voltage of reference is 28V and frequency of reference is 1Khz. Its simulation result is presented as Fig.7, and efficiency is 89%, THD is 1.7%.

Case II: We set circuit voltage of source 3.6V, voltage of output is 28V, voltage of reference is 28V and frequency of reference is 0.8Khz. Its simulation result is presented as Fig.8, and efficiency is 85%, THD is 2.6%.

**B. Dynamic state simulation:**

The dynamic state response simulation is in order to simulate when the circuit have EMI of source and voltage of source variation, so we regulate the converter's voltage of reference and frequency for dynamic state simulation.

Case III-1: First, we set circuit voltage of source 3.6V, voltage of output is 28V, voltage of reference is 28V and frequency of reference is 1Khz. When system operation time into steady state, then we add an additional sin voltage 0.2V to source. Its simulation result is presented as Fig.9 and efficiency is 88%, THD is 2%.

Case III-2: We set circuit voltage of source 3.6V, voltage of output is 28V, voltage of reference is 28V and frequency of reference is 0.8Khz. When system operation time into steady state, then we add an additional sin voltage 0.2V to source. Its simulation result is presented as Fig.10 and efficiency is 85%, THD is 3.1%.

Case IV-1: We set circuit voltage of source 3.6V, voltage of output is 28V, voltage of reference is 28V and frequency of reference is 1Khz. When system operation time into steady state, we set voltage of source value drop from 3.6V to 3.2V. Its simulation result is presented as Fig.11 and efficiency is 86%, THD is 1.9%.

Case IV-2: We set circuit voltage of source equal to 3.6V, voltage of output is 28V, voltage of reference is 28V and frequency of reference is

0.8Khz. When system operation time into steady state, we set voltage of source value drop from 3.6V to 3.2V. Its simulation result is presented as Fig.12 and efficiency is 82%, THD is 3.6%.

From the above simulation, it shows that the proposed converter have pretty good quality of AC voltage, and furthermore, this converter have a stable operation by using PI controller, even thought source voltage is varying.

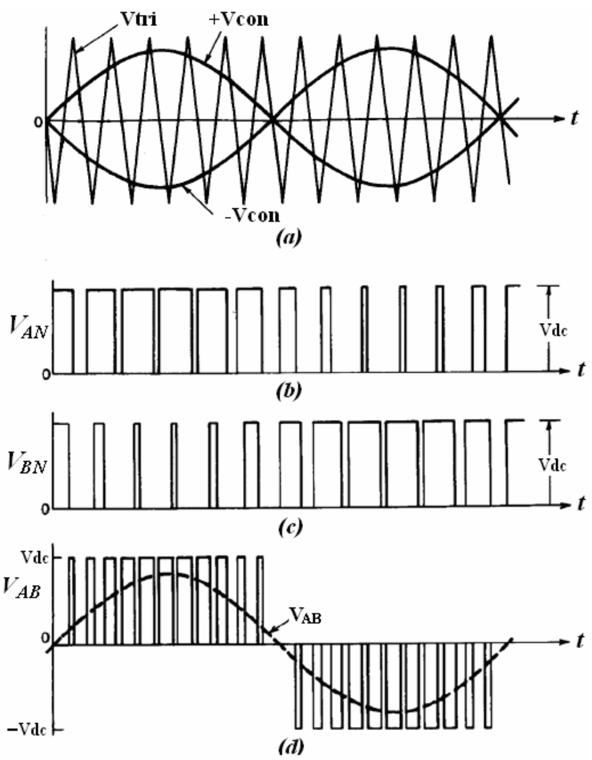


Fig.6 Unipolar voltage switching

**TABLE1. SWITCHED-CAPACITOR BOOST CONVERTER SIMULATING COMPONENTS**

| | |
|---|---|
| **Supply source** | 3.6V |
| **Switch capacitor (C1,C2,C3)** | 350uF |
| **Load capacitor (CL)** | 50mF |
| **Resistance of capacitor (r)** | 0.01Ω |
| **MOSFET** | MbreakN,MbreakP |
| **MOSFET W/L** | 24000u/2u,48000u/2u |
| **Output voltage** | 28.7V~27V |
| **Voltage ripple ratio** | 1.15% |
| **Frequency** | 10kHz |

**TABLE2. SINGLE-PHASE FULL-BRIDGE INVERTER SIMULATING COMPONENTS**

| | |
|---|---|
| **MOSFET** | MbreakN,MbreakP |
| **MOSFET W/L** | 24000u/2u,48000u/2u |
| **Diode** | 1N4149 |
| **Resistance of buffer** | 1KΩ |
| **Capacitor of buffer** | 10μF |
| **Inductance of filter** | 600uH |
| **Capacitor of filter** | 16uF |
| **Output impedance** | 10K ohm |
| **Output voltage** | 19Vrms |
| **Switching frequency** | 0.8kHz、1kHz |

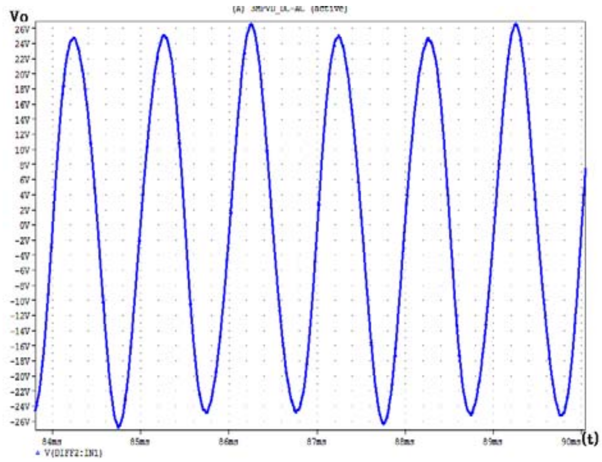


Fig.7 Measured waveforms of case I

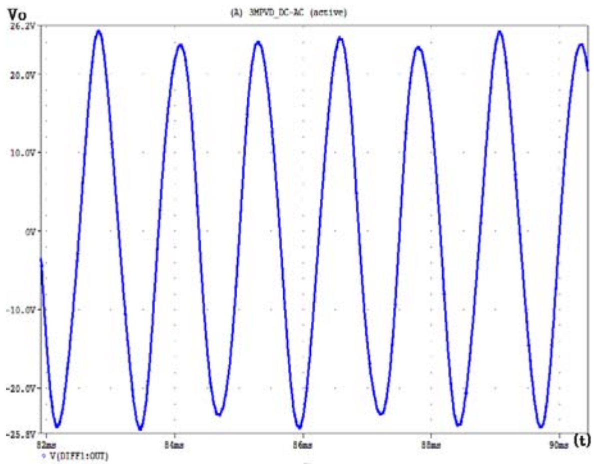


Fig.8 Measured waveforms of case II

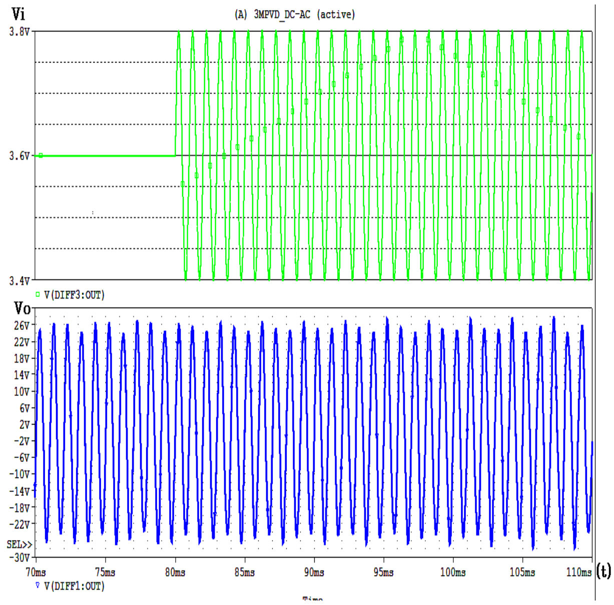


Fig.9 Measured waveforms of caseII-1

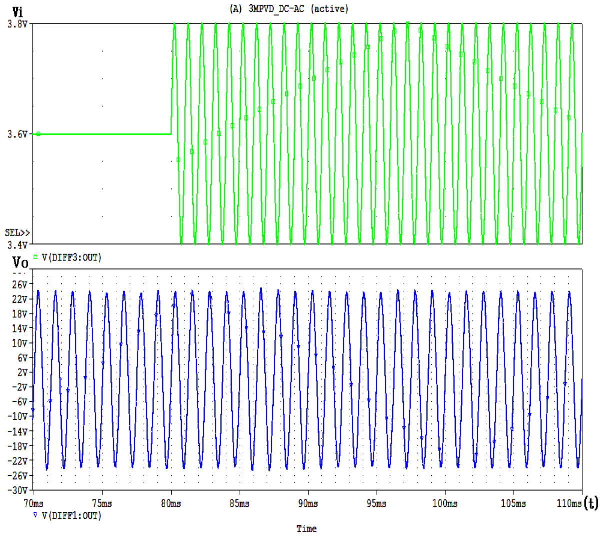

Fig.10 Measured waveforms of caseIII-2

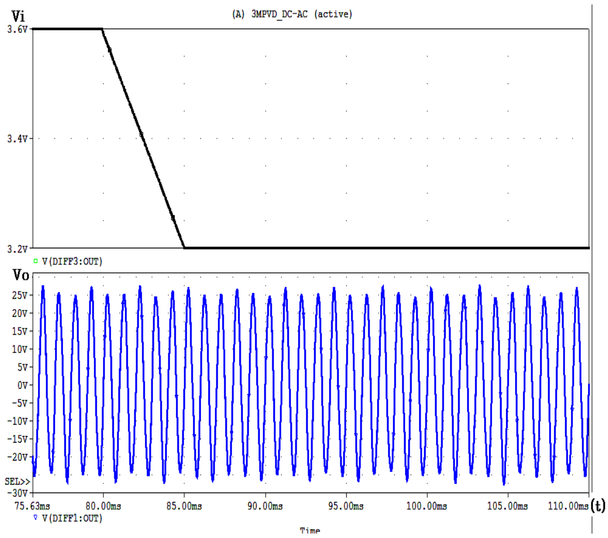

Fig.11 Measured waveforms of caseIV-1

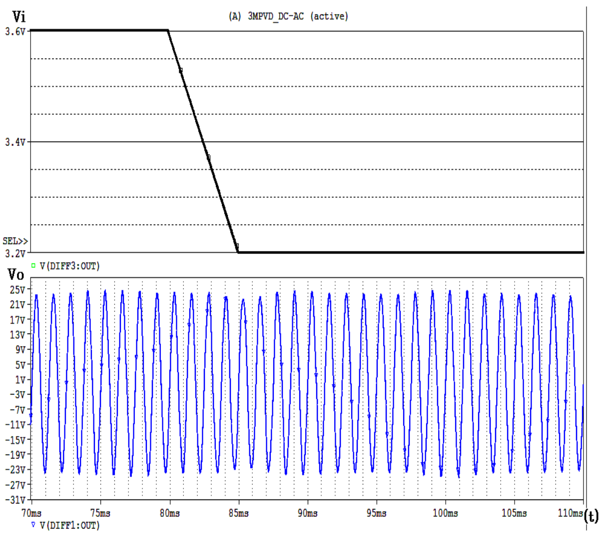

Fig.12 MeasuredwaveformsofcaseIV-2

## 5. Conclusions

The purposed of this paper is to propose a three-stage MPVD-based DC-AC converter using SPWM control, and then it can provide step-up AC output for EL drive. The DC-DC converter is base on MPVD, it can boost voltage of source 3.6v up to 8 times voltage of output (28.8v), and this circuit structure with less switching capacitance to obtain larger voltage conversion ratio. We employ a single-phase full-bridge inverter to exchange DC voltage to AC voltage. The proposed converter have pretty good quality of AC voltage, and furthermore, this converter have a stable operation by using PI controller, even thought source voltage is varying. Finally, the circuit is simulated by OrCAD, efficiency is about 82%~88%, and total harmonic distortion is between 1.7%~3.6%.

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