A Novel Cascaded PV Inverter by Utilizing Ready-Made ICs for Digital Audio Amplifier

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ABSTRACT: This paper presents a novel PV inverter for grid connected by utilizing ready-made PWM IC for class D audio power amplifier. To popularize the PV systems, further cost reduction and mass production have been required. In this study, we propose to apply the ready-made ICs for class D audio power amplifier to the PV inverter for the purpose of cost reduction and mass production. However, the class D audio power amplifier also using the ready-made ICs is not able to produce utility-grid level voltage and the same goes for the PV inverter for grid connection by the ICs without low-frequency (LF) transformer. Against the problem, the cascaded inverter is proposed, which can reach high voltages at transformer less condition. A prototype cascaded PV inverter with the IC was built and verified in the simulation and the circuit experiments.
Keywords: Power ICs-1: Class D audio power amplifier-2: Inverter-3

1. INTRODUCTION

To popularize the PV systems, further cost reduction and mass production have been required. Recently the production line of the PV module has been increased so that the quantity of the production of the PV inverter has to be increased together. Additionally, it is important to reduce the parts of the inverter for mass production. The ready-made integrated circuits (ICs) have advantage to reduce the parts of the inverter and mass production. And the ready-made ICs for class D audio power amplifier are mass-marketed products because of popularity of the class D audio power amplifier recently. However, the class D audio power amplifier also using the ready-made ICs is not able to produce utility-grid level voltage and the same goes for the PV inverter for grid connected by the ICs. As one of the countermeasure, the transformer is used to connect the inverter to utility grid, which requires an extra space and cost. Against the problem, the cascaded inverter is proposed, which can reach high voltages with high efficient operation. A prototype cascaded PV inverter with the IC was built and verified in the simulation and the circuit experiments.

2. RELATIONSHIP BETWEEN INVERTER AND CLASS D AUDIO POWER AMPLIFIER

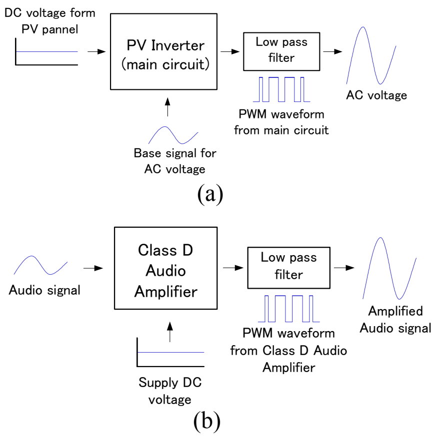


Figure 1: Block diagrams (Basic Formation) (a) of the main circuit of the PV inverter and (b) of a digital power amplifier.

The block diagram of the traditional PV inverter is shown in Figure 1(a) and that of the class D audio power amplifier, often called digital power amplifier, is shown in Figure 1(b). The main function of PV inverter is to transform DC voltage to AC voltage with pulse width modulation (PWM) switching technique. On the other hand, that of class D audio power amplifier is to amplify audio signal input with PWM switching technique. However, to the class D audio power amplifier, DC voltage is supplied to this circuit so that its function is considered as to transform DC voltage to AC voltage as well as the PV inverter in other view point. Therefore, the class D audio power amplifier has a possibility to take a place of PV inverter.

3. READY-MADE ICs FOR CLASS D AUDIO AMPLIFIER

Class D audio power amplifier is divided into various types by their functions. The functions can be classified into four parts:

1) A PWM signal generator shown in Figure 3(A).
2) A switching driver (gate driver) shown in Figure 3(B).
3) A switching stage shown in Figure 3(C).
4) An output filter shown in Figure 3(D).

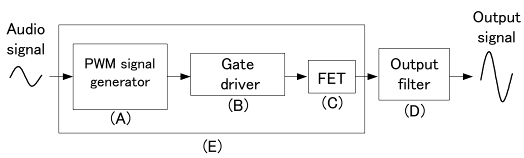


Figure 2: Bock diagrams of PWM audio power amplifier.

And the products of ready-made ICs for class D audio power amplifier also can be classified them. Especially, all-in-one type IC has almost all the functions on-chip shown in Figure 3(E).

The circuit of the PV inverter using these IC can be simplified. The all-in-one type ready-made IC has a controller in which the audio input signal is converted to a PWM signal. The input part of the class D audio power amplifier is classified into an analog signal input type, a digital (PCM) input type and a both of them. The input part of the all-in-one type IC is also classified into them. External demodulation filters are used to filter the audio content of the PWM signal and suppress the energy at higher carrier frequencies. Usually, a second-order *LC* low-pass filter is sufficient. However, it is necessary to create the control circuits to connect the inverter to distribution grid and there is no freedom to design of the inside function of the all-in-one type IC. But, if the all-in-one IC is applied to the grid-connected inverter as the main circuit, the steps and time for manufacturing should be dramatically reduces as a consequence the place will be reduced. Furthermore, since the IC for class D audio power amplifier is circulating widely, the price of it is very low price. Therefore, the inverter's cost can be cheaper than conventional inverter.

The test of this study is performed with the all-in-one type IC (CM8685 Champion Microelectronic Corporation) whose input part is analog signal input type. Internal circuit of CM8685 is shown in Figure 3.

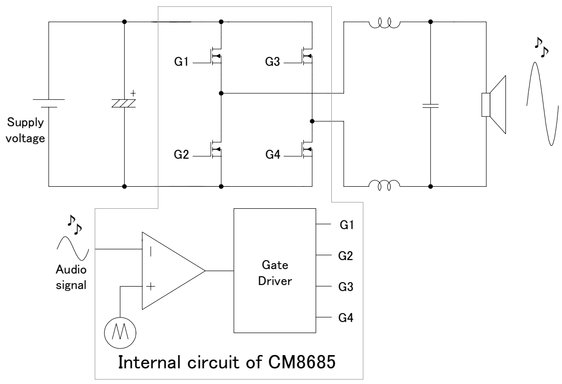


Figure3: Internal circuit of CM8685 (all-in-one type IC).

4. TEST OF GRID CONNECTED INVERTER BY READY-MADE ICs FOR CLASS D AUDIO AMPLIFIER

The design of the experimental circuit is shown in Figure 4. Since the all-in-one type IC which is used in this study is designed for very low power, the output part can't withstand the voltage of the distribution grid. Therefore, the voltage of the distribution grid is reduced by the low-frequency (LF) transformer which separates (electrically isolates) the DC circuit form AC circuit at 50 Hz. However, it is enough to check the fundamental operation whether the inverter using the IC can be connected to the distribution grid or not. As the output of the PV voltage source, the stabilized DC power supply is used. To match the phase of the inverter output current I_o with the phase of the reduced voltage V_a of the distribution grid voltage V_s, the voltage V_a is fed back and to get at the output a current with the same contour of the voltage V_a. Consequently, the power factor would be unity at connection point *A*. The control circuit is composed by analog circuit and using the PI controller defined by the relation:

$$G_{PI}(s) = K_P + \frac{K_I}{s} \qquad (1)$$

$G_{PI}(s)$ is the PI controller gain and that K_P and K_I are the proportional and integral filter gains respectively. The PI controller acts on a DC signal, and therefore provides zero steady-state error at the grid voltage frequency. The sample of the distribution voltage is multiplied by current regulation signal with multiplier and a resulting AC reference current is created. The experimental results are shown in Figure 5 (a), (b) and (c). the waveforms are the reduced voltage waveforms V_a of the distribution grid V_s and the waveforms of the regulated inverter output current I_o. The pictures are arranged in order of decreasing the regulated current level of the inverter output. In this case, these currents are controlled by optional outside DC voltage as the current regulation signal so that the current can be regulated optionally despite the grid voltage which is kept constant. Consequently, even if the voltage amplitude of the distribution grid fluctuates, the inverter output power is independently controlled. And the way of this control meets with the main requirements of the PV inverter with the fluctuation of the DC input power depended on solar power.

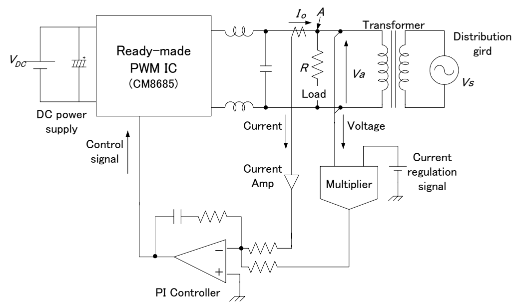


Figure 4: Current controlled inverter circuit.

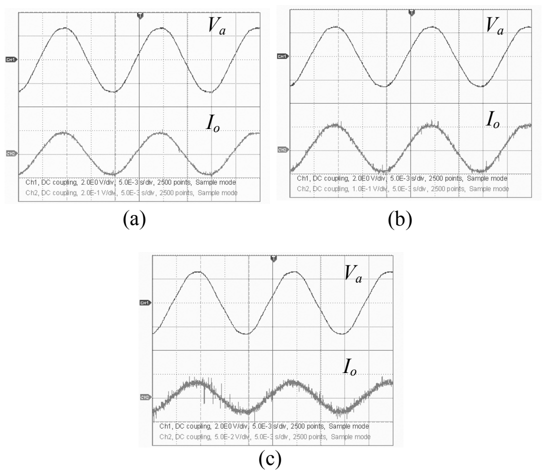


Figure 5: Observed waveforms of transformed grid voltage and inverter output current with multiplier. Scales: (a) 2.0V/div; 200mV/div; 5ms/div, (b) 2.0V/div; 100mV/div; 5ms/div, (c) 2.0V/div; 50mV/div; 5ms/div.

5. CASCADED INVERTER WITH READY-MADE PWM ICs FOR CLASS D AUDIO AMPLIFIER

The fundamental configuration of the cascaded inverter is formed by connecting more than one single-phase H-bridge inverter in series as shown in Figure 6. And the total of the each inverter's output V_{out} reach at the grid level ac voltage. In the all-in-one type IC, the control circuit and the main bridge circuits are not electrically isolated usually. Therefore, the each control signal of the inverter must be isolated to compose the cascaded inverter. The isolated signal control circuit is shown in Figure 7 and the cascaded inverter has been built using this circuit. In this isolation control signal circuit, the phototransistor isolates the each DC voltage. The isolated control signal is entered to input terminal of the each all-in-one IC.

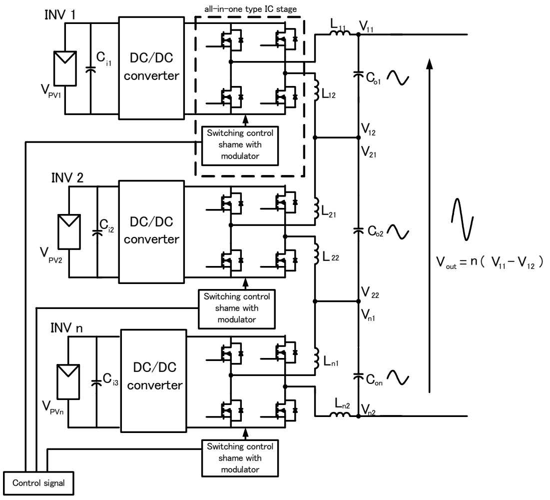


Figure 6: Proposed cascaded inverter with ready-made IC for class D audio amplifier.

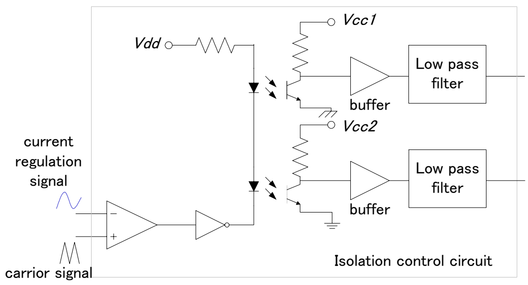


Figure 7: Isolation control signal circuit

The simulation with PSIM was tried as the first phase of this study. The simulation circuits are shown in Figure 8. In Figure 8, the each inverter are cascaded and gave different carrier frequencies by the reason that the all-in-one IC already has signal modulator on-chip but the each carrier frequency is different. The simulation result of the circuit of Figure 8 is shown in Figure 9. The obtained waveforms in Figure 9 (a) to (e) are output voltage of the inverter (*INV1* to *INV5*) and the waveforms are approximately consistent. The total output waveform of V_{out} is in Figure 9 (f) and it can check that the waveform of V_{out} is total of the waveforms in Figure 9 (a) to (e).

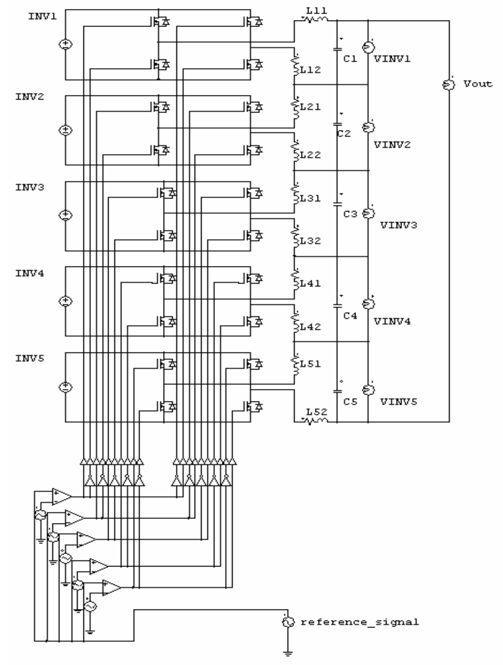


Figure 8: cascaded inverter simulation circuit.

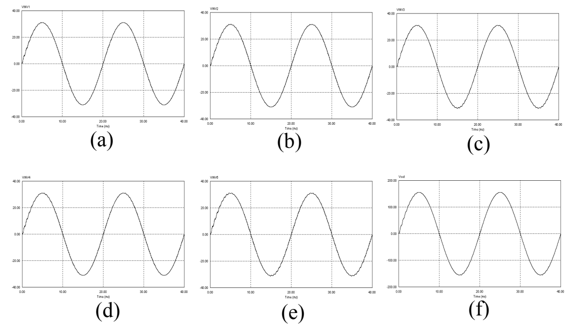


Figure 9: Simulation results with PSIM: from the top, inverter output voltage V_{INV1} (a), inverter output voltage V_{INV2} (b), inverter output voltage V_{INV3} (c), inverter output voltage V_{INV4} (d), inverter output voltage V_{INV5} (e), and output voltage V_{out} (f). Scales: from the top, 20V/div; 10ms/div, 20V/div; 10ms/div, 20V/div; 10ms/div, 20V/div; 10ms/div, 20V/div; 10ms/div, 50V/div; 10ms/div.

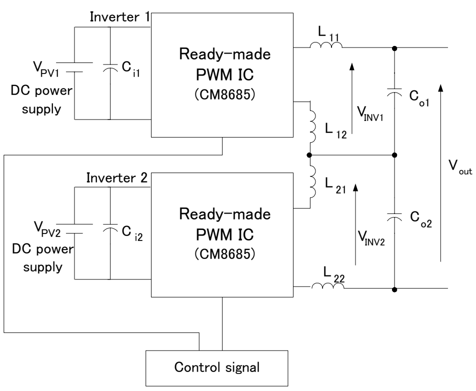
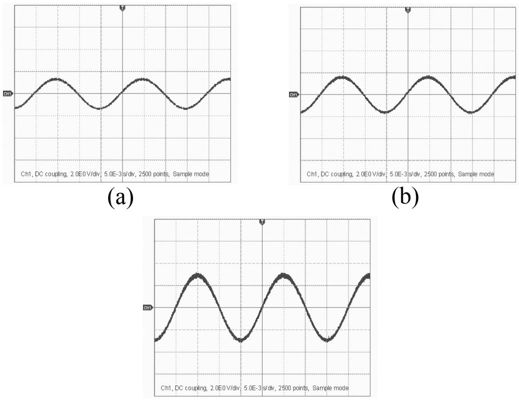


Figure 10: Experimental circuit of cascaded inverter with ready-made PWM IC (CM8685)

To test the scale down cascaded inverter by all-in-one ICs, the open loop control has been realized and the ICs operate at high switching frequency (about 580 kHz). CM8685 (champion microelectronic corporation) was tested in the scale down circuit and the circuit is shown in Figure 11. Figure 11 (a), (b) and (c) show experimental results of the cascaded inverter. It can check that the output V_{out} as shown in Figure 11 (c) is total of the output *VINV1* as shown in Figure 11 (a) and *VINV2* as shown in Figure 11 (b) .



(a) (b)

(c)

Figure 11: Observed waveforms of cascaded inverter with CM8685: from the top, (a) inverter1 output voltage V_{INV1}, (b) inverter2 output voltage V_{INV2}, and (c) output voltage $V_{out,t}$. Scales: from the top, 2V/div; 5ms/div, 2V/div; 5ms/div, 2V/div; 5ms/div.

6. CONCLUTION

The cascaded inverter used ready-made ICs for class D audio amplifier is proposed. Simulation results showed a possibility to cascade the several inverters on structure. Experimental results are presented as an open loop voltage control of the system. The isolated control circuit is described and results are presented. Furthermore, experimental results showed the IC is able to be adapting to the cascaded inverter. The results of that, the cascaded inerter used the IC has possibility to be the PV inverter.

7. REFERENCE

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