FURTHER IMPROVEMENT OF A TRANSFORMERLESS, VOLTAGE-BOOSTING INVERTER FOR AC MODULES

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Abstract

For reducing the manufacturing cost and for increasing the efficiency of module integrated converter the transformerless concept is suitable. The new type inverter, which is proposed in this paper, basically works as buck boost DC-DC converter. Therefore it is possible to reduce the number of the active switches in comparison with conventional inverter for AC modules because of simple circuit topology.

In this paper authors presents the control method and operation test results included both stand alone and grid connected for the new type transformerless inverter. These measurement results show that the performances can compete with the conventional small inverter (rated capacity around 50W).

1. Introduction

AC module technology has become popular and several large PV systems composed of AC modules put into practice in the field [1]. These systems require a lot of module integrated converters (MIC) to attain these scales. Therefore MIC technologies are one of the most important consideration for reducing the manufacturing cost and for increasing the efficiency, reliability of modular PV systems. Furthermore, MIC should satisfy compactness, as well. Because these small inverter is mostly attached the limited place, such as the back surface of PV module. To meet these requirements the circuit topology of MIC should be as simple as possible. However, PV module output voltage is not enough to connect the grid or AC load directly, MIC needs to convert the voltage using some methods.

Recently a lot of MICs have manufactured in practice [2, 3]. These products have transformers to match a voltage and make use of high frequency conversion circuit for reducing transformer size. But this concept makes the main circuit of the inverter complicated.

From these points of view, the transformerless inverter is suitable for MIC. In this paper the control method and operation test results included both stand alone and grid connected for the proposed new type transformerless inverter are presented. This circuit topology can reduce the active switches in series connection in the main current path.

2. Circuitry and Basic characteristic

Several transformerless inverters for modular PV systems were already introduced (one of them is [4]). The authors have attempted using buck boost DC-DC converter which is generally used as a small switching regulator to realize the transformerless concept [5]. In this chapter basic characteristic and the control method for the proposed inverter are described.

2.1 operation mode

The new inverter topology, as shown in Fig. 1, can be derived from buck boost converter (BBC) to add some switch elements for generating alternative output

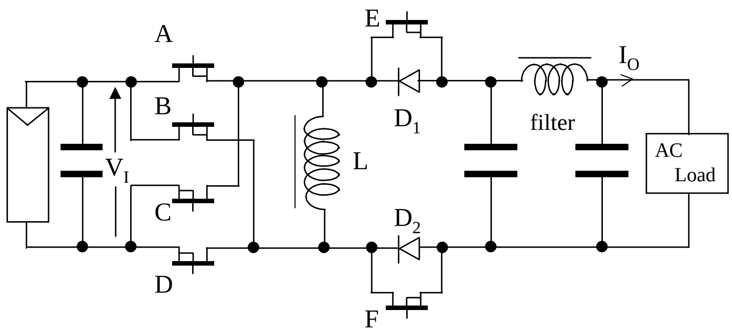

Fig. 1 The main circuit of the proposed inverter

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The inverter capacity was designed as 50W and MOSFETs were used for the switches. The dynamics of the inverter is as same as BBC which can divide discontinuous conduction mode (DCM) and continuous conduction mode (CCM) according to the current that passes the main inductance L. These modes are determined by the load current, the size of inductance and switching frequency.

When the mode change occurs from DCM to CCM, the dynamics changes remarkably. To make stable control the operation mode should be constant. The following equation shows the condition of mode change with the load current.

$$I_O > \frac{V_I \cdot T_{ON} \cdot T_{OFF}}{2L} \cdot f \qquad \cdots\cdots (1)$$

This means if load current Io over the right part of the eq. (1), the current that passes the inductance L becomes continuous. Matching a voltage form PV module output to the grid, the converter needs relatively high boosting ratio. Therefore in this case CCM is suitable. It is clear that large inductance is needed to operate the circuit with CCM in wide current range.

In CCM relations between input voltage (V_I) and output voltage (V_O) can be calculated by using the state space averaging method.

$$V_O = \frac{R \cdot D \cdot (1-D)}{r + R \cdot (1-D)^2} \cdot V_I \quad \cdots\cdots (2)$$

where D is duty ratio $\frac{T_{ON}}{T}$, r is the internal resistance of the converter , R is the load resistance.

If internal losses ignore eq. (2) can be described the following.

$$V_O = \frac{D}{1-D} \cdot V_I \qquad \cdots\cdots (3)$$

Equation (3) shows that wide voltage matching ability can be realized by adjusting duty cycle of the main switch.

Figure 2 gives the boosting ratio versus duty ratio of conventional BBC included the theoretical data which is calculated by eq. (3) and measured data. This measurement was carried out following conditions,

input voltage : 30V, switching frequency : 70kHz, L : 235μH

The measured curve almost fits the theoretical curve. It shows that boost-duty characteristic is non-linear. From this result it seems that using this characteristic the input voltage is possible to boost up more than 5 times.

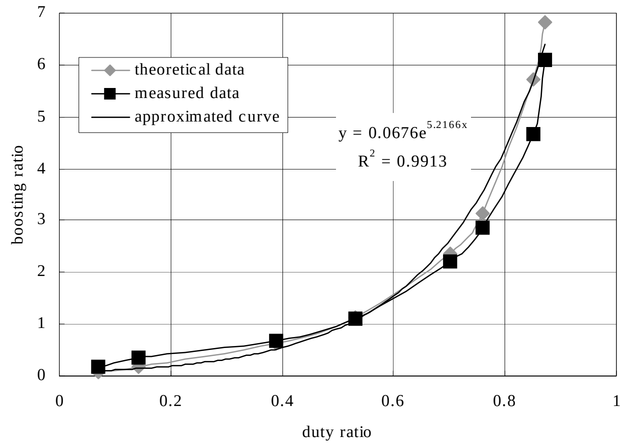


Figure 2 Relation of boosting ratio and duty ratio

In Fig. 2 the least squares approximation result of theoretical curve is also specified. The boost-duty characteristic of BBC is fitted by eq. (4)

$$y = 0.0676e^{5.2166x} \qquad \cdots\cdots (4)$$

2.2 control method

In order to generate a sine wave output, the pulse width modulation (PWM) is employed. As mentioned in paragraph 2.1, the boost-duty characteristic is different from common PWM inverter. Therefore it is necessary to change the reference signal (reference sine wave) for making use of all duty range as shown in Fig. 2 in the inverter operation. The adapted reference signal for the proposed inverter can be calculated by applying (5) to (4).

$$x = \sqrt{\frac{1}{6} \cdot \left| \frac{1}{2} \sin \omega t \right|} \qquad \cdots\cdots (5)$$

Figure 3 shows the measured date is fitted by calculated data . Using this reference signal it is possible to generate suitable waveform for the grid.

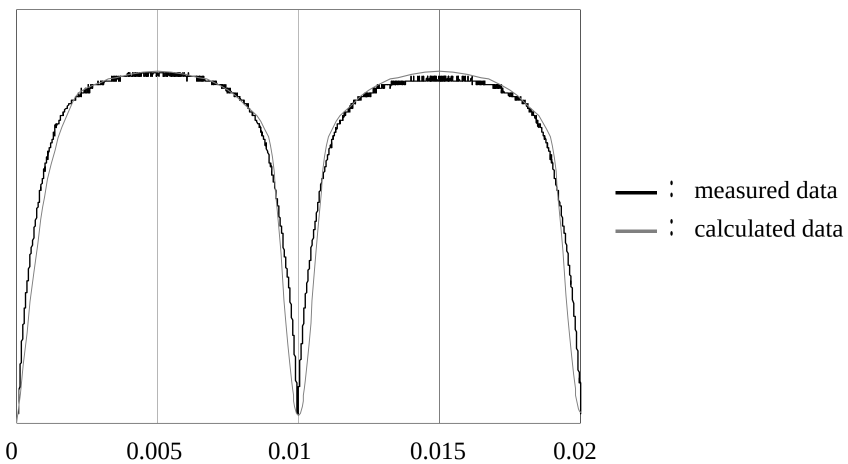
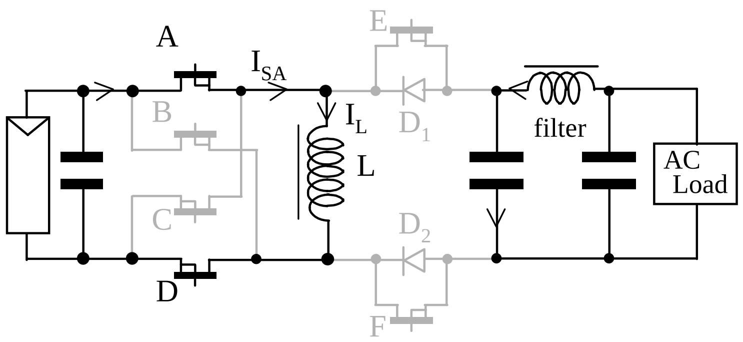
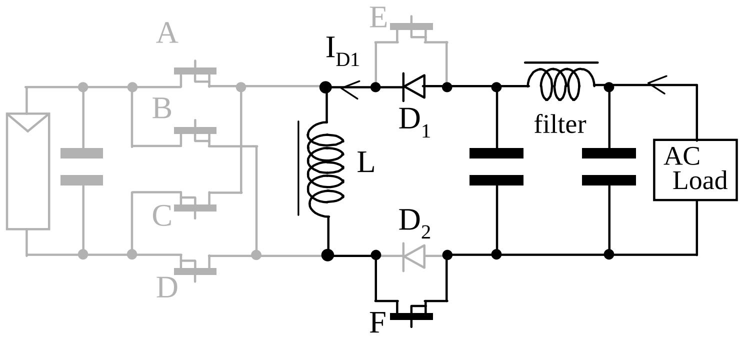


Figure 3 Reference signal for the proposed inverter

Figure 4 gives the current path to generate the negative half wave of output sine waveform. It is clear that three active switches need to generate a half cycle sine wave. The switching waveform for each switch A to F and source current of MOSFET (switch A) I_{SA}, inductance current I_L, diode current I_D and output waveform V_O are shown in Fig. 5.



(State I) energy is stored at L



(State II) stored energy released to the load

Figure 4 Current path to generate the negative half wave

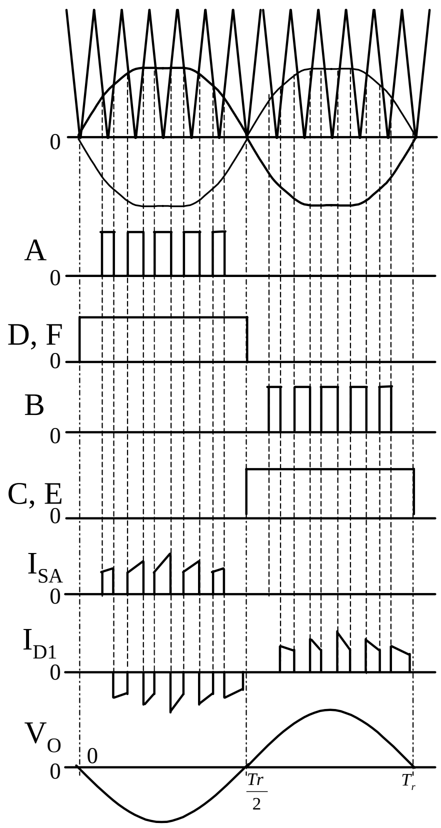


Figure 5 Waveform of each part

As shown in Fig. 5 the output sine wave is generated when switch A, B are modulated by PWM (70kHZ) alternately and D · F , C · E are switched synchronizing with low frequency. The output waveforms are controlled by changing the duty ratio of PWM. The greatest characteristic of the proposed inverter is that it has only one stage to convert form DC voltage which PV module outputs to nominal AC voltage. The conventional MICs have to need two stages to generate AC power.

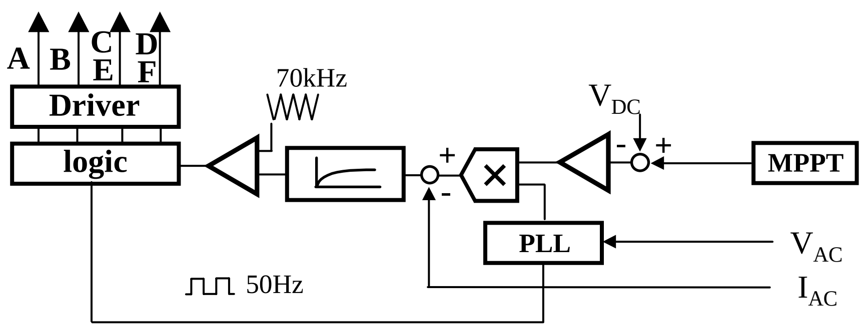


Figure 6 Control circuit diagram

The control circuit diagram for the proposed transformerless inverter is shown in Fig. 6. Most part of the diagram is as same as the conventional PV inverter. But as mentioned above this concept has a particular characteristic. Therefore it is necessary to include a non-liner amplifier for managing this characteristic. It seems that the mode change which is induced by the load current can manage to use the feed back loops.

3. Measurement results

Currently, the main circuit and the control part of the proposed inverter are under developed. But basic inverter operation is possible to use the complete parts. Some test results are shown here.

3.1 Stand alone mode

Figure 7 gives harmonic contents of output voltage during stand-alone operation at the input voltage 25V, 35V, 45V respectively.

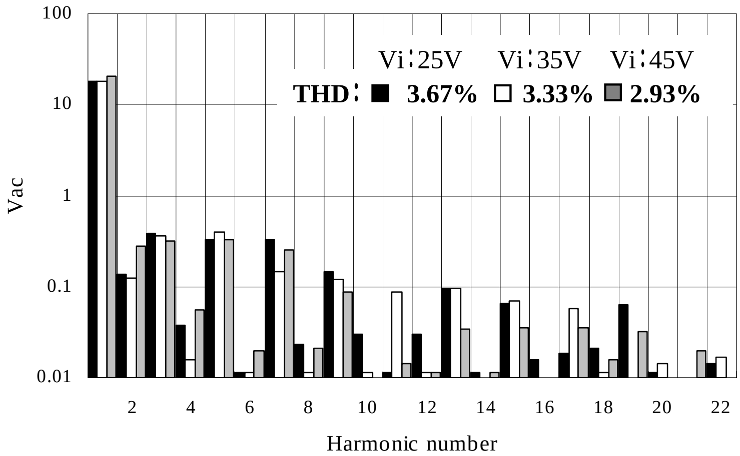
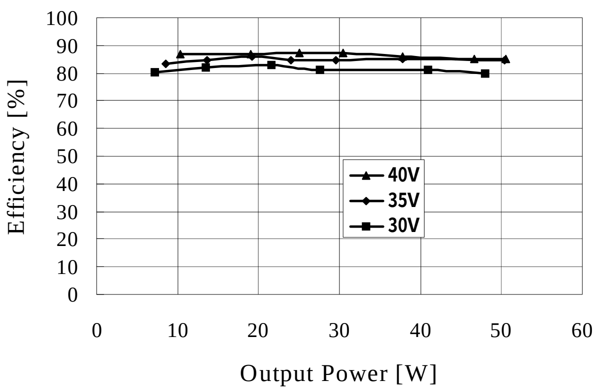


Figure 7 Harmonic contents of output voltage at output power about 30W

This result shows that Total Harmonic Distortion (THD) is less than 4% at all input voltages and each harmonic is also less than 2.2%. Figure 7 denotes that the control method which is discussed in chapter 2 is suited to this inverter.

3.2 Grid connected mode



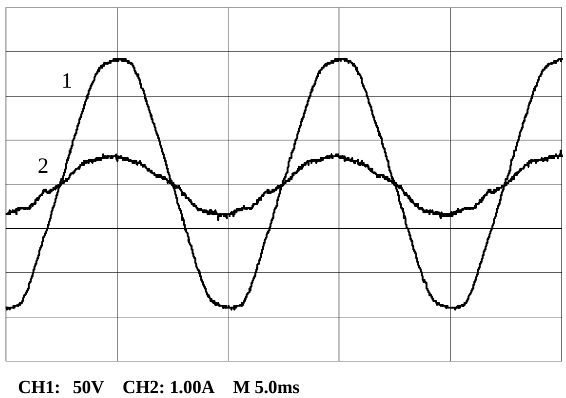


Figure 8 Power conversion efficiency during grid connected mode

Figure 9 Output waveforms at V_I: 40V Trace 1: Voltage Trace 2: Current

Figure 8 shows the power conversion efficiencies which were measured at the input voltage 30V, 35V, 40V respectively. At the all input voltage ranges, an efficiency of over 80% seems feasible over the whole power range. A maximum efficiency of 87% is measured at 0.5 rated capacity.

The output waveforms (voltage, current) during grid connected are shown in Fig. 9. Because of the primary data, the oscillograms show the output current waveform is distorted a little. However, the observed shapes suggest that power factor is almost 1. More decrease of the current distortion factor can be expected from the stand-alone measurement result.

4. Conclusions

In this paper the authors proposed the new type transformerless inverter whose basic topology is buck boost converter. The greatest characteristic of this inverter is that it has only one stage to generate AC power. It means that simple circuitry can be realized. The control method for the proposed inverter also discussed using the particular characteristic of buck boost converter. To control duty ratio of the main switches, the wide range voltage matching is feasible.

The results of primary performance measurements show that the proposed inverter is satisfied with basic operation which is required for PV inverter.

From these results, the proposed concept has a potential to apply to ac module.

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