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A NEW TYPE OF MODULE INTEGRATED CONVERTER WITH WIDE VOLTAGE MATCHING ABILITY

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ABSTRACT: For reducing the costs of modular PV systems, transformer less system is suitable for AC modules. In this paper, new type inverter circuit for AC module use is presented. The circuit of module integrated boosting converter (MIBC) is designed as a transformer less converter with the concept of boosting chopper for voltage matching between PV module output and the grid. Circuit structure of MIBC is very simple and compact compare to the conventional module integrated converters. Hence, MIBC has much ability reducing PV system manufacturing costs. Measurements shows that wide voltage matching ability can be realized in the basic circuit operation and an efficiency is more than 85% over a wide operation range is feasible.
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1. INTRODUCTION

PV systems composed of AC modules (ACM-PV) have many advantages in comparison with the conventional system [1]. Recently, the configuration of PV systems have been diversified. Therefor every PV module that are composed of one system can't be installed in the same optimum azimuth and slope. In such case, AC modules are able to reduce the mismatch losses in the system level. Because each module works with the electrical optimum condition using MPP by the integrated inverter. When PV systems will spread in the near future, more flexible design ability of module arrangement will be required, like a building integrated module. ACM-PV is suitable in these cases. Furthermore, it is possible that AC modules may produce a new application because of high modularity.

The performance of module integrated converter (MIC) is very important consideration in system efficiency, cost and reliability for ACM-PV. Because a lot of MICs are installed in one ACM-PV. MIC that is practically operated in the field has a transformer to make a voltage matching between PV module output and the grid. This circuit concept will be an obstacle to reduce manufacturing cost and size.

To solve these problems a module integrated boosting converter, which is abbreviated MIBC hereafter, that basically works as the boost chopper is developed. Such type system was previously proposed in other paper[2].

2. CHARACTERISTICS OF CIRCUITRY

2.1 Discussion on circuitry

The switching loss occupies large proportion in the losses which are caused in the inverter circuit generally. Recently, in principle both MOSFETs and IGBTs can be used as the power switch .

Table Ⅰ shows the loss comparison in the on period of these two switching components. Table Ⅰ means that for IGBTs the conduction losses are directly proportional to current, whereas for MOSFETs these losses rise with square of the current. Therefore, MOSFETs dose not suit when large current output is needed. However, this relation will be not simple for the low rated switching component. Because the lower V_{DS} MOSFET has smaller on-resistance $R_{DS(on)}$.

Table Ⅰ : the switching loss caused in the on period

	MOSFET	IGBT
conduction losses	$i_D{}^2 \times R_{DS(ON)}$	$i_C \times V_{CE(sat)}$

From this reason, two kinds of circuit concepts for MIBC are considered as shown in Fig. 1.

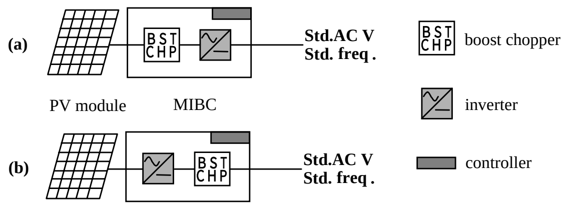

Figure 1: Concepts of MIBC

In the concept (a) , the inverter circuit voltage is high, because the PV module output voltage is boosted up by the boost chopper. Though the switching speed of the IGBT is slower than the MOSFET, the IGBT is advantageous for high voltage and current. Therefor IGBTs are suitable to decrease the conduction losses in this case. In the concept (b) the input voltage of the switching components is low. Because the inverter operates the PV module output voltage directly. MOSFETs have an advantage in such a low voltage inverter operation. In this paper, the concept (b) is descried.

2.2 Principle of operation

Fig. 2 shows the experimental circuit for the case of Fig. 1(b). The circuit of MIBC is designed as a transformer less converter on the basis of the boosting chopper conception. The backboost dc-dc converter was used for the boosting chopper. This circuit is generally used as a switching regulator that outputs the voltage of both poles from the single power source without using the transformer.

Figure 2 gives the switching waveform for switch A to H respectively. Switch E, F are driven by the pulse width modulation (PWM) which controls output voltage waveform. High frequency of more than several kHz is used as a base frequency of PWM. Switch A to D, and G, H are synchronized with 50Hz. The inverter capacity was designed as 50W.

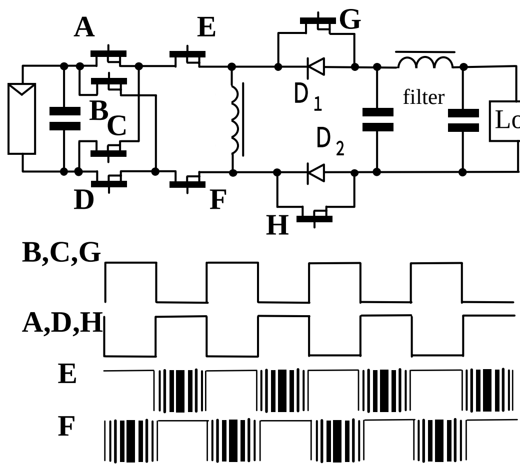

Figure 2: basic circuitry of MIBC and switching waveform

The backboost circuit outputs the reversed polarity voltage against the input voltage. Therefore the positive half-wave is generated when switch F is modulated by PWM and switch B, C, G are on. Another the negative half-wave is generated when A, D, H are on and E is modulated.

In the backboost, the energy is stored at the inductance when the main switch is on (T_{on}), and then the energy released to the load in the off period (T_{off}). Hence, an equation between the input voltage V_{in} and the output voltage V_{out} can be describe as follows :

$$V_{out} = \frac{T_{on}}{T_{off}} \times V_{in} \qquad \cdots\cdots \quad (1)$$

This equation means that the output voltage can be widely controlled from zero to higher value of the input voltage by adjusting duty cycle of the main switch.

The circuit of Fig. 2 shows a combination of the conventional circuit of the inverter and the booster. However the inverter is able to be integrated with a part of the booster. Fig. 3 shows this circuitry which is integrated switch E, F into polarity converter of the Fig. 2.

To output a half cycle sin wave pass through three switching components in the circuit concept. Therefor it is possible to reduce the number of the switching component in comparison with the conventional small inverter. This concept is not developed yet, but it is possible to operate in principle so these is a plan to change Fig. 1 into Fig. 2 finally .

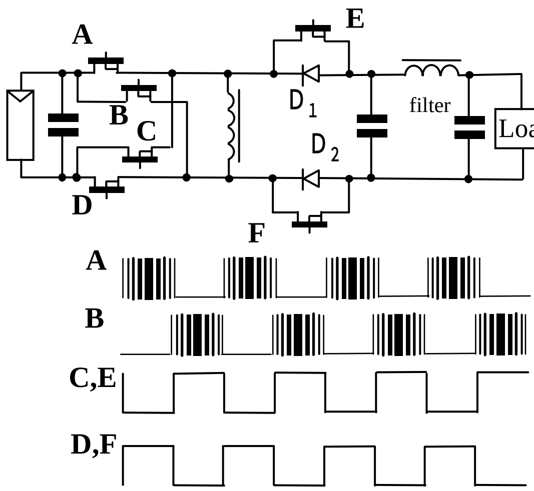

Figure 3: circuitry in which the inverter operates as a part of the booster

2.3 Comparison of the conventional and the new type

The principle of voltage matching method of conventional MICs is discussed in the previous paper [2]. Table Ⅱ shows the performance comparison between the conventional MICs and MIBC.

The voltage matching method of using standard-frequency transformer may be the simplest circuitry of all MIC. But this type has a large transformer, because the operating frequency of the inverter is low. It is a obstacle to reduce manufacturing cost and size. Still more it is reported that this type is not so more efficient than the other small inverters[3].

The voltage matching method of using high-frequency transformer has become the popular circuitry of MIC can miniaturize the transformer. Because this type converts PV

Table Ⅱ : performance comparison between MIBC and conventional types

	factor of reducing efficiency		**voltage matching**	**isolation method**	**performance**			
	number of switching Components	transformer			**compactness**	**cost**	**conversion efficiency**	**design flexibility**
standard-frequency transformer	2	1	narrow Low-voltage inverter	std. freq. transf.	×	△	○	×
high-frequency transformer	4	1	narrow	HF transformer	○	△	○	×
MIBC	5 or 3	−	wide	no isolation direct current canceled by control	○	○	○	○

output DC voltage into high frequency to boost up for using small transformer. Furthermore, most of this type small inverters is reported the efficiency is more than 90%. This type, however, has to redesign the transformer and the circuit components for each PV module that has various rated output voltage, which is unfavorable to reduce the manufacturing cost .

On the other hand, MIBC uses only one inductance in the circuit to boost up the input voltage. It is possible to match voltage simply compared with conventional MICs. Because the output voltage can be controlled by adjusting the PWM duty-cycle. The circuit structure of MIBC is simple and compact, and moreover, this type may be possible to realize the flexible design required in AC modules inverter. From these points of view, MIBC has a potential of a new concept for AC modules.

3. TEST RESULTS

The inverter improved the dc-dc converter is under developed and has been completed to make the power conversion circuit. Some test results are shown here.

3.1Measurement of boosting ratio

Fig. 4 gives the boosting ratio versus duty ratio of conventional backboost circuit. As it was described in 2.2, $\boldsymbol{V_{out}}$ is induced from (1). Fig. 4 shows the theoretical data calculated (1) and measured data. This measurement was carried out in the input voltage DC 10V constancy.

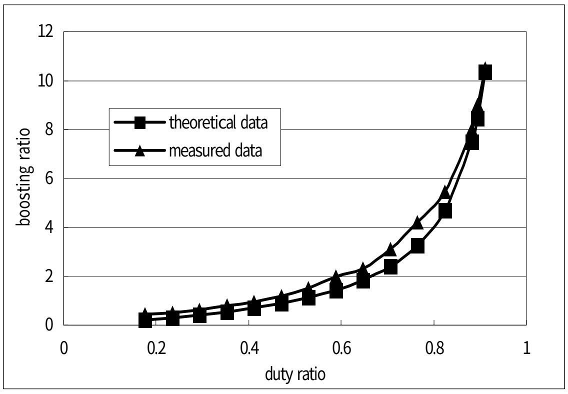

Figure 4: relation of boosting ratio and duty ratio

The measured curve almost fits the theoretical curve. This result shows a potential of MIBC which has a wide voltage matching ability. Because this relation ideally holds even in the inverter operation. Generally, backboost converter is used as a small power converter. This result, however, suggests that this circuit has an ability for high power use.

3.2 Inverter test results

Fig. 5 gives the efficiency of the circuit as function of the input power and the waveform of the output voltage and current are shown in Fig. 6.

These results were measured under following conditions:

- duty cycle 0.66
- PWM frequency 20kHz

The efficiency doesn't include losses caused by the control circuit and the output filter. To consider these losses the efficiency should be decreased by about 0.5 %.

The observed shape of the efficiency shows 85 % over the whole power range. A maximum efficiency of 91 % is measured at 0.2 rated capacity. Although this result is also the initial data, to improve the power section it is possible to decrease some losses. The measurement efficiency shows MIBC is not inferior to conventional MICs.

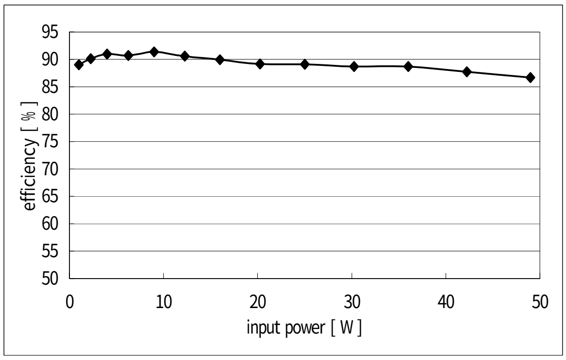

Figure 5: conversion efficiency curve

The output waveforms have been distorted a little in Fig. 6 because of simple sine wave modulation.

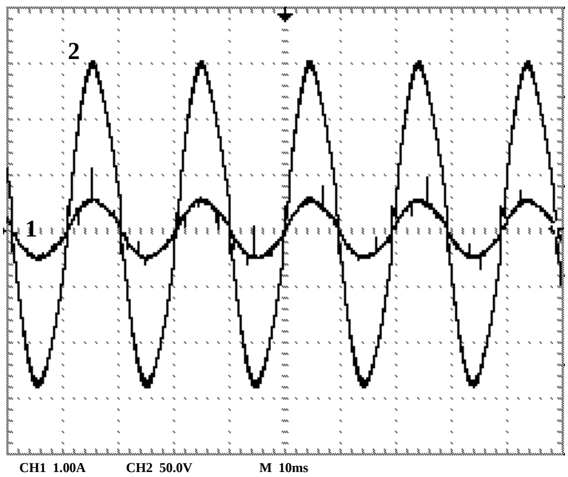

Figure 6: output waveforms(10ms span).
Trace 1: current (0.37A),
Trace 2: voltage (102V)

The waveforms shown in Fig. 6 is the outputs for the DC 70V input voltage. The AC output voltage is about 144 $V_{p\text{-}p}$ from trace 2. This result shows that the boosting ratio has reached about two even in the inverter operation, and it almost agrees with the theoretical data shown in Fig. 4.

4. CONCLUSIONS

The authors presented the development of the MIBC that has wide voltage matching ability. Although only a part of the circuit is examined up to now, test results are summarized presently as follows:

- basic operation was confirmed
- wide voltage matching ability without a transformer

can be realized in the basic circuit operation

- the efficiency is achieved more than 85% over the whole operation power range.
- a maximum efficiency of about 91 % is measured at 0.2 rated capacity.

These results suggest that this circuitry has a potential for AC module inverter.

REFERENCES

[1] H. Hempel, W. Kleinkauf, U. krengel, PV-Module with Integrated Power Conditioning Unit, 11th EPVSEC, MONTREUX, SWITERLAND, 1992 1080-1083

[2] K. Kurokawa, et al, Solar Energy Materials and Solar Cells **47** (1997) 243-250

[3] D. Schekulin, G. Schumm, AC-modules – Technology, Characteristics and Operational Experience; 13th EPVSEC, NICE, FRANCE 1995 1889-1892