Discussions on Proposed Boost Inverters in Integrated Construction

- Pursuit for simple power conditioner -

Keiju Matsui^{a*}, Eiji Oishi^a, Yasutaka Kawata^a,
Mikio Yasubayashi^b, Masayoshi Umeno^b, Hideo Uchida^b, Masaru Hasegawa^b

^aMinna-denryoku, Inc. Setagaya Monozukuri Gakko, 210 Setagaya 154-0001, Japan

^bChubu University Kasugai 487-8501, Japan

Abstract

Photovoltaic power generations (PVG) have been widely accepted and applied. Various power conditioning systems including boost-inverters have been also studied by many researchers. In general utilization, the actual application of such solar panels are almost installed on top of the roof of isolated house. Some residents living in the apartment house, however, have fair desires to contribute for energy saving due to natural energy generation. The generating power in such case is fairly reduced, so the system construction should balance to the reduced power. Thus, it is necessary to improve the construction toward simple one. In this paper, in order to give a reply, simple and concise power conditioner is proposed, especially integrated inverter. Considering fairly reduced generating power and narrow space of installation, the system constructions should be compact. The circuits which gratifies their characteristics are presented and examined.

Keywords: PVG, boost inverter, boost chopper, full-bridge, half-bridge, inverter.

1. Introduction

Preserving the developments of economy, science and technology with conquering the problems against environmental conservation is an important assignment for humanity of the world. The usage of the renewable energies is expected to be able to mitigate such problem, which is an important means [1,2]. Among them, photovoltaic power generation have various advantages such as usage of inexhaustible and unpolluted sunlight, which is advantageous for maintenances, easily construction from small power to large one, and can be installed in various location including city center. In such a way, this power generation system is a promising one with bright future.

As a utilization form, utility interactive power generation system has been accepted and spread widely. In such system, it is necessary to install the chopper, where the lower voltage of solar cell should be boosted to suitable voltage, and inverter where the dc power of boosted voltage should be converted to ac power in the power system [3,4].

The power conditioners-PCS including inverter have been presented in various systems so far [5,6]. However,

it is necessary to reduce the cost even more. It is said that the system is approaching to an ideal ones with respect to efficiency and construction strategy, but that cost would prevent wide spread if there is no public financial support. In such discussions, there are many subjects to be solved to utilize the PV power in utility interactive power generation. Even more, various safeguard equipment required according to regulations make the cost increase. Thus, it is required to obtain even lower cost PCS. [7-9] In an extremely lower capacity PCS as discussed in this paper, a way of handling would be different compared to typical power range. In such case of reduced generating power, quantities of reversed power to the power system would be small, where another mitigated regulation or deregulation would be approved. Thus, in such PV power generation systems, there are so many subjects to be resolved[10].

Under such circumstances accepted by electrical utility industry as recognitions and assessments for renewable energy, spread of application is strongly sustained by financial supports of public organizations, and a lot of consumers are hoping to install such PV power generation system. For ordinary homes, installation of solar panel is restricted to house having roofs. However, a lot of residents living in the apartment house also wish to install the PV panel under considering resource conservation and such public financial support. In the present situation, however, there is no scheme to perform these requirements. The authors have been studied in a series of the small power PV system [11,12]. In this paper, some simple PCS systems, especially the components like inverters and chopper are integrated toward simple construction, which are presented and discussed.

Fig.1. Initial proposed boost inverter.

2. Initial Proposed Boost Inverter Using Half-bridge Circuit

2.1. Summary of operation

Fig.1 shows an example of initial PCS (Power Conditioners) which is intended for compact construction by the half bridge circuit. The single phase or three phase constructions using full-bridge circuit would be possible for various applications, but the explanation is performed for fundamental half-bridge circuit. In the conventional inverter, the boosted output voltage from boost converter is used. In this PCS, however, the supply voltage is given to the midpoint of inverter leg through current limiting inductor as shown.

The operation is performed as follows; for the switches S_1 and S_2 which are operating for normal load of L_o and R_o or ac power source V_o , the sinusoidal signals are given as usual. In this control strategy, for example, of natural sampling method (triangular-sinusoidal wave comparison method), as the average turn-on ratio is given by $\alpha = 0.5$, the dc link voltage of inverter is boosted by two times which can be calculated from the boosting theory in boost converter. As a result, the input dc power supply voltage can be boosted by two times. In such a way, $2E$ voltage can be obtained across the inverter capacitors, where E is input dc supply voltage. S_2 plays also a role of the function of boost converter switches. By means of using merely single inverter construction, a novel inverter construction having boosted voltage capability can be obtained. The dc link voltage of inverter is given by

$$V_l = E/(1 - d) \quad (1)$$

where d : the average value of duty ratio
 E : Input power supply voltage

Assuming the sinusoidal and triangular wave comparison method, regardless of the modulation factor (ratio of sinusoidal amplitude / triangular amplitude), average value of conduction factor becomes $d = 0.5$. Consequently, inverter dc link voltage becomes $V_l = 2E$.

For the input dc supply voltage of E , by means of principle of the proposed circuit, the dc link voltage is given by $V_{C1} + V_{C2} = 2E$. The peak voltage V_o of load becomes $V_o = 2E/2$.

2.2. Characteristics of operation

The input current is varying with output load frequency. The reason can be explained by theoretical equation where the commercial frequency is applied across the current limiting inductor. The average value of this input current is injected as average power. This value of input current has nothing to do with the load current amplitude. That is to say, the ac component with output frequency is superimposed to the constant dc current which is average value of instantaneous input current. From such reasons, input ac current component is limited by small limiting inductor.

On the next stage of comparison with i_{c1} and i_{c2} , the operation mechanism of presented PCS can be confirmed and perceived. The upper side i_{c1} represents the charging current from input current of dc source and the load current from inductive load at S_2 turned off and S_1 turned on, which is shown in the positive side. That is,

When S_1 turned-on, (S_2 turned-off),

$$i_{c1} = i_o \text{ (charge current)} + i_L \text{ (load current)}$$

$$i_{c2} = i_o \text{ (charge current)}$$

When S_2 turned-on, (S_1 turned-off),

$$i_{c1} = 0$$

$$i_{c2} = i_L \text{ (load current)}$$

In upper side loop of current i_{c1} , i_o (charge current) + i_L (load current) and $i_{c1} = 0$ are repeated periodically. Consequently, the current flows through the envelope of $i_o + i_L$. On the other hand, in lower side loop of i_{c2} , i_o (charge current) and i_L (load current) are repeated periodically, where current flows with envelope of i_o and i_L . Such operation is confirmed and perceived.[10]

In this circuit, regenerating operation from ac load power source to input dc source, can be realized in which bilateral control is performed successfully without additional considerations in the circuit construction and the control circuit.

3. Proposed Boost Inverter Using Integrated Full-bridge Construction

3.1. Summary of operation

In order to realize another boost inverter using single stage, the front end of switching devices S_1 and S_2 of inverter are turned on simultaneously to make function as the boost chopper. At this period of simultaneous operation of S_1 and S_2 , the power due to the short circuit is injected into the input inductor.

By means of this single stage, both functions of boosting and dc to ac conversion are intended to realize. The method to realize single stage circuit configuration will be described as follows;

In Fig.4, The terminals A, B, C and D are connected the designated same terminals of Fig.4(b). By using full bridge circuit, where the whole portion constitutes inverter circuit. Partially, the boost chopper is constituted by S_1 and S_2 . By means of single stage, inverter function having boosted voltage can be performed. When the chopper is operating, the electric charge of C_1 or C_2 is provided into the load through switching device S_3 or S_4 . In order to prevent discharge of C_1 or C_2 through short circuit of S_1 and S_2 , the diodes D_5 and D_6 are equipped as preventing the short circuit. There are two operation modes, where one is simultaneous conduction mode of S_1 and S_2 and other is load powering mode due to inverter operation. By means of the smoothing capacitors C_1 and C_2 , the power is injected into the load as inverter operation. When S_1 or S_2 is turned off, the dc power supply and the charged inductor provide the power into the smoothing capacitors C_1 and C_2 .

through the reverse current preventing diodes D_5 and D_6 .

As just mentioned, the chopper operation and inverter operation due to S_1 and S_4 , or S_2 and S_3 are performed simultaneously by means of single stage. The diodes D_5 and D_6 are preventing the short circuit in charging mode due to the boost chopper. By means of single stage, inverter function having boosted voltage can be performed successfully.

3.2. Operational waveforms

Fig.3 shows operational waveforms for the proposed boost inverter. In order to make clear the operation, the carrier triangular frequency is given by lower one and unity power factor of zero load inductance that is $L_o = 0$. When one switch is turned on for half period, the other signal is periodically turned on and off in PWM patter.

Fig.2. Circuit configuration of another boost inverter.

Fig.3. Waveforms.(at $L_o=0$)

The diode currents are flowing through D_5 or D_6 alternately in PWM pattern. When the polarity of load current changes, both diode currents charge both capacitor. As a result, currents become in half as presented. In practical operation, the PWM switching frequency is given by higher one, and additional small inductance is equipped, so load current becomes almost sinusoidal waveform.

3.3. Control of PWM waveforms

(a) single PWM control method

Fig.3 shows simulated results, where the load does not include inductive component ($L_o = 0$) in order to make the circuit mechanism clear. That is, if this configuration is operated satisfactorily according to fairly high power factor load.

In this first single signal method, the PWM signal for S_1 and S_2 is given by simple uni-polar triangular carrier signal, which is compared to sinusoidal modulation wave to obtain the practical signal.

As the period when both switches S_1 and S_2 are turned on simultaneously, is given as the duty cycle = d of boost chopper, it is necessary to obtain the conduction period that is given by the average value. That is,

$$d = (1/\pi) \int \alpha \sin \theta d\theta \\ = 2\alpha/\pi \quad \dots\dots\dots(2)$$

The equation (1) is substituted into the boost ratio that is ratio of input and output voltage.

$$E_2/E_1 = 1/(1-d) = \pi/(\pi - 2\alpha) \quad \dots\dots\dots(3)$$

The maximum boost ratio is given by at $\alpha = 1$.

That is,

$$(E_2/E_1)_{\max.} = 1.47 \quad \dots\dots\dots(4)$$

(b) double PWM control method

In this section, another PWM control method is to be described where both S_1 and S_4 are controlled over this period for obtaining the simple PWM signal. Another signal S_2 corresponds to signal S_3 . The control of S_1 is performed by bipolar carrier triangular wave. The output pulse over half period can be represented by switching function $S_{W1}(\theta)$.

$$S_{W1}(\theta) = 1/2 + (1/2) \cdot \alpha \sin \theta \quad \dots\dots\dots(5)$$

On the other hand, the corresponding S_4 signal is also represented by switching function, that is,

$$S_{W4}(\theta) = 1/2 - (1/2) \cdot \alpha \sin \theta \quad \dots\dots\dots(6)$$

The applied voltage across the load becomes,

$$V_o = E_2 \cdot (S_{W1}(\theta) - S_{W4}(\theta)) \cdot \alpha \sin \theta \quad \dots\dots(7)$$

On the other hand, S_2 has the same period when the signal for S_1 is given as the boosted operation at the same time. That is represented by switching function as follows;

$$S_{W2}(\theta) = 1/2 \quad \dots\dots\dots(8)$$

$$E_2/E_1 = 1/(1-d) = 2.0 \quad \dots\dots\dots(9)$$

The boosting ratio is given by this equation. As

comparison with single PWM control, boosting ratio becomes fairly larger.

3.4. Operation of load capacitor

By means of current limiting inductor, the input current is kept almost constant value. That current is divided into the input front inverter leg and load capacitor. The operation can be executed as follows. When the switch S_1 is turned on, where S_2 is turned on simultaneously, the input inductor is energy-stored by input supply for boost operation. That is,

$$\text{When } S_1 \text{ turned-on, (} S_2 \text{ also turned-on),} \\ i_o = i_s \text{ (short circuit current)} \\ i_L(\text{load current}) = i_{C2} \text{ (capacitor current)}$$

$$\text{When } S_1 \text{ turned-off,} \\ i_o = i_{C2} \text{ (capacitor current)} \\ i_L = 0$$

In the figure, according to the above description, the input supply current is delivered into short circuit and load capacitors alternately. In the transition period, however, as the input current flows through both load capacitors, the overlap period appears as shown.

4. Conclusions

A novel inverter construction termed ‘‘Boost inverter’’ is proposed, whose dc voltage can be boosted by itself without much modification of the circuit configuration. However, the conventional boost inverters are well known as various articles [13-16]. Our proposed method is different from such one. From such reasons, the mentioned configuration is sometimes called ‘‘L source inverter’’, because having input inductor.

In the proposed two types construction, each characteristic can be described with different one.

For initial proposed construction, in satisfactory characteristic is that there is no consideration for signals for boost chopper. In addition, there is no special consideration for changing from powering to regenerating. The conversion operation from powering to regenerating can be altered naturally. In such natural bilateral operation, it can be performed as it is without special configuration and accompanied control circuitry.

In single phase or three phase full-bridge construction, the input power supply could be also connected to each center terminal of inverter legs through inductor of itself, that is double inductors for single phase or three inductors for three phase. In this initial method, however, input inductor size becomes larger one. So, this type is suitable for the constant current source supply.

For secondly proposed construction, The construction becomes a little complicated as compared. However, input inductance becomes much smaller for last PWM strategy. It would be applied to reduced power application. Without changing the configuration, regenerative operation to input side cannot be realized. When it is necessary to realize such capability of power regeneration, some devices

should be installed such as independent boost chopper.

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