Further Development Towards High Performance DC Power Supply

- Pursuit for ideal power conditioner of PVG-

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Abstract

With receiving public support, photovoltaic power generations-PVG have been used generally and expanding broadly. Some power conditioning configurations used in such system have been also studied and discussed by many researchers. In addition to usual utilization, such power generation system is often prepared for the time of disaster. As such generating power is limited, so usually the solar panels that is the energy source of such generation are almost installed in limited area such as on top of the building. Some medical institutions have strong desire to keep such photovoltaic power generation since they must keep the lives of people. The generating power in such case is fairly limited, so the system construction should balance the reduced generating power. Thus, it is necessary to improve the construction toward simplified structure. Our previous research has been pursued for ideal power conditioners. In order to give such reply, simple and concise power conditioners, especially as novel inverter, are proposed by one of the authors. Considering fairly reduced power and narrow space of installation, the system constructions should be compact according to such conditions. In such research process, this paper is presented as a part of the initial result of the whole research. The circuit configuration which gratifies operating characteristic is presented and analytically discussed. The operational constitution is confirmed by using the circuit simulator.

Keywords: power conditioner¹, solar cell², inverter³, half bridge⁴, photovoltaic power generation⁵

1. Introduction

In latest medical equipment, the development of the structural function in the operating system is remarkable. The endoscopic surgery including surgical robot and the catheter intervention have been applied, so that such remarkable operating technique have been developed with like robotic operating room and hybrid operating

room. For almost electrical equipment using in such medical facilities, even instantaneous interruption could never permitted. In general, large scale interruptible power supply installed by generator and batteries is provided. In such system, however, the system scale becomes large which is accompanied by high cost.

The power conditioners-PCS including inverter have been presented in various systems so far^(1,2). However, it is necessary to reduce the cost even more. It is said that the system is approaching to an ideal one with respect to efficiency and construction strategy, but that cost would prevent wide spread. In such discussions, there are many subjects to be solved to utilize the photovoltaic-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. In fair reduced power PCS as mentioned above used in limited facilities. In such case of reduced generating power, that is, in such PV power generation systems, there are so many subjects to be resolved⁽³⁾. The authors have researched in a series of the small power PV system^(4,5). In this paper, some simple PCS systems, especially the components like inverters and chopper are integrated toward simple construction, which are presented and analyzed theoretically. The whole results are analytically discussed^(6,7). In our such research process, it is found that this circuit configuration can be suitably applied to dc power generation. Especially, in the paper, it is made such mechanism analytically clear. The superb mechanism is presented theoretically as compared with well-known conventional method. This item is a prologue of a series of original inverter.

2. Development to DC Voltage Generation

In a series of our research, some simple PCS systems, especially the components like inverters and chopper have been studied. The paper presents the fundamental construction and described an applied dc voltage configuration. Validity of the novel mechanism is verified .

Fig.1. Further Development Towards DC Power Generation.

Fig.1 shows firstly mentioned circuit configuration having resistor load R. Inter connected circuit which is described by rectifier is constructed with interconnecting transformer. The reason of having the transformer is that the object to obtain the dc power is high efficiency and low voltage power such as micro-processor power supply and the like. In comparison to the conventional dc power supply by high frequency inverter, where in half bridge circuit using boosted chopper, the obtained high frequency is rectified as dc-dc converter [8]. The proposed configuration seems to be superior with regard to the number of the circuit component and subsequent efficiency discussed later. Fundamental construction is presented in the figure. Various derived circuit construction could be obtained from this circuit. With regard to the efficiency, however, the power conversion process of the proposed one is simple and the number of conversion process is reduced, so the proposed circuit is prominent in comparison. Those validities are confirmed as follows;

When the switch S_2 is turned-on at the beginning, the power supply provides the load through transformer and inductor L_1 in parallel connection. Secondly, when S_2 is turned-off and S_1 is turned-on, the stored energy in L_1 is provided to R and at the same time the excess energy is delivered to the auxiliary capacitor. During last half period, as the supplied power from L_1 is reduced gradually, a deficiency for supplied power from L_1 is provided from auxiliary capacitor C. Looking at the whole period, it can be seen that the contribution for power transmission through inductor L_1 is predominant. On the other hand, the power transmission through C is a role of auxiliary power transmission. The percentage of power transmission from L_1 to R, δ_{LI-R} is

$$\delta_{LI-R} = (I_1 + I_2) / 2 \dots\dots\dots(1)$$

where I_1 is peak value of ripple current of L_1 ,
 I_2 is bottom value of L_1 .

At usual specification, one from L_1 to R through C is

$$\delta_{LI-C} = (I_1 - I_2) / 8 \dots\dots\dots(2)$$

For your information, the one of the direct transmission E to R is

$$\delta_{E-R} = (I_1 + I_2) / 4, \dots\dots\dots(3),$$

and is given by 50% relative to the total load current..

It is interesting that the auxiliary capacitor C plays a role of like inductor current filter.

In Fig.2, the power transmission flow chart is dictated. Where the power line is plotted by heavy solid line, it means the transmitted power is fairly large. On the other hand, thin line represents small power transmission. Looking at the whole period, it can be seen that the contribution for power transmission consists of direct transmission from E to R. In addition, the route through inductor L_1 is also predominant. It is remarkable strategy that the power transmission is predominant by the direct transmission. Furthermore, as another route, one is via-point of C whose transmission power is small.

Fig.2. Power Flow for Original Power Converter.

Fig.4 shows the power flow chart for the conventional high frequency converter reported as BHB-Boost Half Bridge⁽⁸⁾, in which the circuit mechanism is compared and discussed with our strategy. Fundamental construction is shown in Fig.3 described later. The input power supply voltage is boosted in the half bridge inverter. After this operation, the high frequency ac power is obtained. After the energy of input power supply E is stored into L, the capacitor C is charged from power from L at switch turned-off. By means of this capacitor charge, the load R is supplied. The figure shows the flowchart of such operating mechanism, where there are plural number of power transmissions. On the other hand, for the proposed high frequency conversion, main transmission is performed by direct conversion from E to load, the other is a simple transmission way via single L or C. The number of conversion stage is much reduced. Consequently, the transmission efficiency can be expected as much our research process, this paper is presented especially in more detail of initial part of the whole result.

Under a few hundred watts of small photovoltaic power

generation system-PGS, it is important to pursue for simple circuit configuration in proportion to small power. In order to realize this situation, the unified chopper and inverter circuit configuration was presented by the other authors. In this strategy, one of the well-known conventional inverter switches was also used for the switch of boosting chopper, which brings a simple and low cost configuration.

Fig.3. Conventional Circuit presented by Half Bridge⁽⁸⁾.

The remarkable characteristic is to obtain the boosted voltage inverter function, by means of merely changing the connecting point of the input power supply from the dc link terminal which is the midpoint of inverter leg. By such a way, simple BHB-INV can be obtained in a very simple manner. [11] By means of this, the dc link voltage becomes double and an unique sinusoidal inverter can be obtained in half bridge constructed by the minimum circuit components.

However, the applied voltage across the chalk inductor L_1 becomes $v_{LI} = v_{AB}$, where the commercial frequency is generated in the chalk inductor. Consequently, the size of L_1 would become much large. Because of such reasons, for practical applications, there is a problem, so in practice, it could be applied for current source inverter and the like, so the application is limited to restricted fields. Actually, this circuit is described as dc power supply for micro-processor.

Fig.4 above explained, shows as BHB-Boost Half Bridge. The purpose of the circuit mechanism is to boost the dc link voltage. By means of boosting the voltage the efficiency could be improved by reducing the current.

It is compared and discussed with our strategy. The input power supply voltage is boosted in the half bridge inverter. After this operation, the high frequency dc power is obtained.

Fig.4. Power Flow chart of Conventional Circuit.

Consequently, the efficiency could be improved due to increasing the voltage. After the energy of input power supply E is stored into L, the capacitor C is charged from power from L at switch turned-off. By means of this capacitor charge, the load R is supplied. Fig.4 shows such flowchart of the operating mechanism, where there are plural number of power transmissions. On the other hand, for the proposed power conversion, main transmission is performed by direct conversion from E to load, the other is a simple transmission way via single L or C. The number of conversion stage is much reduced. Consequently, the transmission efficiency can be expected as much improvement. Looking the whole chart of the conventional one, the power transmission route is more complicated so efficiency would be worse.

3. Analytical Circuit Operation

3.1 Proposed circuit operation

In order to verify the validity of this circuit mechanism, that operation is analytically confirmed by the circuit simulator.

The circuit parameters are given by, $R = 15 \text{ ohm}$, $L = 1 \text{ mH}$, $C = 1000\mu\text{F}$, operating frequency $f = 20 \text{ kHz}$, $E = 300 \text{ V}$, S_2 turn-on time = $25\mu\text{s}$, S_2 turn-off time = $25\mu\text{s}$. The obtained the load voltage and current waveforms are shown in Fig.5. as the supply voltage applied across the load, so the current are gradually and exponentially increasing according to the applied voltage polarity as can be seen. The load is inductive, so delayed current is flowing. As can be seen the regenerative operation is occurred, such operation can be satisfactorily processed by auxiliary capacitor. Such operation analytically is described

Fig.5. Load Waveforms.

Fig.6. Analytical Circuit Operation.

•Period I ($t_0 - t_1$) When S_1 is turned-off and turned-on, the power supplying current route is altered from auxiliary capacitor C to the input power supply E . The inductor provides the power into the load. At that time load current is larger than the inductor current. As a result, the excess current of i_R flows into the power supply E as regenerative current. At this time, though

turned-on, the actual current is not flowing through S_2 , but through D_2 . When the load current i_R is inductive, such operation is generated. The current, $i_E = i_R - i_{L1}$ is flowing through D_2 and E as power regeneration. In such condition, when i_{L1} is smaller than i_R , the inductor cannot provide the total current so generative operation is occurred.

When the load current i_R becomes smaller than the inductor current i_{L1} , the power regeneration is ceased so that the input current gradually starts to increase from zero, then this period comes to an end.

Period II ($t_1 - t_2$)

The current is increasing through zero point. The auxiliary inductor current i_{L1} is also increasing linearly according to the circuit differential equation

$$E = L_1 \frac{di_{L1}}{dt} \dots \dots \dots (4)$$

By means of suitably selecting L_1 and selecting relatively higher frequency, the inductor current ripple is suppressed which brings the improved efficiency.

Period III ($t_2 - t_3$)

When S_2 is turned-off and S_1 is turned-on, this period starts. As the polarities of the inductor current i_{L1} and load current i_R are the same direction, the current, $i_{L1} + i_R$ through S_2 is commutated to D_1 . This current is flowing into the auxiliary capacitor that is charged by this current. The steady state charged voltage can be easily solved by means of studying the characteristic of the auxiliary inductor, as follows; according to "Equal Area Law of $V \times T$ ", that is,

$$EE \times TS_{2on} = E_C \times TS_{1on} \dots \dots \dots (5)$$

where TS_{1on} and TS_{2on} are operating periods of S_1 and S_2 respectively. E_C is auxiliary capacitor voltage.

E_C can be obtained. For a case of selecting, $TS_{2on} = TS_{1on}$, voltage of C is equal to supply voltage, that is

$$E_C = E \dots \dots \dots (6).$$

When the current i_R becomes zero, this period is ceased.

Period IV ($t_3 - t_4$)

The load current is increasing from zero. During relatively small value of load current, providing current from L_1 is

Fig.6. Single Circulating Loop. $i_{RL} = i_{L1}$.

relatively small. The excess current is flowing into C. As i_{RL} is increasing gradually and is larger than i_{L1} , the deficient current that should be provided to load current i_{RL} starts to flow and to be supplied from capacitor C, so load current becomes $i_{RL} = i_{L1} + i_C$. The load current is increasing from zero. During relatively small value of load current, providing current from L_1 is relatively small. The excess current is flowing into C.

3.2. Single circulating loop ($i_{RL} = i_{L1}$)

During periods I and IV, the load current and inductor one are identical with each other, that is $i_{RL} = i_{L1}$. At that time, single current loop is established as shown in Fig.6. At this instance, there is only single current loop, when the power is provided and processed in the inner circuit only. This operation process is remarkable phenomena, because at this time there is no switching operation and does not generate an external noise toward outside.

4. Comparison of Estimated Transmission Efficiency

4.1 Local transmission efficiency

The number of components of circuit construction gives an influence for efficiency. The estimated efficiency will be calculated by means of number of stages by which goodness of converter will be estimated. In order to estimate the whole power transmission efficiency, efficiency of one transmission is assumed to be, for example, 90 %. The transmission power efficiency is shown as follows;

In this calculation, the delivery power in the route of E, L to R is assumed to be zero because of zero inductor current ripple.

The quantities of transmission power are represented by weighing method. Total efficiency is 85.50%.

On the other hand, in the conventional converter strategy shown in Fig.4,

$E \rightarrow L(90\%)$, $E L \rightarrow R(90\%)$, $E \rightarrow C(90\%)$, $C \rightarrow R(90\%)$.

The quantities of transmission power are represented by weighing method. Total efficiency is 81.0%, where there is no current loop through C_2 because of no ripple of inductor current.

The efficiency is about reduced by about 5 %. For proposed circuit, efficiency is improved because of dominant direct transmission.

4.2 Comparison of efficiency

Table 1 represents above mentioned efficiency for comparison. Upper two stages and lower two ones are a little different construction. Lower two items are represented that is previously presented construction.[7]. Comparing proposed Buck – boost Inverter with BHB, for load voltage, the supply voltage can be applied directly as advantage. The maximum, current of component is double of load current as disadvantage. For proposed converter, the number of component is reduced from nine to eight, which brings efficiency improvement. In lower two stages, the load voltage is reduced to half of the supply voltage as disadvantage, but the load current does not flow over load current. Comparing both inverters, the number of components of proposed converter is reduced by unity.

5. Conclusions

The high performance dc power generator is proposed and discussed whose idea is obtained from unified inverter circuit constructed by chopper and inverter circuit. In the first version which can realize by simple circuit component, the number of the circuit construction can be made minimum. The number of the conventional corresponding circuit configuration is totally nine, while for the proposed construction, the number is eight. This result is the reason why the proposed inverter is called as minimum circuit construction. Upper two stages and lower two ones are a little different construction. In comparison with proposed Buck-boost Inverter to BHB, for load voltage, the supply voltage can be applied directly as advantage. The maximum, current of component is double of load current as disadvantage. For proposed converter, the number of component is reduced which brings efficiency improvement. In lower two stages, the load voltage is reduced to half of the supply voltage as disadvantage, but the load current does not flow over load current. Comparing both inverters, the number of component of Buck Inverter is reduced by unity., which can be developed to dc to dc converter, as the number of conversion stages is reduced satisfactorily, an improved efficiency can be achieved. Finally as looking at the whole view compared with the usual half bridge construction, one of double supply capacitors is replaced by dc power supply from regular position, that is an interesting appearance.

Table 1. Characteristics of Various Converter.

	Eff %	Num.	Load V	Load I
Buck-Boost Inv	85.5	8	E	I
Buck-Half-Bridg	81.0	9	E	I
Buck Inverter	85.5	7	$E/2$	$I*2$
Half Bridge Inv.	85.5	8	$E/2$	$I*2$

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