Research on Boost Converter in Photovoltaic DC Boost Collection System

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Abstract. With the development and utilization of renewable energy, the DC collection of photovoltaics has solved the difficult problem of photovoltaic transmission, and the research of high-voltage and high-power converters has become the key. The boost full-bridge isolated converter (BFBIC) is used as the basic boost module, and the voltage level of the DC transmission line is reached through the independent input of the photovoltaic array and the parallel output of the boost converter. Moreover, after analysing the working principle of BFBIC and introducing the control transfer function of the boost module, this paper combines the principle of maximum power point tracking (MPPT), and adopts the classic double closed-loop control strategy. Finally, the simulation model is built in RTDS. By considering the operation of the system under the conditions of constant irradiation and changing irradiation, the simulation results verifies the feasibility of the system.

Keywords: Photovoltaic, DC collection, boost converter, maximum power point tracking

1. Introduction
With the increasingly serious environmental problems, it is particularly urgent to accelerate the development of new energy. Solar energy has advantaged that other new energy sources cannot match [1, 2], but the delivery of photovoltaic power generation is difficult to become a bottleneck hindering the development of photovoltaic power generation.

Large-scale photovoltaic power generation that bases on DC collection access is a new way of energy collection. Reference [3, 4] proposed a series-isolated full-bridge DC/DC converter solution is used to solve the DC boost problem of photovoltaic power plants, and each photovoltaic power generation unit performs independent maximum power tracking. In [5], taking the photovoltaic converter station cascaded with active clamp BFBIC modules as an example, the maximum power control active clamp part or boost part is used to analyze the pros and cons of the two control strategies. Reference [6] uses photovoltaic modules with cascaded half-H-bridge converters to obtain a DC voltage of 20kv. At the same time, there is a buck circuit on each module to achieve MPPT. The switch of the half-H-bridge is used to control the discharge of the capacitor. The stability of the capacitor voltage in turn maintains the voltage of the DC transmission line. In [7], by introducing a quasi-Z source impedance network into the series DC boost converter sub-module unit, it can not only...
deal with the mismatch phenomenon of the photovoltaic sub-module, but also provide the circuit with the ability to resist through short-circuit faults.

The topology of the photovoltaic DC boost collection and grid-connected system used in this paper is shown in Figure 1. In this paper, based on the photovoltaic DC collection boost system with the output of the series boost converter, the topology of the boost converter is designed, the working principle is analyzed in detail. Then combining the classic double closed-loop control strategy, the paper proposes a boost converter control strategy. In addition, the working principle of MPPT is analyzed. Finally, a simulation model is built in RTDS to verify the effectiveness of the control strategy.

![Figure 1. Topology structure of photovoltaic DC boost collection and grid-connected system.](image)

### 2. Working Principle of Boost Converter

![Figure 2. Topology structure of active clamp BFBIC.](image)

In this paper uses an active clamp BFBIC as the basic boost unit. The topology of BFBIC is shown in Figure 2. The input voltage $U_{PV}$ is the output voltage of the photovoltaic array, $L_{boost}$ is boost inductor; $S_1$–$S_4$ are power switches and their anti-parallel diodes; $T$ is a high-frequency transformer; $L_r$ is the equivalent leakage inductance of the transformer; 4 rectifier diodes $D_1$–$D_4$ form a full-bridge uncontrolled rectifier circuit; $C_O$ is the output filter capacitor; $U_{out}$ is the output voltage. $S_C$ and the capacitor $C_c$ in series form an active clamp circuit to control the peak voltage [8]. By controlling the turn-on and turn-off timing of $S_1$–$S_4$, the AC square wave voltage can be obtained on the primary side of $T$, and after $T$ the square wave voltage of $n$ times the amplitude of the primary side voltage can be obtained on the secondary side of $T$, and finally Flow through the uncontrolled rectifier circuit and filter capacitor to obtain the required DC voltage.
Stage 1(0-\(t_0\)): The power switches \(S_1\sim S_4\) are all turned on, the voltage the power switches bears is 0, the input voltage charges the boost inductor, the inductor current increases, and the active clamp power switch tube turns off. On the secondary side of the transformer, the output filter capacitor \(C_O\) is discharged to provide energy to the outside. The switch stage a in Figure 3 is shown. The input voltage is expressed as:

\[
U_{PV} = L_{boost} \frac{di_L}{dt}
\]  

(1)

**Figure 3.** The timing diagram and the key waveforms of the converter.

![Figure 3. The timing diagram and the key waveforms of the converter.](image)

Figure 4. BFBIC switch stages.
Stage 2 (t_0 - t_1): The power switches S_2, S_3 are turned off at the same time, and the power switches S_4, S_5 are still on. The power supply and the input inductor output energy to the load at the same time. Due to the leakage inductance of the transformer, the inductor current cannot be transferred to the transformer immediately Primary side. At this time, the active clamp power switch S_C is turned on. In this way, a part of the inductor current is transferred to suppress the voltage peak [9]. The switch stage b in Figure 3 is shown. The inductor current is decreasing, as follow:

\[ U_{py} - \frac{U_{out}}{n} = L_{\text{boost}} \frac{d_i}{dt} \]  

(2)

Stage 3 (t_1 - t_2): The state of the power switch is the same as stage 2. At t_1, i_c drops to 0, and all the current flowing through the boost inductor is transferred to the primary side of the transformer. At this time, C_C begins to discharge. The current flowing through C_C starts to increase in the opposite direction. The switch stage c in Figure 3 is shown.

Stage 4 (t_2 - t_3): The power switches S_2, S_3 are turned on, and the four power switches of the bridge arm are turned on at the same time. When the boost inductor stores energy, the active clamp power switch is turned off. This process is the same as stage 1.

Stage 5 (t_3 - t_4): At t_3, S_4, S_5 are turned off. This switch mode is similar to stage 2.

Stage 6 (t_4 - t_5): This switch mode is similar to stage 3, so it will not be repeated.

The input and output relationship of the circuit can be obtained [9], as follow:

\[ U_{out} = \frac{nU_{py}}{2(1-D)} \]  

(3)

3. Control Strategy of BFBIC

Combined with the classic double closed-loop PI control, the transfer function of the boost system can be obtained as Figure 5. Control strategy block diagram can be obtained as Figure 6.

The control strategy takes the output value U_{ref} of maximum power tracking as the reference value. Then it is compared with the actual output voltage sampling value. Then, the output of the PI regulator is used as the reference value of the current inner loop. The current reference value is compared with the input current sampling value of the DC/DC module. The duty cycle is obtained by PI adjustment [10]. The clamp switch absorbs part of the current when the other switches are turned off, so the control method of its conduction is the exclusive OR operation (XOR) of the turn-off signals of other switches.

![Figure 5. Transfer function block diagram of the system.](image-url)
The MPPT method generally includes the disturbance observation method, the conductance increment method, etc. In this paper, the conductance increment method is adopted. The control block diagram is shown in Figure 7.

4. Simulation Analysis

4.1. Simulation parameters
In the simulation of this paper, the design capacity of the photovoltaic power station is 4MW, which is composed of four 1MW power generation modules connected in series, the DC bus voltage of MMC is 60kV, the rated output voltage of BFBIC is 15KV, and the PV modules 1, 2, 3, 4 are set. The initial irradiation intensity is 1000 W/m² and the temperature is 25 °C. This simulation model uses RTDS.
4.2. Simulation analysis during normal operation
When t=0s, the system runs normally under the initial irradiation intensity, and the photovoltaic power generation module runs in the maximum power mode at this time. At t=3s, the irradiation of photovoltaic modules 2, 3, and 4 began to gradually decrease from 1000 W/m², and at t=5s, it dropped to 800 W/m². The power of each photovoltaic array module, the output voltage of each photovoltaic array module, the DC bus voltage and the active power output by the system are shown in Figure 8.
Figure 8. Simulation diagram of various parameters of system operation.

It can be seen from the figure that each photovoltaic module adopts the MPPT mode during normal operation. When the irradiation conditions change, the photovoltaic modules 2, 3 and 4 can still perform maximum power tracking, and the photovoltaic DC boost collection system can operate normally. The photovoltaic module 1 has a significant overvoltage due to the unchanged light intensity. It can be seen from the figure that the DC bus voltage fluctuates slightly when the irradiation changes, but the overall voltage remains stable at around 60kV. When the irradiation does not change, the output power is 3.83MW and the transmission efficiency is 95.5%, indicating that the system is operating normally. When the irradiation changes, the photovoltaic output power decreases gradually. When the irradiation stabilizes again, the output power is 3.15MW, and the transmission efficiency drops to 94.3%.

5. Conclusions
Aiming at the application background of DC collecting and boosting and grid-connected photovoltaic power plants, this paper proposes a high-voltage DC grid-connected converter topology scheme for photovoltaic power generation. The output of the active clamp BFBIC in series is used for collecting and boosting, and the basic of the topology is analyzed. Its working mode is analyzed, and a control strategy suitable for this topology is proposed. The classic double closed-loop control is combined with MPPT, and the MPPT adopts the conductance increment method. Finally, a 4MW simulation model was built in RTDS to verify the topology scheme and control strategy. It was found that under normal operation, the photovoltaic power generation module can realize MPPT, and the system operates stably and has high transmission efficiency. At the same time, the system can still keep running when the irradiation changes.

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