Contrastive Studies of Z-Source Converter and Boost Converter on Photovoltaic Maximum Power Point Tracking System

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Abstract. Aiming at a series of issues on traditional boost converter which commonly used in photovoltaic maximum power point tracking (MPPT) devices, such as the limited output voltage, the low boost efficiency, the excessive heat generating, this paper proposed a novel z-source converter. Compared with traditional boost converter, several researches have done among topology structure, operational principle, boost factor. Based on the theoretic analysis, this paper given two schemes of photovoltaic MPPT system which using boost converter and z-source converter, the models of them are established based on Matlab. The simulation results indicate that the duty-ratio of photovoltaic MPPT system based on z-source converter is smaller, the stability of MPPT is better. The novel z-source converter can fundamentally solve the issues caused by traditional boost converter in photovoltaic MPPT devices, and it has incomparable advantages than traditional boost converter in the field of photovoltaic power generation.

Keywords: z-source converter; boost converter; photovoltaic; MPPT; duty-ratio; stability.

1. Introduction
Photovoltaic power generation, as one of the cleanest, most direct and most large-scale development and utilization prospects in the field of renewable energy in the world today, is an important measure to provide users with "green power" and achieve the goal of "energy saving and emission reduction" in China [1]. However, because the output power of photovoltaic cells is a nonlinear function affected by light intensity and ambient temperature [2], in practice, there is no guarantee that photovoltaic cells will always operate at the maximum power point; At the same time, if the photovoltaic system does not accurately track the maximum power point, it may cause the system to oscillate or even not function properly [3]. So the maximum power point tracking (MPPT) device must be added between the photovoltaic cells and the load.

In traditional MPPT device, the boost converter is the most commonly used topology in its DC-DC segment. However, this topology has some defects, the main deficiency is its boost factor, when the requirement of system boosting is high, the duty-ratio is close to 1, which will lead to the switching tube heat increase, loss increase, efficiency reduction and many other problems [4]. In 2003, Professor Peng Fangzheng first proposed a unique z-source network in the literature. z-source network has...
received research and attention from scholars in the fields of photovoltaic power generation, wind power generation and electric vehicles. [6-9]. However, in these studies, the z-source network is almost always used in DC-AC inverters, while in DC-DC converters are rarely used. The literature [10] has given one kind the z-source converter which grows by the z-source network, and has analyzed based on its constitution charging circuit charge characteristic; The literature [11] has given another form z-source converter, and analyzed it to make and break under the working pattern operational factor in the inductance. However, the above literature tends to study the principle of the converter itself, and does not explore the new features of the new z-source converter in the context of solving the practical engineering problem, nor does it compare it with the traditional boost converter.

Based on previous research, combined with the characteristics of photovoltaic power generation itself, this paper gives a novel z-source converter topology, and deduces the boost factor is \( B = (1 - D)/(1 - 2D) \). It can achieve a high boost requirement when \( D \) less than 0.5, so it can overcome the shortcomings of the traditional boost converter [12]. The photovoltaic power generation MPPT system schemes based on boost converter and z-source converter were presented in this paper, and this two schemes were compared with simulation analysis. The results indicate that the scheme with z-source converter has a smaller duty-ratio, better MPPT stability under dynamic perturbation.

2. Z-Source Converter

2.1. A. Topology

The topology of the z-source converter is shown in Figure 1 (b), \( U_S \) is the direct-current power source, \( T \) is the switch component, such as MOSFET, IGBT and so on, \( D \) is the diode. As can be seen from Figure 1(a), the z-source converter is replaced by the input inductor of the Boss circuit with the z-source network, and the diode \( D \) is advanced, while the LC filter circuit is added to the output to obtain a stable output.

![Fig. 1 Topology contrast of z-source and boost converter](image)

2.2. B. Working Principle

Functionally, the z-source converter is a single-tube, non-isolated DC boost converter that controls the size of the output voltage by adjusting the duty-ratio of the switching tube. The z-source converter is corresponding two kind of active statuses, its working principle is [13,14]:

\[ B = (1 - D)/(1 - 2D) \]
When the switch tube T is on, its equivalent circuit diagram is shown in Figure 2 (a). At this point, the diode is cut off by the reverse voltage, and the input power source is disconnected from the circuit, the capacitor C3 is supplied to the load R, and the inductive L1/L2 is powered by C1/C2 and the energy is stored.

By circuit symmetry:

\[
\begin{align*}
U_{C_1} &= U_{C_2} = U_C \\
U_{L_1} &= U_{L_2} = U_L
\end{align*}
\]  

(1)

By KVL law:

\[
\begin{align*}
U_C &= U_L \\
U_{in} &= U_C + U_L = 2U_C \\
U_{out} &= 0 \\
U_{L_3} &= -U_R
\end{align*}
\]  

(2)

When switch tube T is switched off, its equivalent is shown in Figure 2 (b). At this point, the diode is on, the inductive L1/L2 and the power supply Us together to power the load, then:

\[
\begin{align*}
U_L &= U_S - U_C \\
U_{in} &= U_S \\
U_{out} &= U_L - U_C = 2U_C - U_S
\end{align*}
\]  

(3)

In the entire switch cycle, by the stable state inductance magnetic flux conservation, the inductance voltage mean value should be 0, then has:

\[
U_L = \bar{U}_L =\frac{DT_S U_C + (1-D)T_S(U_S - U_C)}{T_S} = 0
\]  

(4)
Substitute (2) and (3) into (4), which can be simplified to:

\[
\frac{U_C}{U_S} = \frac{(1-D)T_S}{(1-D)T_S - DT_S} = \frac{1-D}{1-2D}
\]  

(5)

Because the inductance in a cyclical internal voltage mean value is 0, then has:

\[
U_{L_S} = (2U_C - U_S - U_{out})(1-D)T_S
\]

\[-U_{out}DT_S = 0
\]  

(6)

Substitute (5) into (6), which can be simplified to:

\[
\frac{U_{out}}{U_S} = \frac{1-D}{1-2D}
\]  

(7)

And the boost factor for the z-source converter is:

\[
B = \frac{1-D}{1-2D}
\]  

(8)

2.3. C. Boost Factor
As can be seen from the above theory, the boost factor for the z-source converter is \( B = \frac{(1-D)}{(1-2D)} \), The boost factor for traditional boost converters is \( B = \frac{1}{(1-D)} \), its theoretical inferences can be found in the literature [15]. The comparison curve of the two transformer boost factors is shown in Figure 3, where the horizontal coordinate is the duty-ratio, and the ordinate coordinate is the transformer boost factor. As can be seen from the curve in the figure, under the same duty-ratio, the boost efficiency of z-source converter is higher than the traditional boost converter, and the total duty-ratio of the switch tube of the z-source converter is always less than 0.5.

Fig. 3 boost factor contrast of z-source and boost converter

2.4. D. Efficiency Analysis
Efficiency is an important evaluation index of transformer performance. The loss of DC converter mainly includes the following two aspects:

1) Conduction loss: conduction loss is to point to switch tube conduction, when current flows through the inductor winding and semiconductor switch tube when the loss, its size and the size of the output power loss;
2) Switching loss, switching loss is refers to the switch tube in the open and shut off the conversion process of losses, its size is almost not influenced by power output, only related to the frequency of the switch tube size.

Assuming that the resistance value of the inductor and switch tube in the on loss is $R_L$, and the current loss in the switching loss is $I_{sw}$, the efficiency of the converter is:

$$
\eta = \frac{1}{1 + \frac{R_L(1-D)^2}{(1-2D)^2} \left( \frac{I_{out} + I_{sw}}{I_{out}} \right)^2 + \frac{I_{sw}}{I_{out}}}
$$

(9)

Regardless of switching losses, set $I_{sw} = 0$, $R = \frac{U_{out}}{I_{out}}$, then has:

$$
\eta = \frac{1}{1 + \frac{R_L(1-D)^2}{(1-2D)^2} \frac{1}{R}}
$$

(10)

The z-source converter and the Boost converter duty-ratio and efficiency relations curve as shown in Figure 4 (set $R_L / R = 0.005$). It can be seen that when $D \leq 0.43$, z-source converter efficiency is always higher than that of the boost converter.

Fig. 4 Efficiency contrast of Z-Source and Boost converter

3. Photovoltaic Mppt System

3.1. System Scheme

The scheme for photovoltaic MPPT system based on traditional boost converter and z-source converter were shown as Figures 5 (a) and 5 (b). The output voltage and current of photovoltaic array are sampled in real time, and the sampled data is sent to MPPT controller. A fixed value will be obtained after calculation by MPPT controller, then the PWM pulse is generated by the PWM drive circuit, adjustment of the output voltage of the photovoltaic array to the Maximum point voltage.

The photovoltaic array, the load, and the MPPT controller are the same in Scheme 1 and 2, the only difference is: the traditional boost converter is used in the DC-DC link of scheme 1, and the new Z-source converter is used in the DC-DC link of scheme 2.
a) scheme 1: Photovoltaic MPPT control system based on boost converter

b) scheme 2: Photovoltaic MPPT control system based on z-source converter

Fig. 5 Structures and control strategies of two Schemes

3.2. Simulation Analysis

The system simulation models of schemes I and II are established based on matlab. The photovoltaic array module is based on the mathematical model of photovoltaic cell and the losses of converters are considered. The MPPT control algorithm adopts Perturb and Observe Algorithm [16]. Assuming that the external ambient temperature T remains at 25 degree, the dynamic response of the system is observed by dynamically disturbing the light-strength signal S. The simulation algorithm uses the variable step ode23tb algorithm, and the simulation time is 1s.

The simulation results for schemes I and II are shown in Figures 6 (a) and 6 (b), it can be seen that both schemes can successfully track the maximum power point of the photovoltaic array in real time. However, in scheme II, the output voltage/current and output power curves of the system have a less fluctuate when the light-force disturbance instantaneously, and the system can reach a stable state more quickly.

The duty-ratio of the converter in scheme I and II are shown in Figure 7, it can be seen that the duty-ratio of scheme II is significantly smaller than scheme I.

The simulation results of scheme I and scheme II are shown in Table 1.
a) scheme I: the waveform of Photovoltaic MPPT control system based on boost converter

b) scheme II: the waveform of Photovoltaic MPPT control system based on z-source converter

Fig. 6 Dynamic simulation waveform of PV system

Fig. 7 Contrast of duty-ratio perturbation
Table 1. Detailed results of the simulation

| scheme I (boost) | temperature °C | Light (W/m²) | Input voltage (Uin/V) | Input current (Iin/A) | Output voltage (Uout/V) | Output current (Iout/A) | Duty-ratio (D) | Input power (Pin/W) | Output power (Pout/W) |
|-----------------|----------------|--------------|----------------------|---------------------|------------------------|------------------------|---------------|-------------------|-------------------|
| 25              | 600            | 17.6         | 4.55                 | 27.8                | 2.78                   | 0.37                   | 80.08         | 77.28             |
|                 | 800            | 18.4         | 6.10                 | 32.8                | 3.28                   | 0.44                   | 112.24        | 107.58            |
|                 | 1000           | 19.1         | 7.61                 | 37.2                | 3.72                   | 0.49                   | 145.35        | 138.38            |
| scheme II (z-source) | 25              | 600            | 17.6         | 4.58                 | 28.3                   | 2.83                   | 0.27          | 80.61             | 80.08             |
|                 | 800            | 18.4         | 6.11                 | 33.3                | 3.33                   | 0.31                   | 112.42        | 110.89            |
|                 | 1000           | 19.1         | 7.63                 | 37.8                | 3.78                   | 0.33                   | 145.73        | 142.89            |
| Reference       | 25              | 1000         | 19.2                | 7.81                | ---                    | ---                    | 149.95        | ---               |

4. Conclusion

Based on theoretical research and simulation analysis, the following conclusions can be drawn:

1) The photovoltaic power MPPT system based on z-source converter has a small duty-ratio and high boost efficiency, which can effectively solve the problem of limited output voltage and low boost efficiency of MPPT system based on traditional boost converter;

2) The photovoltaic power MPPT system based on z-source converter fluctuates less when the external environment changes, can reach stable state faster, which has good dynamic stability.

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