Multy-modality Switch Modeling and Simulation of A Three-port DC-DC Converter

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Abstract. A three-port DC-DC converter (TPC) for photo voltaic (PV) electric vehicle (EV) was presented in this paper. A PV module and a battery consist of the power supply for electric vehicle. A boost converter helps the PV module to output maximum power. A sepic-zeta converter helps the battery to be charged by PV power or output power for EV. A cuk converter was used to keep the stability of output voltage for load. There are five modalities for the TPC model and three applications were simulated to verify the performance of different modality switching. The simulation results show that the given TPC model have some advantages, such as small steady errors, short transient times and small fluctuation of voltage and power. This TPC can be used in EV to provide a steady voltage for motor and extend the driving distance.

1. Introduction

Green and renewable energy is a good solution for energy crisis and environment pollution. EV has received strong support and promotion in many countries. But there are two problems that prevent the promotion of EV. The first problem is driving distance of EV. The traditional EV is powered only by battery. Small capacity battery will limit the EV driving distance. Large capacity battery will enlarge the heavy of EV and decrease the efficiency of electrical vehicle. The second problem is pollution. The battery is always charged by power from fossil-fuel power station. The EV only reduce the pollution that they emit. But the total pollution is not reduced[1,2].The introduction of PV through TPC can effectively solve this problem.

Bidirectional DC/DC (BD) converter and three port DC/DC converter have been used in EV and micro-grid. There are two types converters today, such as isolated converter and non-isolated converter[3-7]. There is a high-frequency transformer for isolated converter. It is used to separate the high voltage signal and low voltage signal and make sure the safety of low voltage element[8,9]. The non-isolated converter is usually composed of Boost, Buck and other topologies[10-12]. They have the advantages of high-power density, compact structure and high efficiency[13].

In view of the new requirements of renewable energy applications for multi-port power conversion and high-gain output capabilities, the paper proposes a non-isolated three-port converter based on sepic-zeta. By comparison, the converter has a simple structure, strong voltage controllability between ports, and a stable output can be achieved through a simple modulation strategy. It can realize the bidirectional flow of energy [14,15]. The working principle of TPC is analysed. And some applications are simulated.
2. The Principle of TPC

2.1. Structure of TPC
When the PV is input EV as an extra power, the PV must be working under maximum power to make sure the maximum utilization of solar panels. Because the output voltage is less than operating voltage of motor, a boost converter is used to realize the maximum power tracing (MPPT) of the PV and provide a steady voltage for motor.

For a EV without PV, there are ±10% voltage fluctuation for battery. This is detrimental for MPPT and motor efficiency. A sepic-zeta converter can make sure the output voltage stability and can be adjusted with the PV output voltage. The output voltage of MPPT circuit of PV maybe not equal to the working voltage of motor. A cuk converter is used to keep the voltage stability of motor. The TPC structure is shown in Figure 1.

![Figure 1. Structure of the TPC](image)

There are five working modalities for the TPC, such as single input and single output from PV to motor (SISO-PM), single input and single output from battery to motor (SISO-BM), single input and single output from PV to battery (SISO-PB), single input and double output form PV to battery and motor (SIDO), double input and single output from PV and battery to motor (DISO).

2.2. SISO-PM
When the output power of the PV module is equal to the rated power of the load, the battery does not work. The PV module provides power to the load alone. The circuit topology is shown in Figure 2 based on the switching state of S1 and S4.

![Figure 2. Circuit topology](image)
In Figure 2.(a), PV charges L1. C2 and C5 are connected in parallel to charge L4. C6 supplies power to L5 and the load loop.
In Figure 2.(b), PV and L1 charge L4, C2, and C5. C6 continues to supply power to L5 and the load loop.
In Figure 2.(c), PV and L1 charge C2, C5, and C6. The load circuit is powered by L5.

2.3. SISO-BM
When the energy output of the PV module is 0, the battery provides all power for motor. The circuit topology is shown in Figure 3 based on the switching state of S2 and S4.

In Figure 3.(a), the battery charges L2. C4 charges L3. C5 charges L4. C6 supplies power to L5 and the load loop.
In Figure 3.(b), the battery and L2 charge C4, C5, and L4. L3 charges L4. C6 continues to supply power to L5 and the load loop.
In Figure 3.(c), the battery, L2, and L4 provide power for C4, C5, and C6. The load circuit is powered by L5.

2.4. SISO-PB
When the motor is stop and the SOC of battery is less than 95%, PV module provides power to charge the battery. The circuit topology is shown in Figure 4 based on the switching state of S1 and S3.

![Figure 4. Topology of TPC in SISO-PB mode:](image)

In Figure 4.(a), PV charges L1. C2 and C5 are connected in parallel to charge L3. At the same time, C2 and C4 are connected in series to provide power for the battery, C3 and L2.
In Figure 4.(b), PV and L1 charge C2, C5, and L3. In addition, PV, L1 and C4 are connected in series to charge the battery, C3 and L2.
In Figure 4.(c), PV and L1 continue to be connected in series to charge C2 and C5. L3 charges C4. L2 provides power for the battery circuit.

2.5. DISO
When the output power of the PV module is less than the rated power of the load, the load is supplied by PV and battery together. The circuit topology is shown in Figure 5 based on the switching state of S1, S2 and S4.

![Figure 5. Topology of TPC in DISO mode:](image)
In Figure 5.(a), PV charges L1, C2 and C5 are connected in parallel to charge L4. C6 supplies power for L5 and the load loop. The battery supplies power to L2. C4 charges L3.
In Figure 5.(b), PV and L1 are connected in series to charge C2, C5 and L4. C6 supplies power to L5 and the load loop. The battery charges L2. C4 charges L3.
In Figure 5.(c), PV and L1 continue to charge C2, C5 and L4. The battery and L2 charge C4, C5, and L4. L3 charges L4. C6 continues to supply power to L5 and the load loop.
In Figure 5.(d), PV and L1 continue to supply power to C2 and C5. And PV, L1 and L4 charge C6. The battery, L2, L4, and L3 are charged for C4, C5, and C6.

2.6. SIDO
When the output power of the PV module is greater than the rated power of the load and the SOC of the battery is less than 95%, the PV module provides power to the load and charges the battery at the same time. The circuit topology is shown in Figure 6 based on the switching state of S1, S3 and S4.
In Figure 6.(a), PV charges L1. C2 charges L3, while C2 and C4 are connected in series to provide power for the battery circuit and L2. C5 and L4 charge C6. The load circuit is powered by L5.

In Figure 6.(b), PV and L1 are connected in series to charge C2, C5 and L3. At the same time, PV, L1, and C4 are connected in series to provide power for the battery circuit and L2. PV, L1 and L4 charge C6. The load loop continues to be powered by L5.

In Figure 6.(c), PV and L1 are connected in series to continue to charge C2, C5 and L3. And PV, L1, C4 are connected in series to continue to provide power for the battery circuit and L2. PV and L1 charge L4. C6 charges the load circuit and L5.

In Figure 6.(d), PV and L1 are connected in series to continue to charge C2, C5 and L4. C6 continues to charge the load circuit and L5. L2 provides power to the battery circuit. L3 charges C4.

3. Simulation

In order to prove the performance of the TPC, the simulation of three application is performed.

3.1. Application 1

The light intensity is 300 lux and the load is open at 0s. The ambient temperature is 25℃. The SOC of battery is 45%. At the beginning, the voltage of C2 is less than the voltage of battery, the charge circuit is not working. PV charges C2, and the voltage of C2 rises. After 0.4s, the voltage of C2 is above the voltage of battery, the PV start to charge the battery. The light intensity steps up to 500lux at 0.7s. The charging power increased. During the charging process, due to loss, the output power of PV is about 10W higher than the power absorbed by the battery. The working model is SISO-PB. The working process is shown in Figure 7.
3.2. Application 2

The simulation show that the charging voltage is stable and the power fluctuation is small.

The light intensity is 580 lux. The ambient temperature is 23℃. The SOC of battery is 97%. The power of load is 350W at 0s and step up to 395W at 0.7s. In the first 0.7s, the output power of PV meets the load demand, the output power of battery is 0. After 0.7s, the load power increases. Because the output power of PV is not enough to meet the load power demand at this time, the voltage of load begins to decrease. In this mode, the system detects that the voltage of load is lower than 47V for 0.3s, so the SISO-PM mode is switched to DISO mode. The battery starts to output power and load power is satisfied. The working process is shown in Figure 8.
The simulation shows that the TPC can change the working mode according to the working condition. When the PV power is less than the load, the voltage will drop slightly and the battery is put into operation. The working mode change from SISO-PM to DISO.

3.3. Application 3
The light intensity is 650 lux. The ambient temperature is 23℃. The SOC of battery is 60%. The power of load is 350W at 0s and step up to 395W at 1s. The working mode is SIDO between 0s to 1s. after 1s, the working mode change to DISO. The working process is shown in Figure 9.

![Figure 9. Application 3](image)

At the beginning, the power of PV is greater than the load. The TPC working mode is SIDO. Some of PV power is proved to load and the others charge the battery. The SOC starts to rise. After 1s, the PV power is less than load. The TPC is working in DISO mode. The battery begins to output power for load and SOC decreases. The power and voltage fluctuation of different mode switching is small.

4. Conclusion
The TPC is the bond among the PV, battery and motor. It is a key element to manage the power flow in EV and change the working mode under different working condition. The TPC can realize five working mode of EV, such as SISO-PM, SISO-BM, SISO-PB, DISO and SIDO. Three application simulations show that the TPC can make sure the stability of voltage and power flow when the working model is switched. There are few elements in the TPC. This promises the small volume and high-power density of controller. The introduction of PV will extend the driving distance and battery life. This will promote the development of EV.

5. References
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Acknowledgment

This project is supported by the fund of the Science and Technology Research Program for Colleges and Universities in Hebei Province, China (grant No.ZD2020342). And the funding for the Hebei Province University Student Innovation Project (grant No. S202010082010). This is a postgraduate innovation project of Hebei University of Science and Technology. This project is the teaching and research project of Hebei University of Science and Technology.