DESIGN AND ANALYSIS OF PV SYSTEM WITH Z-SOURCE HALF-BRIDGE CONVERTER

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Abstract: In a grid-connected photovoltaic (PV) system, the traditional Z-source inverter uses a low frequency transformer to ensure galvanic isolation between the grid and the PV system. Half bridge converter system is developed for to convert dc power in to the ac and also boost dc output. Due to less no of switches, complicity of converter has been reduced. By adding this Z-source network in between the half bridge converter then this half bridge converter can be also able to operate if duty ratio goes beyond the unity. Conventional half bridge Z-source converter can be used for resistive load. By using the simulation results we can analyze the proposed method. This paper presents a modified single-phase transformerless Z-source PV grid-connected inverter and a corresponding PWM strategy to eliminate the ground leakage current in order to combine the advantages of both Z-source inverters and transformerless PV inverters.

Index Terms—Half-bridge converter, reduced number, shoot-through, Z-source

I. INTRODUCTION

The traditional power converters are basically of two types: voltage-source converters and current source converters. These can be used in single phase as well as three-phase power converters. This paper mainly focuses on a single-phase power conversion. In case of voltage- source (V-source) converters, it acts as a buck (step-down) converter for DC to AC power conversion and as a boost (step-up) converter for AC to DC power conversion. In case of current source (I-source) power converter, it acts as a boost converter for DC to AC power conversion and as a buck converter for AC to DC power conversion. Thus, Vsource and I-source power converter can be used as either as a boost or a buck converter and not as a buck-boost converter.

Moreover, in case of a three-phase power conversion, if both the upper and lower switches of the same leg are simultaneously turned ON either by purpose or by electromagnetic interference, a shoot-through occurs and the converter is damaged. At the past conventional half bridge converter has lots of problem like it cannot produce a broader range of the output voltages and also the shoot-through problem occurs. In conventional half-bridge converter has two switches and they are in one leg as shown in Fig. 1.

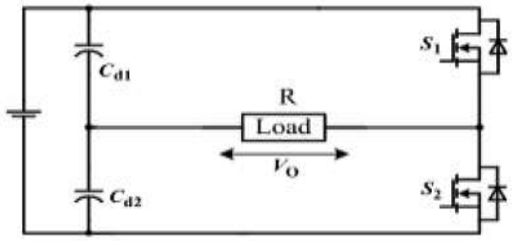


Fig. 1. Conventional half-bridge converter.

If both switches are turn-on at same time the shoot-through problem can occur. Due to this shoot-through problem, large current can flows through these switches, and this makes to short circuits and the switches are getting damage.

The half-bridge inverter output voltage is lower than its source voltage. Furthermore in the conventional half-bridge converter, unbalanced midpoint of split capacitors are makes the system unbalance due to the large ripple.

For the solving of shoot-through phenomenon and limited voltage problem, Peng was proposed the LC network, which is named as the Z-source network as shown in the Fig. 2.

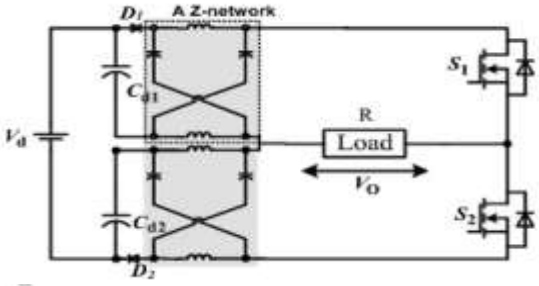


Fig. 2. Z-source half-bridge converter with two Z-networks

The Z-source inverter topology has been significantly modified later. Modified Z-source converter and the control methods have been proposed. New algorithms are proposed to controlling of both AC output voltages and boost DC source of the Z-source converters and dual input and dual output Z-source inverter. Z-source topology is used for lots of applications like a fuel cell system which is proposed.

The Z-source converter has ability to work in the shoot through phenomenon, and the output voltage of the Z-source converter has broader ranges

than that of conventional half bridge converter. Many topologies were developed for the PV applications like a half-bridge converter and full-bridge converter. Conventional half-bridge converters have their switches in series, as shown in Fig. 1, with which the shoot-through can occur, which means that the strong current flowing through the switches makes them break down. Moreover, the ac output voltage is limited below the dc voltage, which is named the limited voltage problem, because, in practice, ac output voltage is sometimes desirable to be higher than the dc voltage. Furthermore, an unbalanced midpoint of input capacitors in conventional half-bridge converters leads to large ripples making the system unstable.

Electroplating is a kind of electrochemical process, whose fundamental operation diagram and operation principle are shown in Fig. 3 and described in the following.

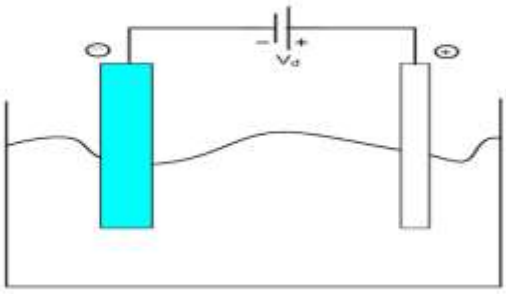


Fig. 3. Diagram of electroplating

The electroplating process is a redox reaction, with fundamental components: two electrodes (+and−), a dc source (Vd), and the solution, as shown in Fig.3. The purpose of the electroplating is to make the metal ions cover the surface of the negative electrode evenly and smoothly. However, due to the non uniformity of the solution, the dc-voltage direction and the current density should be changed from time to time, which requires complicated designs according to different products and processes With the rapid growth of the demand on electroplating products with very different voltages and duties, there are more stringent requirements on the electrochemical power supplies to provide a broad range of outputs, asymmetrical positive and negative voltages, step waves, recurrent pulses, square waves, triangular waves, and saw-tooth waves which can be quite well fulfilled by the proposed converter.

II. SYSTEMDESIGN ANDANALYSIS

The proposed converter is depicted in Fig. 4, in which an LC Z-network, consisting of capacitorsC1 andC2 and inductors L1andL2, is integrated into a traditional half-bridge converter, consisting of capacitorsCd1andCd2, switches S1andS2, and diodeD, which is used to prevent the current from flowing back to the source. Therein, the use of the inductors in the Z-network is to avoid strong current in the circuit when the switches are inthe shoot-through state

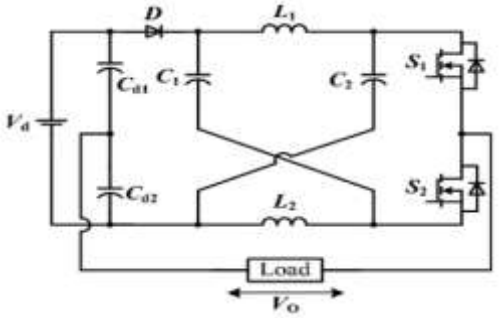


Fig. 4. Z-source half-bridge converter

For simplicity, the following conditions are assumed: 1) All the components are ideal; 2) the dead time in the driven pulses is ignored; 3) L1=L2andC1=C2in the Z-network; 4) C1, C2, Cd1, and Cd2 are large enough; and 5) the freewheeling diodes of the switches are ignored in the analysis since the load characteristic of the electrochemical solution is resistance or resistance with a small capacitance. Denote the duties of the switchesS1 and S2 byD1 and D2, respectively. The proposed converter performs differently in two cases:D1+D2≤1andD1+D2>1.

A. Case 1:D1+D2≤1

In this case,S1andS2are not switched on at the same time; then, the circuit is in the non-shoot-through state. There are three modes corresponding to the states of the switches.

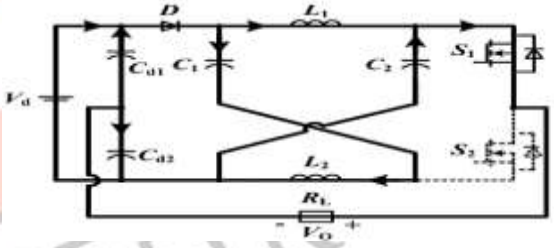
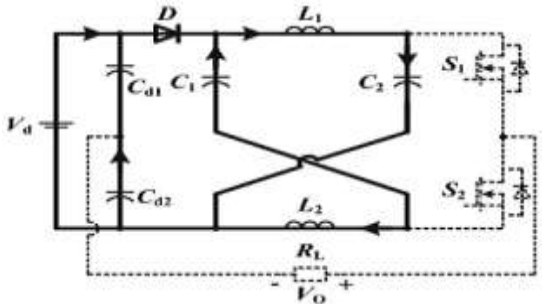


Fig. 5. Equivalent circuits in case 1. (a)S1on andS2off.

In the first mode, Fig. 5(a) shows an equivalent circuit for the mode when theS1is on andS2is off, in which the current flows out of the source, through the diode, the Z-network, andS1, and then back to the source. The arrows indicate the current directions.



(b)

Fig. 5. Equivalent circuits in case 1. (a)S1on andS2off. (b)S1off and S2off.

In the second mode, Fig. 5(b) shows an equivalent circuit of that whenS1andS2are off, in which the current also flows out of the source, through the diode and the Z-network, and back to the source; there is no output here. In the third mode, Fig. 5(c) shows an equivalent circuit of that whenS2is on and S1is off, in which the diode suffers a negative voltage and, thus, turns off. The current flows out of the source, through the load,S2, and the Z-network, and then back to the source. Furthermore, the current direction is also indicated. The operation process for this case is similar to the traditional one for half-bridge converters, which is not detailed here.

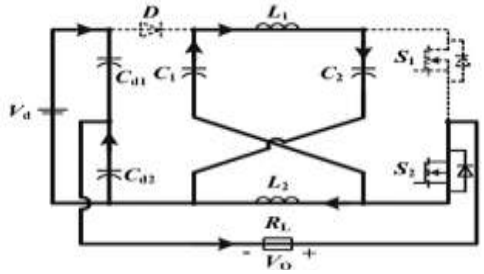
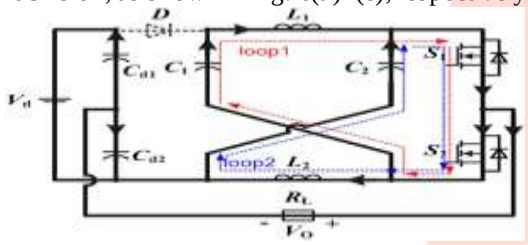


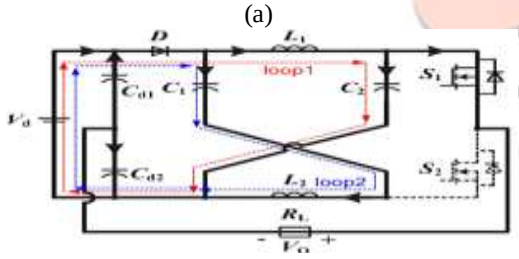
Fig. 5. Equivalent circuits in case 1. (a)S1on andS2off. (b)S1off and S2off. (c)S1off andS2on

B. Case 2:D1+D2>1

In this case, the behavior of the switches in the circuit leads to three modes within a switch period T, which correspond to three linear equivalent circuits: Mode 1, when S1 andS2 are on; Mode 2, whenS1is on andS2is off; and Mode 3, whenS1 is off andS2is on, as shown in Fig. 6(a)–(c), respectively.



(a)



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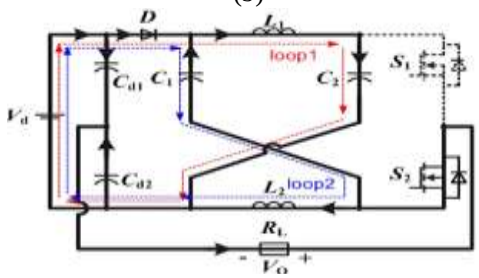

(c)

Fig. 6. Equivalent circuits in case 2. (a) Mode 1: S1 on and S2 on. (b) Mode 2: S1 on and S2 off. (c) Mode 3: S1 off and S2 on.

In the steady state of the converter, its operation process in a switch period is analyzed in the following, and the output voltage vo will be deduced in each mode.

1) Mode 1:t∈[t0,t1]: As shown in Fig. 6(a), in loops 1and 2, capacitorsC1andC2discharge the energy to inductors L1andL2; thereafter, iL1 andiL2 increase. Thus, L1andL2 store the energy, and one has

$$\begin{cases} v_{L_1} = v_{C_1} \\ v_{L_2} = v_{C_2} \end{cases} \quad (1)$$

whereiL1, iL2, vL1, vL2, vC1, and vC2are the currents ofL1 andL2and the voltages ofL1,L2,C1, andC2, respectively. The voltage of diode Dis −(vC1+vC2−Vd), so Dundertakes negative voltage stress and, thus, turns off. The energy ofC2 is delivered to the load RLandCd2 through the C2−RL−Cd2loop, soCd2charges andCd1discharges. In terms of theC2−RL−Cd2loop, the output voltage of the converter reads

$$v_O = v_{C_2} - v_{C_{d2}} \quad (2)$$

wherevCd2 is the voltage ofCd2. 2) Mode 2:t∈[t1,t2]: As shown in Fig. 6(b),S1is on, and S2is off. In loop 1, the sourceVdandL1discharge the energy to C2, so that vC2 increases. In loop 2, the source VdandL2 discharge the energy toC1; thereafter,vC1 increases. Then, the energy ofC2is delivered to the load RLandCd2through the C2−RL−Cd2loop, so Cd2charges andCd1discharges. From loop 1, one has

$$v_{L_1} = V_d - v_{C_2} \quad (3)$$

In terms of theC2−RL−Cd2loop, the output voltage of the converter is the same as that in (2). Mode 3:t∈[t2,t3]: In Fig. 6(c), S1 is off, and S2 is on. In loop 1, the source Vd andL1 discharge the energy toC2; thus, vC2 increases. In terms of loop 1, one has the same equation as (3). In terms of theVd−D−C1−RL−Cd2loop, the output voltage i

$$v_O = -\left(v_{C_{d2}} + v_{C_2} - V_d\right) \quad (4)$$

As a result, vocan be deduced as follows. The voltage–second characteristic ofL1leads to

$$\int_0^T v_{L_1} dt = 0 \quad (5)$$

Substituting (1) and (3) into (5) leads to

$$(D_2 + D_1 - 1)T_{vC_1} + (2 - D_2 - D_1)T(V_d - vC_2) = 0 \quad (6)$$

Assume thatL1=L2, C1=C2, and C1 andC2 are large enough. Due to the structural symmetry of the Z-network, (6) can be rewritten as

$$v_{C_1} \approx v_{C_2} = \frac{2 - D_1 - D_2}{3 - (D_1 + D_2)} V_d \quad (7)$$

The ampere–second property ofCd2implies that

$$\int_0^T i_{C_{d2}} dt = 0 \quad (8)$$

whereiCd2 is the current ofCd2. Denote the voltage and current ofCd1byvCd1 and iCd1

,respectively. It is known from Fig. 6 thatvCd1+vCd2=Vd. Due to Vd being a constant, one has ΔvCd1=−ΔvCd2 , and straightforwardly,iCd1=iCd2 in terms ofi=Cdu/dt. Moreover, from io=iCd1+iCd2 , one has iCd2 =io/2where io is the current of the load; thereafter, (8) can be rewritten as

$$\frac{\left(v_{C_2}-v_{C_{d2}}\right)}{2R_L}D_1T+\frac{-\left(v_{C_2}+v_{C_{d2}}-V_d\right)}{2R_L}(1-D_1)T=0 \quad (9)$$

and it follows that

$$v_{C_{d2}}=\left(2v_{C_2}-V_d\right)D_1-v_{C_2}+V_d \quad (10)$$

When switchS1 is on, substituting (7) and (10) into (2) results in the positive output of the convertervpas

$$v_p=v_o=v_{C_2}-v_{C_{d2}}=\frac{(1-D_1)}{3-2(D_1+D_2)}V_d \quad (11)$$

When the switchS2is on and S1is off, substituting (7) and (10) into (4) leads to the negative output of the converter nas

$$v_n=v_o=v_d-v_{C_2}-v_{C_{d2}}=-\frac{D_1}{3-2(D_1+D_2)}V_d \quad (12)$$

According to (11) and (12), the relationships ofD1, D2, and vo/Vd are drawn in Fig. 7.

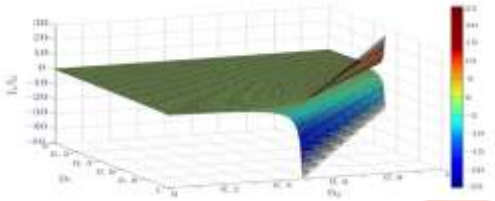

Fig. 7. Relationship figure ofD1,D2,and vo/Vd

There in,vo/Vd increases dramatically asD1+D2is about 1.5, which is zoomed in in Fig. 8. When vo/Vd<1, the converter functions as a buck converter; otherwise, the converter acts as a boost converter.

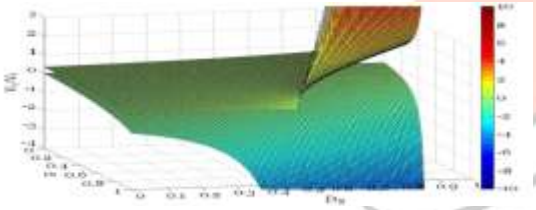

Fig. 8. Zooming in of Fig. 7.

Therefore, it is a buck–boost converter. By controlling the duty of the switches, special output voltages can be obtained, including the buck–boost voltages, asymmetric and symmetric voltages, positive and negative peak output voltages, and the time ratio between positive and negative voltages.

Additionally, according to (11) and (12), the values of vp and vn are not equal whenD1=0.5, but they are equal whenD1= 0.5, which will be explained hereinafter. First, whenD1=0.5, the key waveforms of the Z-source half-bridge converter in case 2 are drawn in Fig. 9

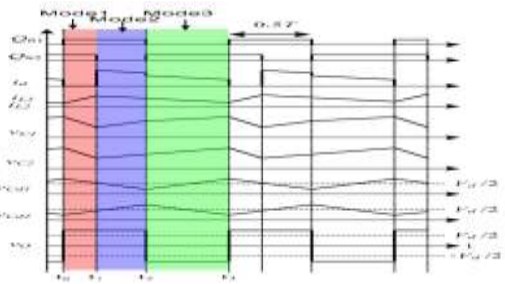

Fig. 9. Key waveforms of the Z-source half-bridge converter in case 2 when D1=0.5andD2=0.7

According to the analysis for three modes, whereQS1 andQS2 stand for the driving voltages of switchesS1andS2, respectively Vd/2and−Vd/2are marked at the output voltage waveform vo, and it is shown that the output voltages of the proposed converter can exceed the limited one. Second, the corresponding waveforms for D1=0.5 are shown in Fig. 10. Here, the conduction and switching loss is taken into account, which is indicated in Pin −Pout.

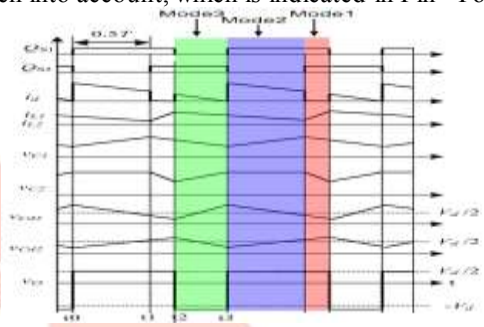

Fig. 10. Waveforms of the Z-source half-bridge converter in case 2 when D1=0.7andD2=0.5

III. MIDPOINTBALANCE OFINPUTCAPACITORS

The stability of the midpoint voltage in the converter plays a key role for the system's stability. The midpoint voltages of the input capacitors in the conventional converter and the proposed converter will be analyzed and compared in this section.

A. Midpoint Voltage in Conventional Half-Bridge Converters

In this section, the midpoint voltage in conventional half-bridge converters will be analyzed, and the fluctuation equation of the midpoint voltage will be deduced. Fig. 11 shows the equivalent circuits of that in Fig. 1.

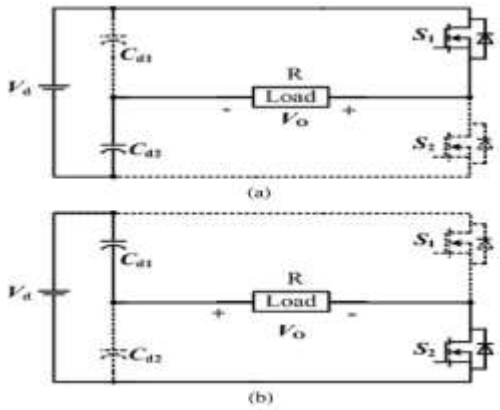

Fig. 11. Equivalent circuits of the conventional half-bridge converter. (a) Mode 1:S1on andS2off. (b) Mode 2:S1off andS2on.

In a switching period,S1is on andS2is off ast∈[0,D1T], while S1is off andS2is on ast∈[D1T,T]. Denote the initial voltage ofCd2 byVCd20. In terms of the Kirchhoff's voltage law (KVL), vCd2 can be derived in frequency domain as

$$v_{C_{d2}}(s) = \frac{V_d}{s} - \frac{V_d - v_{C_{d2}0}}{s + \frac{1}{v_{C_{d2}R}}} \quad (13)$$

Employing Laplace inverse transformation to (14) results in

$$v_{C_{d2}}(t) = V_d - \left(V_d - v_{C_{d2}0}\right)e^{-\frac{t}{C_{d2}R}} \quad (14)$$

Denote the maximal and the minimal voltages ofvCd2 by vCd2maxandvCd2min, respectively, and the maximal fluctuation ofvCd2 byΔV. Following (15), one has

$$\Delta V = v_{C_{d2}}max - v_{C_{d2}}min = \left(V_d - v_{C_{d2}0}\right)\left(1 - e^{-\frac{D_1 t}{C_{d2}R}}\right) \quad (15)$$

In the high-frequency power supply, T is always very small, the input capacitance Cd2 is always quite large, particularly in electrochemical application, and its load is very large. Thus, D1T is much smaller than Cd2R, and (16) can be approximated by

$$\Delta V \approx \frac{D_1 t}{C_{d2}R}\left(V_d - v_{C_{d2}0}\right) \quad (16)$$

B. Midpoint Voltage in Z-Source Half-Bridge Converters

It is described in [29] that the input part can be regarded as a dc voltage source or a dc current source due to the Z-network. Similarly, the output part of the Z-network can be treated as a dc current source. Hence, the equivalent circuits are derived as follows.The differential equation of the circuit shown in Fig. 12(a) can be described as

$$C_{d2}\frac{dv_{C_{d2}}}{dt} = I_P \quad (17)$$

whereIpis the current of the constant current source. Integrating both sides of (18) leads to

$$v_{C_{d2}}(t) = v_{C_{d2}0} + \int \frac{I_P}{C_{d2}}dt \quad (18)$$

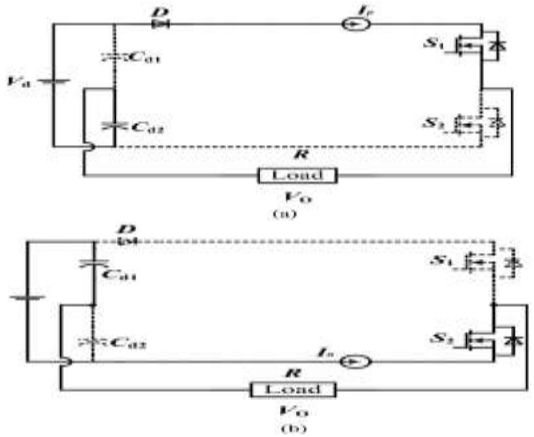

Fig. 12. Equivalent circuits of the Z-source half-bridge converter. (a) Mode 1: S1on andS2off. (b) Mode 2:S1off andS2on

Ipcan be derived by Kirchhoff's current law (KCL) as

$$I_P = \frac{V_d - v_{C_{d2}0} - V_{Ip}}{R} \quad (19)$$

Where VIp is the voltage of the constant current source. Substituting (21) into (20) leads to

$$\Delta V_Z = D_1 T \frac{V_d - v_{C_{d2}0} - V_{Ip}}{C_{d2}R} \quad (20)$$

Therein, the ratio of ΔVZ to ΔV can be derived from (17) and (22) as

$$\frac{\Delta V_Z}{\Delta V} = \frac{V_d - v_{C_{d2}0} - V_{Ip}}{V_d V_{C_{d2}0}} * 100\% \quad (21)$$

It is obvious that ΔVZ<ΔV, if VIp is positive; the smaller the ΔVZ/ΔV is, the smaller the ripple in the proposed converter is and, consequently, the more stable the proposed converter is.

IV. PARAMETERDESIGN

The parameters of the Z-network are designed in this section, including capacitor and inductance parameter design.

A. Parameter Design of the Capacitor in the Z-Network

Normally, the design of the capacitor is to determine the rated voltage and capacitance with a permitted fluctuation range xC% (xC is preassigned), a given output voltage Vo, a given output current Io, and a given switching period T. From (7), (11), and (12), one has

$$v_{C_2} = \frac{2 - D_1 - D_2}{D_1}V_O \quad \text{when } (S_1)=(\text{on}) \quad (22)$$

$$v_{C_2} = \frac{2 - D_1 - D_2}{1 - D_1}V_O \quad \text{when } (S_1, S_2)=(\text{off, on}) \quad (23)$$

Denote the rms currents ofL2 and C2 byIL2 and IC2, respectively. Then, from , one has

$$I_{C_2} \approx I_{L_2} = \frac{I_0}{2} \quad (24)$$

1) Determination of the Rated Voltage: The range ofvC2 is determined by (24) and (25). Thereby, the rated voltage of C2can be determined by the maximalVC2M. Considering the safety margin, the rated voltage ofC2is normally set between 1.5VC2Mand2VC2M.

2) Determination of the Rated Capacitance: The ripples of the capacitors have great influence on the

stability of the converter, whose permitted fluctuation range can be used to design the capacitance.

The high harmonic frequency of the capacitance is nearly equal to the switching frequency of the converter, as shown in Fig. 9, namely,

$$dt \approx (D_1 + D_2 - 1)T \quad (25)$$

Denote the permitted error ofVC2MbydvC2 , according to the permitted fluctuation rangexC%;dvC2 is expressed as

$$dv_{C_2} = xc\%v_{C_2}M \quad (26)$$

Substituting (27), (29), and (30) into (28) leads to

$$C_2 = \frac{I_0(D_1+D_2-1)T}{2xc\%v_{C_2}M} \quad (27)$$

B. Parameter Design of the Inductor in the Z-Network

Similar to the parameter design of the capacitor, the parameter design of the inductor is to determine the rated current and capacitance with a permitted fluctuation range xL% (xL is pre assigned), a given output voltage Vo, a given output current Io, and a given switching period.

1) Determination of the Rated Current: IL2 can be determined by (27). Considering the safety margin, the rated current ofL2is normally taken as2IL2

2)Determination of the Rated Inductance: The ripples of the inductors also have great influence on the stability of the converter; therefore, the inductance can be designed in terms of the permitted ripples. The inductances in the Z-network can be designed according to the differential equation of inductance

$$L_2 = \frac{vL_2\,dt_L}{di_{L_2}} \quad (28)$$

In theL1−C2−L2−C1loop, the KVL equation can be expressed asvL2+vC1 =vL1+vC2 so the Z-network, the rms voltages ofC1, C2, L1, and L2are denoted byVC1, VC2, VL1,andVL2, respectively, and one has vC1 ≈VC2 andVL2 ≈VL1. Thereby, the maximum ofvL2 is derived a

$$V_{L_2M} \approx V_{C_2M} \quad (29)$$

Denote the permitted error ofIL2 bydiL2. According to the permitted fluctuation rangexL%, diL2 is expressed as

$$L_2 = \frac{2V_{C_2M}(D_1+D_2-1)T}{xL\%I_0} \quad (30)$$

Substituting (24), (25), (27), and (33)–(35) into (32) leads to the inductance ofL2

$$diL_2 = xL\%I_{L_2} \quad (31)$$

PV SOURCE

Photovoltaics (PV) covers the conversion of light into electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon studied in physics, photochemistry, and electrochemistry. The dynamic model of PV cell is shown in below Fig.13.

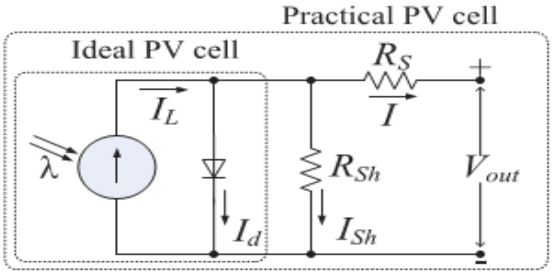

Fig 13.Equivalent electrical circuit of the PV cell.

The basic equation describing the I -V characteristic of a practical PV cell is

$$I = I_L - I_d - I_{sh} = I_L - I_D\left[e^{\frac{QV_{oc}}{AKT}-1}\right] - \frac{V_{out}+IR_S}{R_{Sh}} \quad (27)$$

where I D is the saturation current of the diode, Q is the electron charge, A is the curve tting constant (or diode emission factor), K is the Boltzmann constant and T is the temperature on absolute scale.

V. SIMULATION RESULTS

To verify the feasibility and validity of the proposed converter, Simulink software is applied for the simulation of the converter. The pre assigned parameters are as follows: xC%=1%,xL% = 10%, Vd=48V,Vo= 100V,Io=10A, and T= 20μs. According to the design, the parameters of the converter can be calculated:C1=C2= 482.5μF andL1=L2= 105.5μH. However, in practice, the parameters can be chosen as follows:C1=C2= 470μF andL1=L2= 100μH

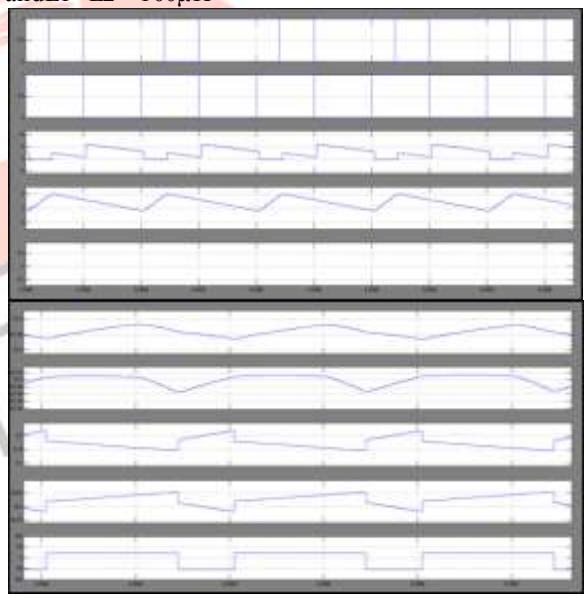

Fig. 14. Simulation waveforms whenD1=0.5andD2=0.7

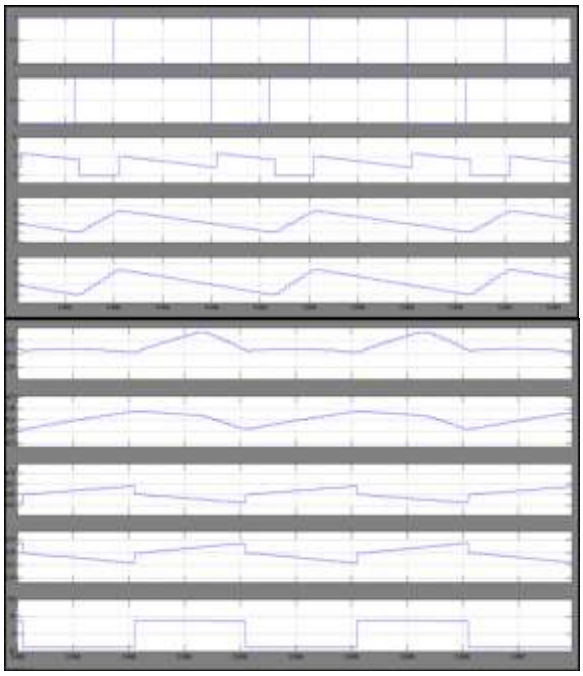

Fig. 15. Simulation waveforms whenD1=0.7andD2=0.5.

The simulation results are shown in Figs. 13 and 14, which are consistent to the theoretical analyses shown in Figs. 9 and 10.

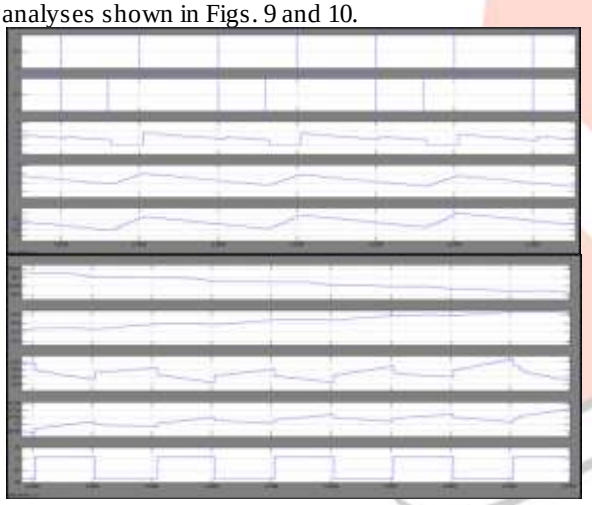

Fig :16 simulation waveform with pv when D1=0.5 and D2=0.7

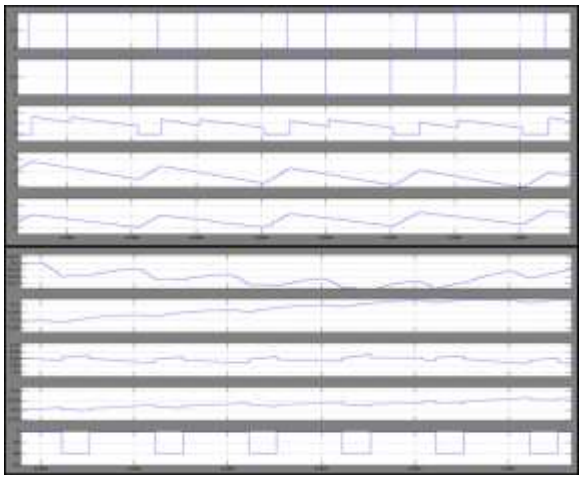

Fig :17 simulation waveform with pv when D1=0.7 and D2=0.5

VI. CONCLUSION

This paper proposes a Z-source half bridge converter for a photovoltaic application. This paper presents the improved performance of the Z-source half bridge converter. These are the following advantages of existing half bridge converter over the proposed Z-source half bridge converter. 1 Proposed topology can be able to operate for the resistive and the inductive load. 2 Proposed topology also capable for the photovoltaic application. the converter has been analyzed in two different states, including the shoot-through and non-shoot-through states. Furthermore, the feature of the proposed converter owning abundant outputs under an appropriate control is very desirable for requirements of the electrochemical power supply. By using the simulation results we can analyze the proposed method.

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