Hybrid Power System with A Two-Input Power Converter

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Abstract: - An isolated two-input power converter for hybrid power supply systems is proposed in this paper. The proposed converter is derived from the integration of a forward converter and a Cuk converter. The grid and solar energy are used as the two input power sources. The power flow of each energy source can be independently controlled. Also, the proposed converter can be operated with single power source or dual power sources. Once the maximum available solar power is insufficient for the load, the converter would automatically complement the power demand by drawing power from the grid side. A prototype system is constructed and some experiments are carried out to evaluate the validity and performance of the proposed two-input power converter. From the experimental results, one can see that the proposed converter can provide a stable output with 90V /3.85A and the efficiency is about 90%.

Key-Words: -Two-input power converter, Hybrid power supply, solar energy.

1. Introduction

The available power of green energy sources varies with the seasons and the weather. Therefore, to provide a stable power, another power source is always required. Two of the most popular green energy systems are the grid-connected system and stand-alone system. The cost of the inverter of the grid-connected system is relatively high. The lifetime and maintenance issues of the battery tank in the stand-alone system are always the most important problems. Therefore, to avoid using the costly inverter and battery tank, various multi-input converters are recently studied.

The topology of multi-input converter structure can be divided into inductive circuit architecture, capacitive circuit architecture, and multi-winding circuit architecture [1]-[6]. The inductive and capacitive architectures use the energy storage component as the main circuit component for integrating multiple input power sources.

In the multi-winding circuit architecture, the input power sources are integrated by a multi-winding transformer. In the primary side of the transformer, the number of turns of each windings is designed individually with respective to the specifications of the input power sources. [7]-[10]. The input power sources and the output side are then isolated to each other. However, self-inductance, mutual inductance, and leakage inductance between windings need to be considered in the design of the multi-winding transformer which will result in difficulty of the parameter design.

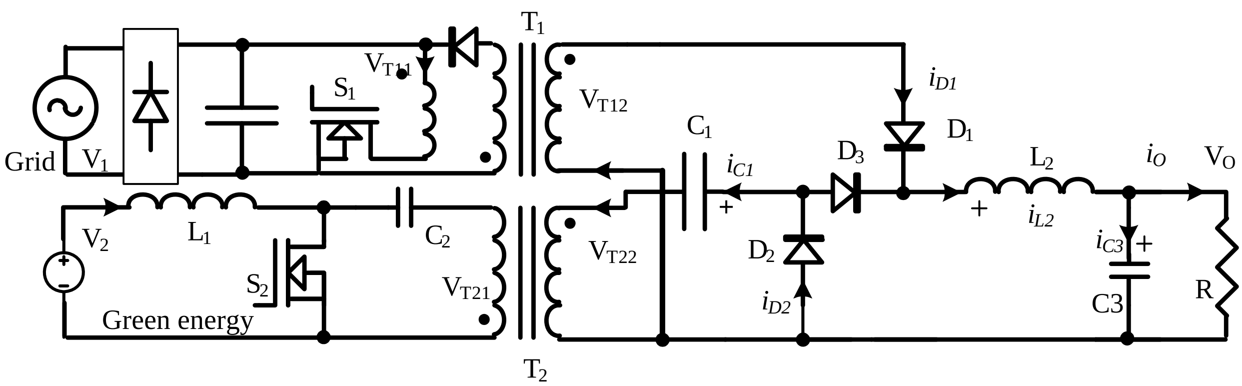


Figure 1. The Proposed Isolated Two-input Power Supply Circuit Architecture

Therefore, this paper aims to develop a grid complementary power supply system, with a two-input converter circuit topology integrated with green energy and the grid supply. The power supply system proposed in this paper integrates inductance circuit topology with forward converter and Cuk converters, and can be operated in the single power supply operating mode or the hybrid power supply operational mode. In the prototype system, grid and solar power are converted and delivered to the dc output for lighting up a high-luminance LED module. When the available power from the green energy is not enough, the grid would automatically complement the load demand.

2. Operation Principle of the Proposed Converter

The isolated two-input power converter proposed in this paper combines a forward converter with a Cuk converter and integrates their circuit topologies to reduce the number of components. Fig.1 shows the isolated two-input power supply circuit architecture. According to Fig.1, Grid power supply V1 is the mains supply, which is converted into DC power by a full-bridge diode rectifier, and connected in parallel to Cuk converter through power switch S1 and transformer T1. The input power supply V2 is controlled by power switch S2, and delivers the power to the load via capacitors C1,C2 , transformer T2 and inductor L1.

In the hybrid power supply mode, the system is controlled by switch S1 and switch S2 in the meantime. While the two active switches are controlled with interleave phase shift technique, there would be five operation modes in one switching cycle as shown in Fig.2. In order to simplify the analysis of the operation principles, the system is assumed operated in hybrid power supply mode and the output power is provide 50% from the grid and 50% from the green energy. The waveform of the major components and various points of the circuit are shown in Fig.3. The operation of the circuit in each mode is described as follows:

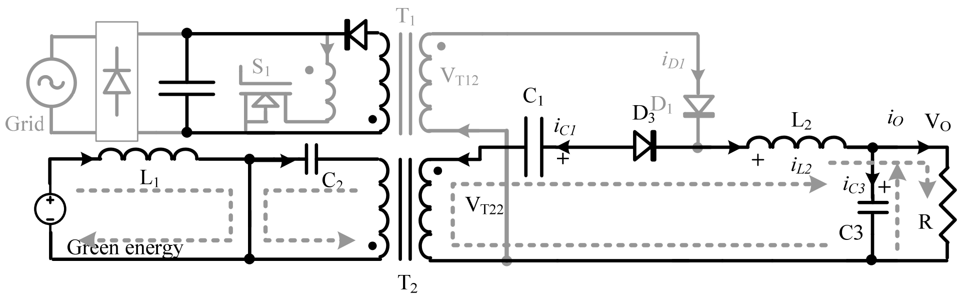
Model1 — (t0 ≦ t<t1) ： In this operating mode, switch S2 is turn-on and S1, D1, D2 are turn-off, the corresponding circuit state is shown in Fig.2(a). The energy in inductors L1 and L2 are both increased, and capacitors C1, C2 and C3 are in discharging condition.

Model2 — (t1 ≦ t<t2) ： In this operating mode, the operations of switches S1 and S2 and diodes D1 and D2 remain unchanged, the corresponding circuit state is shown in Fig.2(b). The current of inductors L1 and L2 increases gradually, capacitors C1 and C2 remain unchanged, C3 is in charging state.

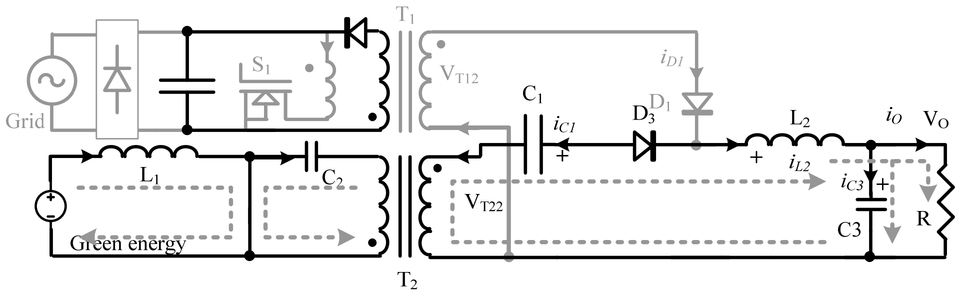
Model3 — (t2 ≦ t<t3) ： In this operating mode, the operations of switch S1 and diodes D1 and C3 remain unchanged. However, S2 changes to the turn-off state, and the corresponding circuit state is as shown in Fig.2(c). The inductors L1 and L2 change to energy releasing operation. Capacitors C1 and C2 change to energy storing state, and diode D2 is turned on.

Model4 — (t3 ≦ t<t4) ： In this operating mode, the operations of switches S1 and S2, diodes D1 and D2, and inductors L1 and L2 remain unchanged, the corresponding circuit state is as shown in Fig.2(d); the terminal voltage of inductor L2 is decreased in this mode, and the capacitor C3 changes to discharging operation.

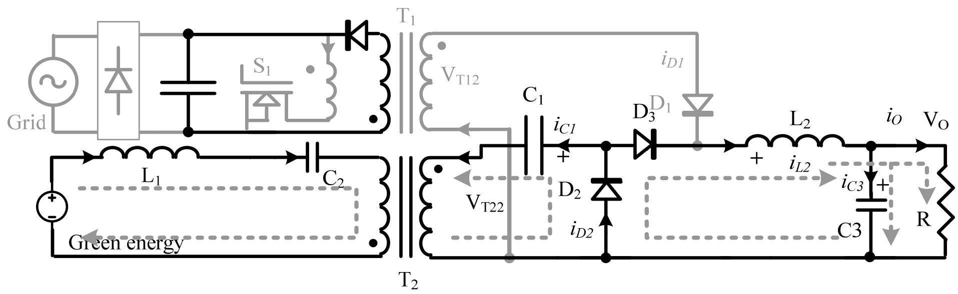
Model5 — (t4 ≦ t<t5) ： In this operating mode, switch S1 is turned on, operation of S2 is unchanged, diode D1 is turned on, and the corresponding circuit state is as shown in Fig.2(e). The current of iD1 gradually increases and flows to the inductors L2. In this mode, the current of inductors L2 increases gradually, the current of iD2 gradually approaches to zero. This operation mode would be ended while the active switch S1 is turned off and then the operation mode would be recycled to mode 1.



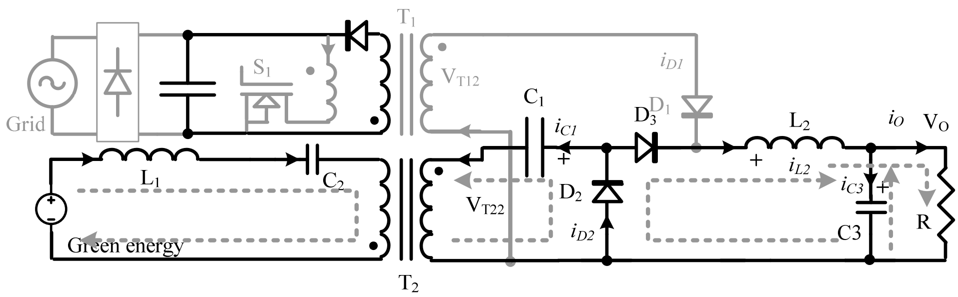
(a) Model 1



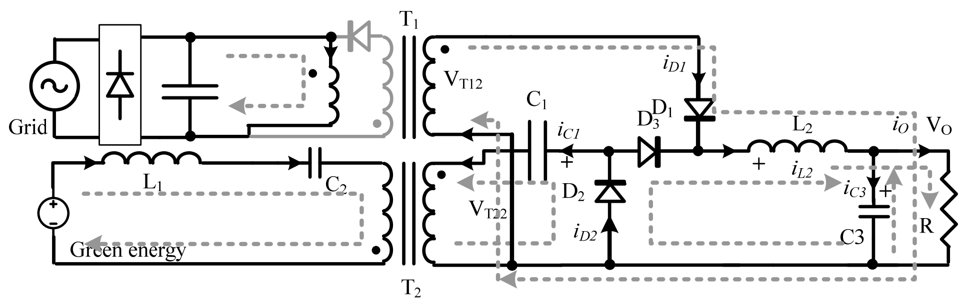
(b) Model 2



(c) Model 3



(d) Model 4



(e) Model 5

Figure 2. Equivalent Circuits of the Proposed Converter in different Operation Modes

3. Control Algorithm of Proposed System

One of the main characteristics of the circuit proposed in this paper is that the system can be operated in single power supply mode or hybrid power supply mode. When the available power from the green energy supply is sufficient, the solar energy is used for full load power supply. Once the available renewable power is not enough, the lack of electric power is supplemented by grid supply to stabilize the electric power for the load.

The controller is implemented by a micro-processor, HT46R23, and the diagram of the microprocessor is shown as Fig.4. Basically, any kind of the current controlled maximum power point track (MPPT) method can be directly applied in the proposed system. In the constructed prototype system, a well-known perturbation and observing MPPT is adopted. If the power supply capacity of solar energy is higher than the load consumption, the microprocessor will control the circuit operation in solar power supply mode. If the power from solar energy is insufficient for load, the microprocessor will then change the circuit operation to hybrid power supply mode. If the solar energy is unavailable, the operation is changed to grid power supply mode, and the grid supply provides full power for the load to maintain stable power output.

The system operation flow chart of the microprocessor is as shown in Fig.5. When the power from solar energy is insufficient, the grid power supply supplements the power to the rated power through the two-input power converter. When solar energy can supply adequate electric power, the grid power supply does not supplement service power. When the solar energy is failed, the grid power supply supports full power.

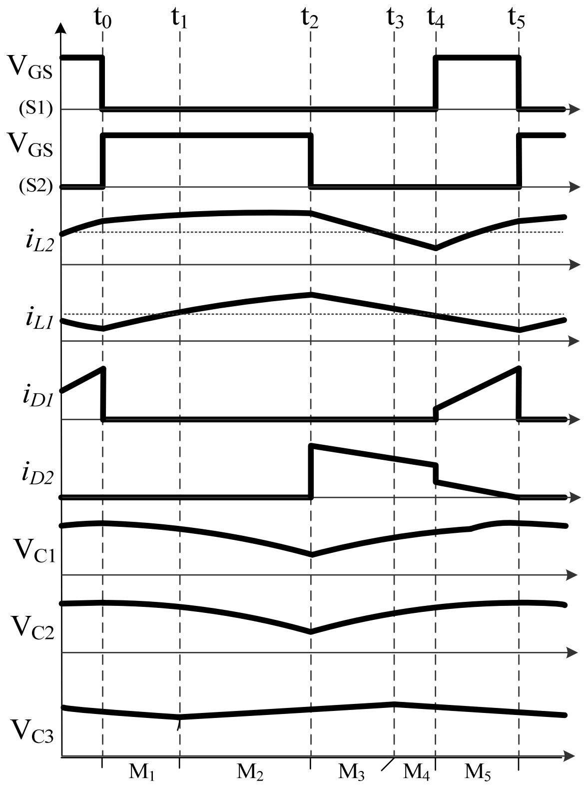


Figure 3. Relative Waveforms in one Switching Cycle

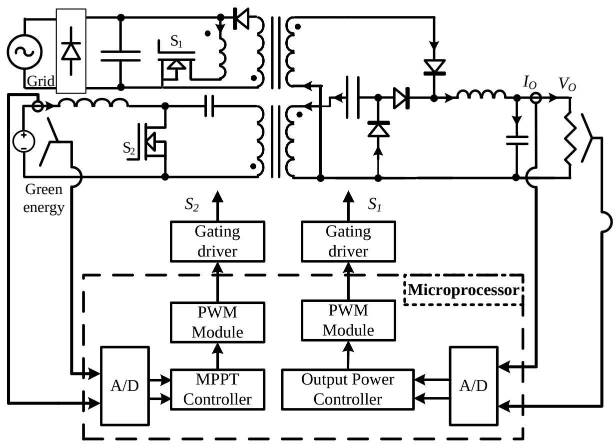


Figure 4. Controller Diagram for Proposed Hybrid Power System

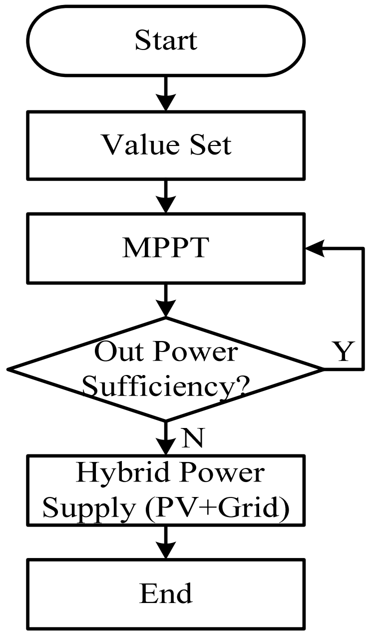


Figure 5. The Flow Chart of the Microprocessor Operation

4. Experiment Results

A prototype hybrid power system with the proposed two-input power converter is constructed to verify the performance and validity. The relative parameters of the prototype system are shown in Table 1. The green energy supply side consists of 6 pieces of 24V solar cells which is series-connected to provide 144V dc voltage source. The dynamically measured waveforms of output and input supply voltage, and current of the isolated two-input switching circuit in hybrid power supply mode are shown in Fig.6. Fig.6(a) shows the measured waveforms of input power supplies V1 (Grid) and V2 (PV).

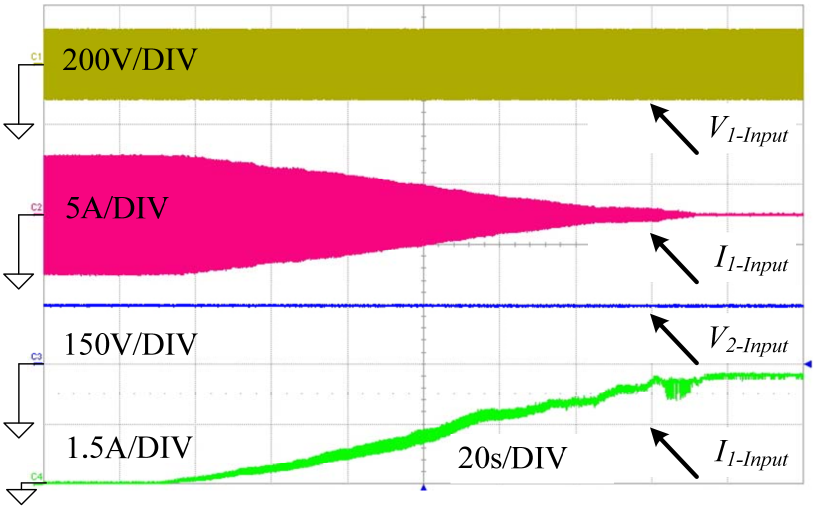
The measurement condition is that the grid power supply provides power when the system circuit is starting and then the solar power is gradually increased. The system therefore reduces the electric energy of grid power supply in order to maintain stable output. Fig.6(b) shows the output voltage and current waveforms of the system operated in hybrid power supply mode. It is observed that the circuit can provide 90V/ 3.85A dc output power. According to the experimental results, the system circuit developed in this paper can be operated in single power supply mode or hybrid power supply mode. When the power supply of green energy is insufficient, the main supply can supplement electric energy to maintain stable output power.

TABLE 1. The Circuit Design Parameters

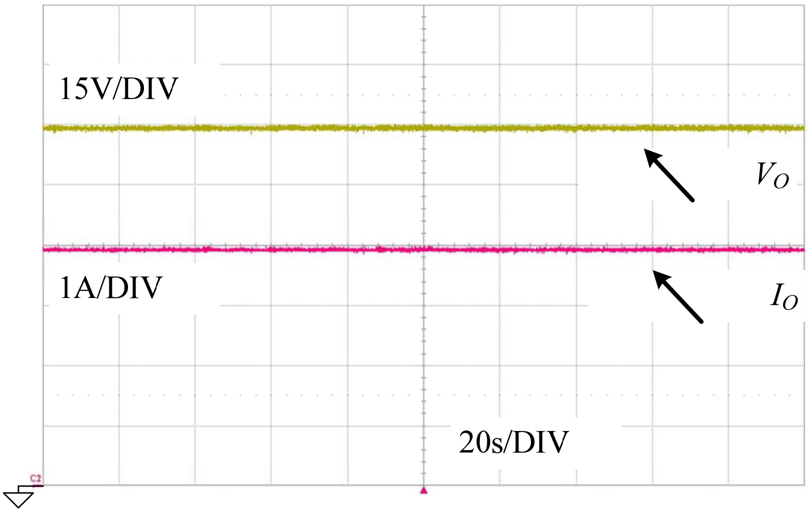
Title	Number	Parameter
Power Source	V1	*AC110 V/60 Hz*
	V2	*144 VDC(24 V*6)*
Indication	L1, L2	*500uH*
Capacitor	C1	*6uH*
	C2	*1uH*
	C3	*220uH*
Transformer	T1,T2	*EE42*
	T1P,T2P	*55N*
	T1S,T2S	*35N*
Switching Frequency	-	*93.25 kHz*

When the system circuit is operated in grid power supply mode, the measured waveforms of the voltage and current of the power switch S1 are shown in Fig.7(a). It is observed that the maximum duty ratio of power switch S1 is 40%, and the switching frequency is 38.4kHz. The voltage stress Vdc of the switch is slightly higher than the input voltage, and the maximum peak of current is 10.4A. When the circuit is operated in green energy supply mode, the measured waveforms of voltage and current of power switch S2 are shown in Fig.7(b).

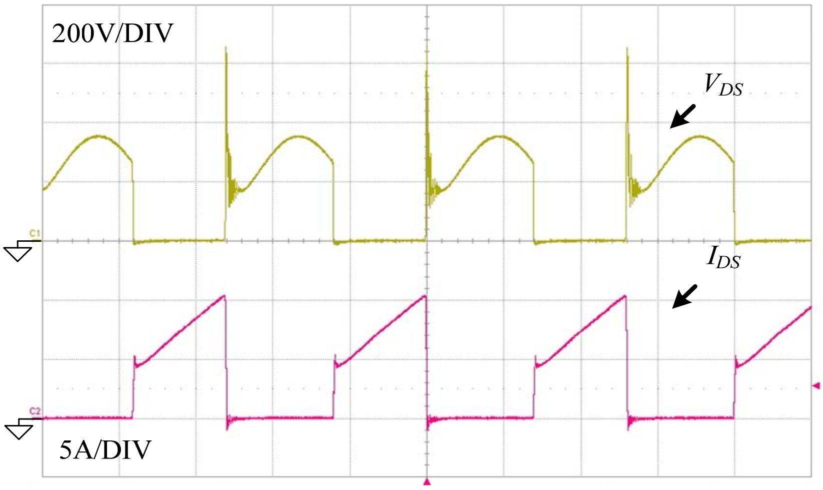
It is observed that the maximum duty cycle of power switch S2 is 57%, the switching frequency is 38.4 kHz, and the maximum current peak value of IDS is 6.7A. In the hybrid power supply mode, the measured waveforms of voltage and current of power switches S1 and S2 are shown in Fig.7(c). According to Fig.7(c), the switch S1 and S2 of the circuit control in this paper are controlled for the interleave phase shift technique. It is observed that the duty cycle of power switch S1 is 24.3%, and the duty cycle of power switch S2 is 30.2%, and the switching frequency is 38.4kHz. In the hybrid power supply operating mode, the peak current of power switch S1 is 7.5A, the peak current of power switch S2 is 4A, and the maximum current stress of the switch is lower than that in the single power supply operating mode.



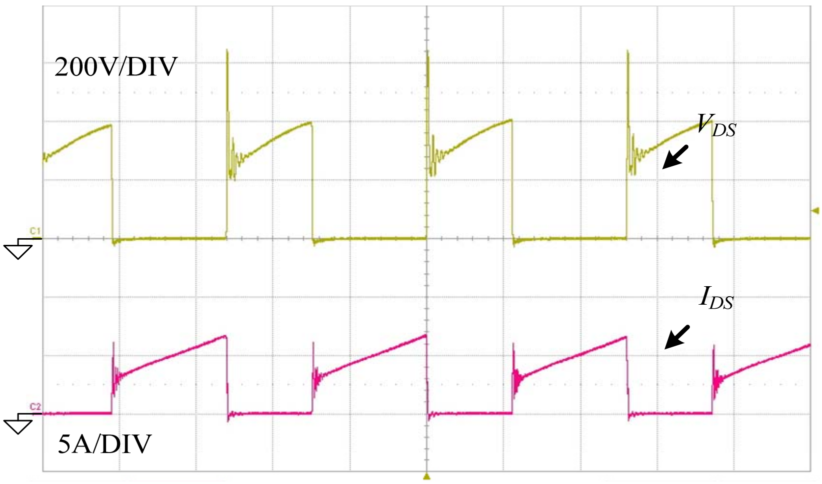
(a)Waveform of Input Power Supplies



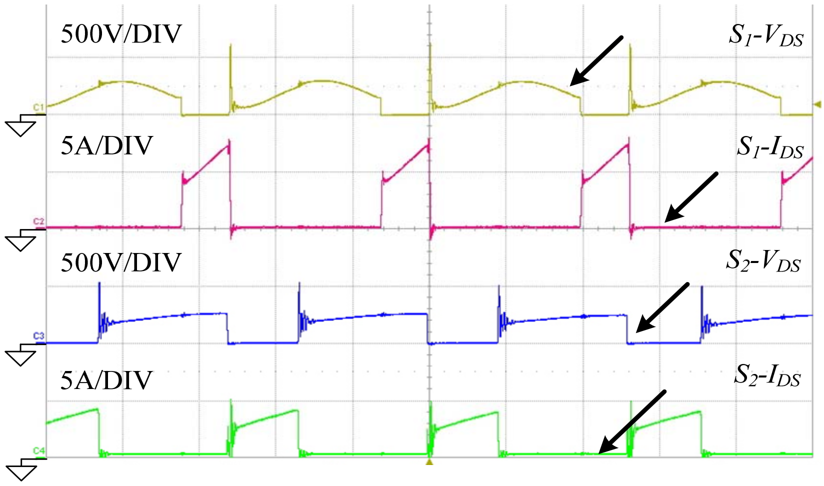
(b) Waveform of Output Voltage and Current
Figure 6. Dynamically Measured Waveform



(a) The Switch S1 (grid power supply mode)



(b) The Switch S2 (solar power supply mode)



(c) The Switch S1 and S2 (hybrid mode)

Figure 7. Measured Waveform of the Voltage and Current of the Power Switch S1 and S2

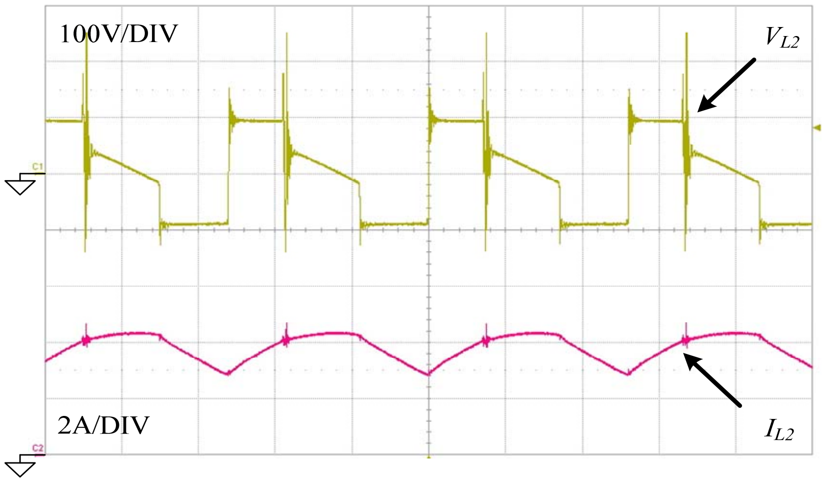


Figure 8. Measurement Waveform form of the Inductance L2

Fig.8 shows for the voltage and current measurement waveforms of the inductance L2 in hybrid power supply mode. Each input power sources provide half the load demand. According to the measurement results, the single power supply mode and the efficiency characteristic curve are shown in Fig.9. When the system is operated in hybrid power supply mode, the power conversion efficiency is calculated by the equation expressed as Eq. (1). Fig.10 shows the efficiency curve in hybrid power supply mode.

$$Efficiency = \frac{P_O}{P1_{in} + P2_{in}} \quad (1)$$

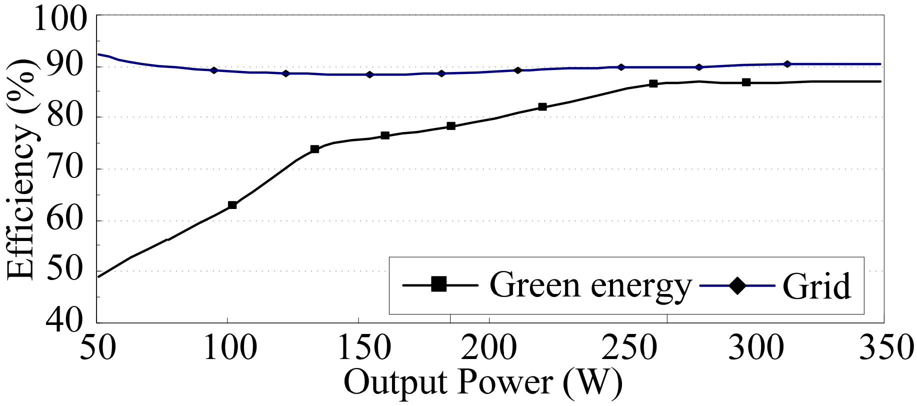


Figure 9. The Efficiency Characteristic Curve of Single Power Supply Mode

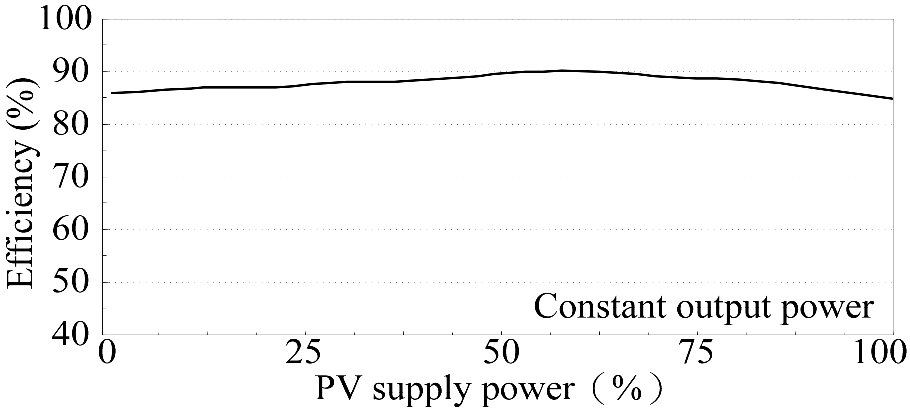


Figure 10. The Efficiency Characteristic Curve of Hybrid Power Supply Mode

5. Conclusion

The system circuit topology proposed in this paper integrates a forward converter with a Cuk converter for converting the grid power and green energy into DC output power. The system uses a microprocessor as the control unit, and it can be operated in single power supply-greed energy supply operating mode, single power supply-grid supply operating mode, and hybrid power supply mode. The optimum efficiency of the system operated in grid power supply mode of single power supply is 91%; the optimum efficiency operated in the solar energy supply mode of single power supply is 86%; and the optimum working efficiency of the circuit in the hybrid power supply mode is 90%.

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