Research on a Multi-Energy complement system based on Solar Power

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***Abstract*—Under the circumstance of the depletion of coal and oil, We have to focus on renewable energy sources especially the solar energy. Since the output power of the photovoltaic cells is affected by the intensity of the light and the external environment, it is necessary to use backup power. In this paper, photovoltaic cells, batteries and the grid are combined at the same time, and a multi-energy complement system is proposed. For different external environments, an energy management strategy with five work modes is proposed to enable the system to operate stably under any circumstances.**

***Index Terms*--photovoltaic, multi-energy complement system, energy management strategy , five work modes**

I. THE SOLAR ENERGY

In recent years, China's new energy industry has continued to grow and develop which has become an important force in promoting energy transformation and development. The "Energy Production and Consumption Revolution Strategy" points out that the modern energy system will be initially constructed in 2030 when non-fossil energy generation will strive to reach 50%[1].With the development of photovoltaic cells and power electronics technology, the application of solar power has become more and more extensive, and the solar energy system has become the focus of the renewable energy research in many countries.

II. THE MULTI-ENERGY COMPLEMENT SYSTEM BASED ON SOLAR POWER

The independent renewable energy power system has disadvantages such as high volatility, high cost and environmental constraints. Considering the reliability, flexibility and economy of the renewable energy power system, research on the multi-energy complement system is the future trend. The multi-energy complement system using solar energy is the most widely used at present. Literature [2-4] is an independent photovoltaic system which combines photovoltaic cells with storage batteries. Literature[5-8] describes the supplementary power supply of wind and solar energy. In literature[9,10], a power generation system that combined wind energy, solar energy with hydropower has been introduced.This paper proposes a multi-energy complement system based on solar power. Meanwhile, the system use the battery and and the grid as backup power. The working process is roughly as follows: in normal operation, both the solar energy and the battery work, the power is supplied to the load after the DC(direct current) power is converted to AC(alternating current) power.When neither the solar energy nor the battery can output the rated power required by the load, the utility continues to supply power to the AC load as a backup energy source.

A. The topology of the system

The multi-energy complement system based on solar power consists of three energy sources which are photovoltaic arrays, batteries and the grid and three energy conversion units which are DC conversion unit, invert unit and switch unit, as shown in Figure 1.

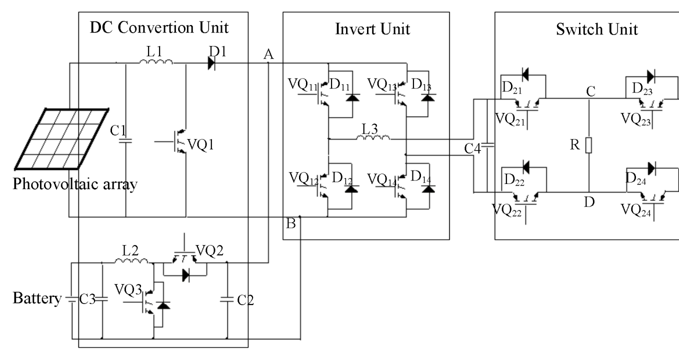

Figure 1. The topology of the multi-energy complement system based on solar power

B. Five work modes of the system

- The first work mode:

When the load is supplied power by the solar energy and the battery, the Boost circuit works in MPPT(Maxium Power point tracking) mode. The bidirectional Buck-Boost circuit works in Boost mode or in Buck mode.The direction of energy flow is shown in the figure2.

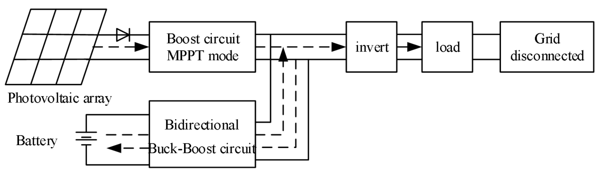

Figure 2. The first work mode of the system

- The second work mode:

If the solar energy continues to charge the batteries, the charging voltage will be too high (>220V). Therefore, the boost circuit must be switched from the MPPT mode to the constant voltage mode to trickle charge the battery. At the same time, the boost circuit will adjust its duty ratio and maintain the voltage output on as a stable voltage value (about 400V).The direction of energy flow is shown in the figure3.

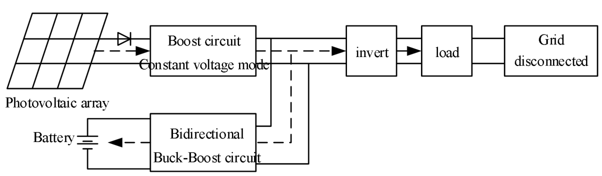

Figure 3. The second work mode of the system

- The third work mode:

When the voltage of the photovoltaic cells is less than the minimum value under the rainy or nighttime conditions, the boost circuit will not work and the bidirectional buck-boost circuit works in Boost mode. The batteries will separately supply power to the load. The direction of the energy flow is shown in the figure 4.

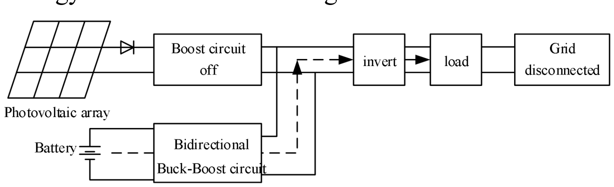

Figure 4. The third work mode of the system

- The fourth work mode:

If the third work mode lasts for a long time, batteries will be in an over-discharge state due to long-term discharges resulting in voltage drop. Ultimately, the load will be supplied separately by the grid. The direction of the energy flow is shown in the figure 5.

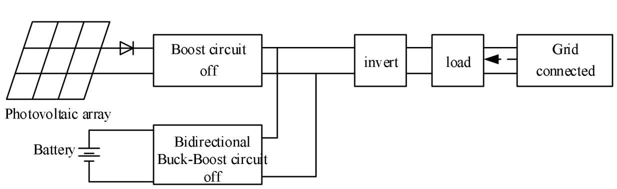

Figure 5. The forth work mode of the system

- The fifth work mode:

When the voltage of the battery is less than the minimum value and the voltage of the photovolatic cells is relatively low, which means neither of them are unable to supply power to the load, the solar energy can only supply a small amount of power to charge the battery. At the same time, the boost circuit work in the constant voltage mode and the bidirectional buck-boost circuit works in the Buck mode.

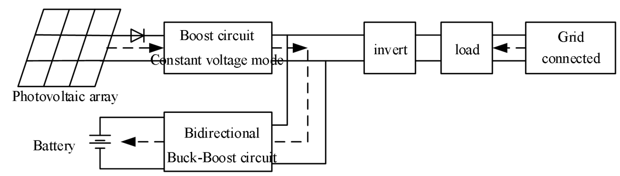

Figure 6. The fifth work mode of the system

According to the previous analysis, the different work modes of the system in different environments are obtained. Therefore, the boost circuit, the bidirectional Buck-Boost circuit and the grid should have several work modes as shown in Table I respectively. The realization of these modes can be accomplished through the system energy management circuit.

TABLE I. Work modes of the three energy sources

Energy sources	**work modes**		
Photovolatic cells	MPPT mode	Constant voltage mode	Off
Batteries	Boost mode	Buck mode	Off
Grid	Connected	Disconnected	none

Because the system works in five modes, the realization of its energy management circuit can refer to the functional block diagram in figure 7. I_{Bat} means for battery current. U_{Bat} means for battery voltage. U_{PV} means for the voltage of the photovoltaic array. E_{mode} means for the enabling signal of Boost circuit and bidirectional Buck-Boost circuit work mode. E_{boost} and E_{bi} means for the enabling signals of Boost circuit and bidirectional Buck-Boost circuit respectively.

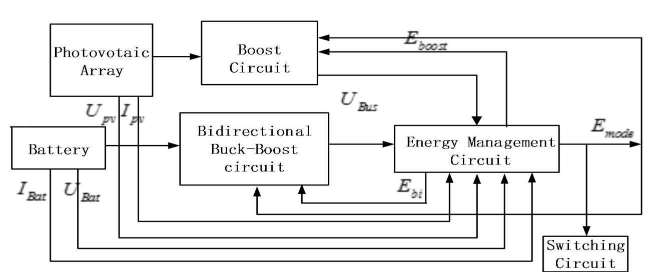

Figure 7. The functional block diagram of the energy management circuit of the system

III. Simulation Analysis of the System

C. The Simulation Model

The simulation model of the system is show in Figure 8 .

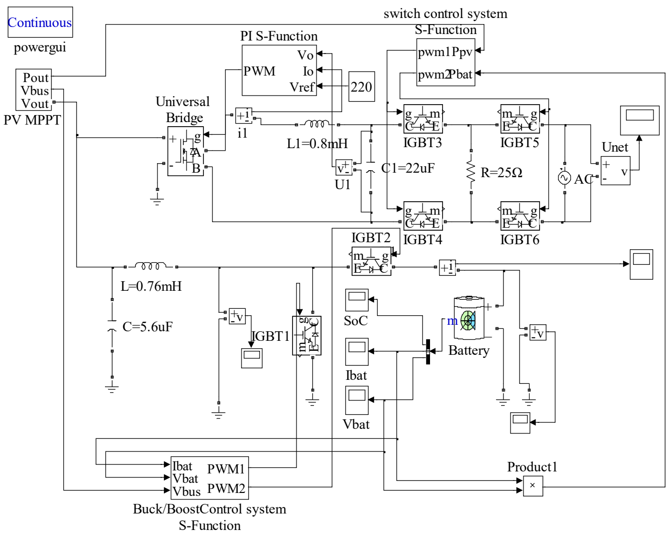

Figure 8. The simulation model of the system

The work principle of the system is as follows: after the maximum power tracking is realized by the PV MPPT module, the full-bridge inverter circuit, the filter circuit composed of L1 and C1 and the switching circuit composed of IGBT3~IGBT6 are supplied to the load R. The double loop control of the inverter is realized by the PI module, and the drive waveform of the switching circuit is output by the switch control system. When the output power of the photovoltaic cell is sufficient or insufficient, the battery is charged and discharged by the bidirectional switching circuit composed of L, C, IGBT1 and IGBT2. The driving waveform is generated by the Buck/Boost control system.

D. The Simulation Waveform

Waveform of the Maximum power point tracking is shown in figure 9.

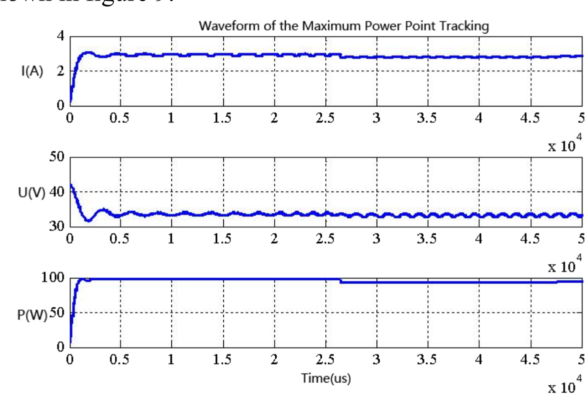

Figure 9. Waveform of the maximum power point tracking

Figure 9 shows that the system can quickly find the maximum power point and keeps the stable motion through the conductance increment method when the external changes occur.

Figure 10 shows the charging current waveform of the battery when the power of the photovoltaic cell is sufficient. Due to the opening and breaking of the thyristor, the current waveform keeps fluctuating around 3.9A. Since the battery is used as the load during the simulation, the charging voltage is basically kept at about 15.19V.

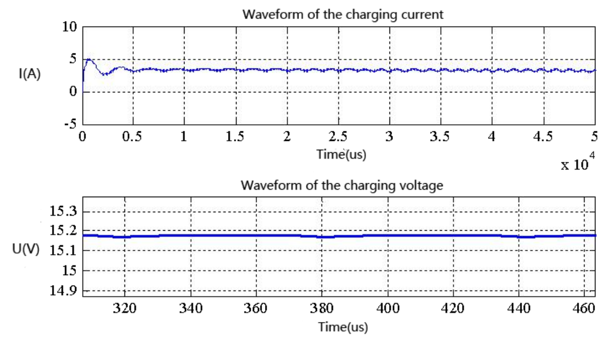

Figure 10. Waveform of he charging current and charging voltage

As shown in Figure 5-8, when the photovoltaic cell and the battery are unable to provide the load power, the waveform is switched to the mains supply. It can be seen from the figure that the waveform is switched at 46ms. Since the switch is in an ideal state, there is no switching recovery time.

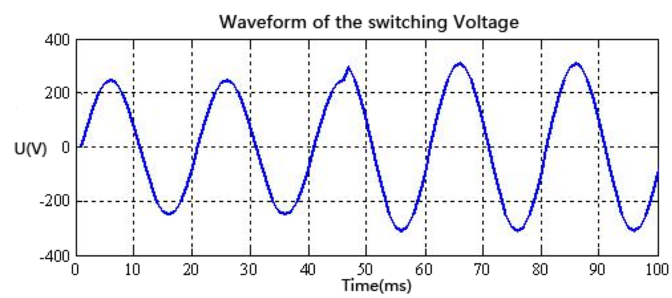

Figure 11. Waveform of the switching voltage

The waveform of the inverter is shown in Figure 12.It shows that the voltage waveform has good sinusoidality and the current waveform has some fluctuations.

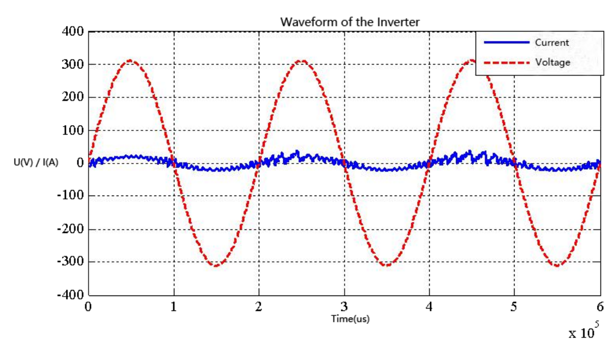

Figure 12. Waveform of the inverter

IV. THE CONCLUSION

In this paper, the multi-energy complement system based on photovoltaic is taken as the research object, and a reasonable energy management strategy is adopted to make the system work normally under the five modes, and can switch freely between the work modes according to the operation situation. The rationality and feasibility of the strategy are verified by experiments.

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