A research of high conversion efficiency power supply

Xiao-Jun Chen, Yilin JIN[+], Xiao-Ping Zhang,
Xu-Dong Song and Ying-Song Deng

*Electric Power Research Institute of Guangdong Power Grid Co. Ltd.,
Guangzhou, China*
*Power Grid Automation Key Laboratory of China South Grid,
Guangzhou, China*
[†]E-mail: 987928937@qq.com

The development of smart grid is more and more rely on the improvement of online monitoring device, and the development of power supply technology is the key to improve the level of online monitoring. In this paper, a design of a high conversion efficiency inductive power supply is proposed. A low-loss AC-DC converter circuit without rectifier bridge is designed, and a "black start" circuit is designed to deal with the power shortage. Different line state of the power control strategy, and finally through the experiment on the system functions were verified. The power scheme designed in this paper can work in a wide current range, and can switch the working mode quickly to ensure stable power supply and maintain high power conversion efficiency.

Keywords: Power Supply; Current Transformer; Rectifier Circuit; Black Start.

1. Introduction

The development of smart grid requires online monitoring devices to be more intelligent and perfect in order to ensure the high reliability of grid development. Advanced online monitoring technologies can greatly improve the efficiency and reliability of transmission lines.

Now some equipment manufacturers have developed a large number of online monitoring devices, including Power Donut from USi, Powerline Sensor from Protura, Lighthouse MV Sensor from Tollgrade and Line IQ from Grid Sense, etc. However, the power supply of online monitoring devices still needs to be improved greatly. Considering the safety of lines, the weight of the online monitoring devices needs to be strictly controlled. The solution to the above problem is to increase the unit power density of the energy supply, in order to minimize the weight of the equipment.

Considering the cost of power supply, the best choice for energy supply scheme with high power density is the inductive power supply based on the current transformer [1-3]. This scheme has the characteristics of small size, low cost and convenient installation, which has been widely used in recent years.

In this paper, a high conversion efficiency inductive power supply is designed, including transformer feeding, power conversion module, control module and backup battery, etc. The design of the high efficiency power supply will further improve the level of online monitoring, and further improve the reliability of the development of smart grid.

2. Hardware Design of the Induction Power Supply System

The system block diagram of the induction power supply is shown in Figure 1.The system works as follows, current is acquired from the energy-gaining coil firstly, and then voltage is raised above the forward threshold voltage of rectifying transistor by the step-up transformer, and finally rectifier circuit composed of MOSFETs makes the voltage an AC-DC conversion. The signal of the controlling end is provided by a DC bias generated from a self-excited oscillator. The output signal from the rectifier is transmitted to the DC-DC module. The DC-DC module consists of two stages. The former DC-DC converts the DC voltage from the rectifier to the voltage (5V) which meets the lithium battery charging requirement. The latter DC-DC converts it to the voltage(3.3V) matching the load. The control module mainly realize the management of lithium battery charge and discharge. It decides the lithium battery to charge or to discharge by parameters, such as, the power taken by the magnetic core, the rear stage load power, the state of the lithium battery.

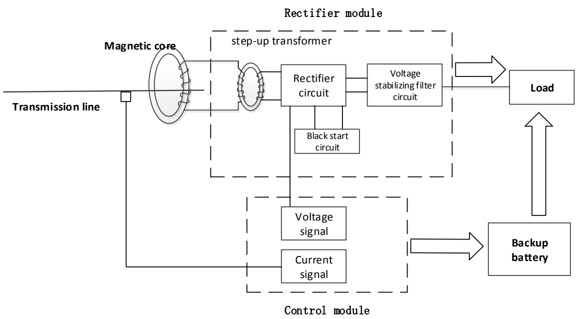


Fig. 1. Structure diagram of the induction power supply

2.1. *Design of the rectifier filter circuit and the black-start circuit*

The rectifier filter circuit after the magnetic core is shown in Figure 2.

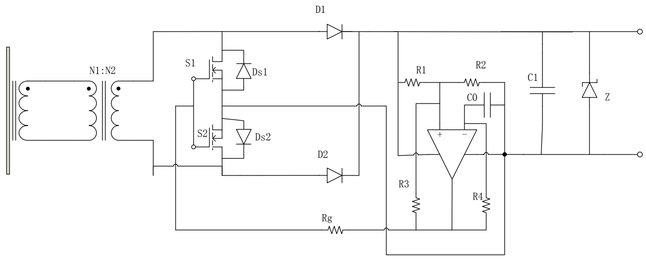


Fig. 2. Rectifier filter circuit

The boost transformer converts the induced current from the magnetic core to a voltage above the forward threshold voltage of MOS tubes and diodes. Since there is a limit determined by the permissible voltage and the design of the magnetic core to its boost capability, another rectifier boost module is needed. The secondary side of the step-up transformer is connected to the AC-DC module composed of MOS tubes and diodes. Rectification is divided into four processes during a period, charging, discharging, charging, discharging. Inductance of magnetic core and leakage inductance of the step-up transformer are both the energy storage components in the current path during the charge-discharge process. Charge when the MOS tubes turn on, and discharge when they turn off, so as to realize the rectification. The rectifier circuit is connected to an astable multivibrator. By positive feedback, the oscillator generates a DC bias as the gating pulse to “black start”. Voltage stabilizing tube ensures that the voltage is maintained in the safe operating range of the MOSFET, and ensures the stability of the system. The capacitor is used as a filter. Finally the output signal from the rectifier is regulated by voltage stabilizing tube, then is provided to the DC-DC module.

The black-start circuit is shown in Figure 3. The black start circuit is equivalent to an astable multivibrator. The input of the oscillator comes from the rectifier, while the output of the oscillator is connected to the control end of the MOS tube via a resistor. When the input voltage is low, the oscillator can generate a DC bias as the gate pulse by a positive feedback effect to control the push-pull circuit. We change the duty-ratio by selecting the proportion of the connected resistance and capacitor, which ensures constant DC voltage output from the rectifier. The module can “black start” with certainty when the source power is low.

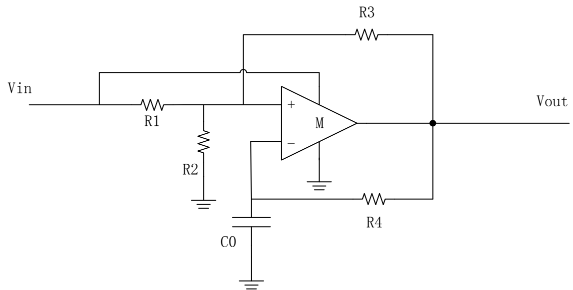


Fig. 3. Black start circuit

The AC-DC boost converter without rectifier bridge eliminates the multilevel loss brought by the rectifier bridge. Using the inductance of magnetic core and leakage inductance of the step-up transformer as the energy storage components successfully avoids to add a separate inductor in the circuit, so that the power management circuit comes to be easier. Black start makes it easy to start inductive power supply with a low current in primary winding. The voltage stabilizing filter module ensures a normal output when the voltage is high, which means a wide operating range to the circuit.

2.2. *Design of the control module circuit*

There should be a positive correlation between the power supplied by the energy-gaining coil and bus current. The on-line monitoring device will not be able to work normally when the bus current is too low. The black start circuit solves the technical problem that power taking device generates no gating pulse so that it cannot start the rectifier module when the power supply is restored from the blackout. But it can’t keep the system working continuously with no load or light load. It still needs to add the lithium battery as a backup power supply. The control module circuit is used to collect the voltage and current signal from former circuit, then to decide the circuit to turn on or to turn off. We charge the backup battery with excess power by PWM control when the bus current is larger, and the backup battery supplies power to the load when the power supply is insufficient. The structure of the control module is shown in Figure 4.

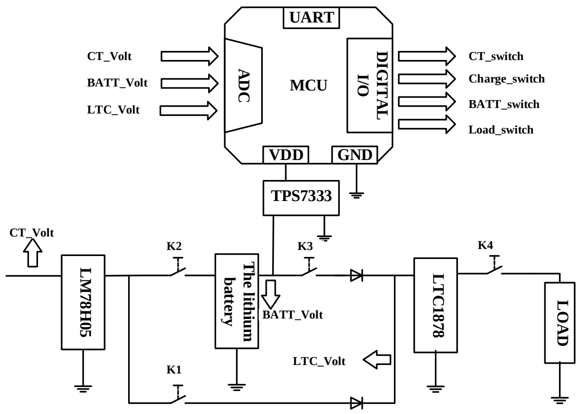


Fig. 4. The structure of the control module

In this module, MCU acquires multi-channel signal of DC voltage, outputs multi-channel signal of switch control, sends a group of PWM signal and realizes serial communication. The input signals that MCU collects include the voltage, the current and the voltage of the battery. The output consists of the control signals of the CT switch, charge switch, battery switch and load switch. We use the PWM control to manage the lithium battery charging. PWM wave with variable duty-ratio is output by the programmable counter array of the MCU. It is easy to control the charging current of the battery by adjusting the duty-ratio. When the system works, turn on the switch K1 to provide power to the load, and control the lithium battery charging by the switch K2. When the line power supply is insufficient, turn on the switch K3, and the lithium battery supplies power to the rear stage.

3. Control Strategy of Induction Power Supply System

The strategy of finite state machine is adopted to the induction power supply system, realized by microcontroller. Finite state machine is the specified time mark. According to the main voltage and current signals acquired, we determine the logical update status, and finish corresponding operation, and then output the corresponding control signal, lastly switch working mode. Keep the control signal constant until the next time tag comes. Power supply system has three working modes, normal working mode, charging mode and auxiliary power supply mode. When the line current is moderate, the magnetic core is used for power gaining and power supply, while the lithium battery is used as a backup power supply. When the bus current is sufficient, the magnetic core is used for power gaining and power supply, and the lithium battery is charged at the same time. When the line current is insufficient or the rear stage load is too large, switch the power supply to the lithium battery. Though bus current is used as the main criterion of state switch, the upper limit and lower limit value of backup battery is still should be considered.

As soon as the system starts, the lithium battery will be connected for power supply which can meet the requirements of the starting power of the rear stage load. After the system is initialized, the control module will detect the working state of the power module. When the coil gains power sufficiently, the power supply works in normal working mode, while the lithium battery works as a backup power supply. At the same time, we manage the lithium battery charging according to the lithium battery charging strategy chosen before. The start-up process can also satisfy the “black start”. When the front stage current is low, the system can start without connecting the lithium battery. After starting the system, the current and voltage signals are detected according to the corresponding control strategy, which decides how to change the working mode.

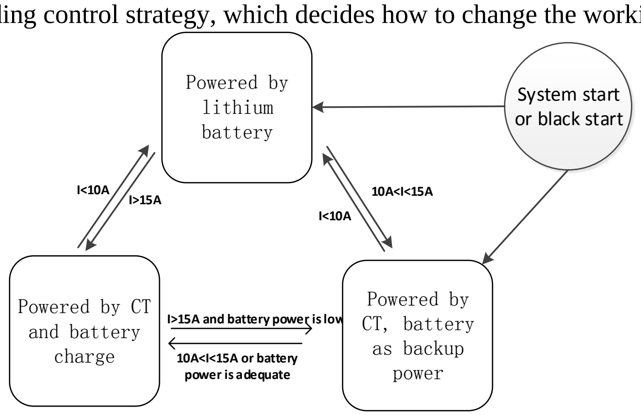
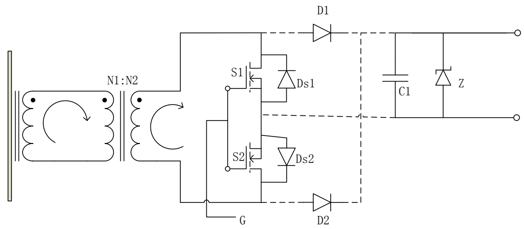


Fig. 5. powered by CT/charge state switching

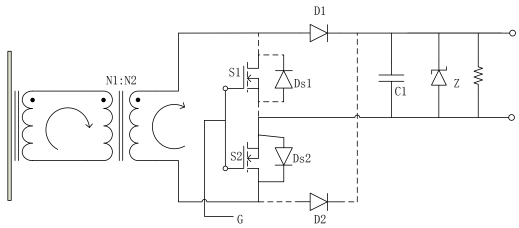
3.1. *Control strategy of the AC-DC conversion circuit*

The AC-DC conversion circuit proposed in this paper contains no rectifier bridge. The rectifier circuit is composed of MOS tubes and diodes, so the control strategy needs to be matched. Rectification is divided into four processes during a period, charging, discharging, charging, discharging. Inductance of magnetic core and leakage inductance of the step-up transformer are both the energy storage components in the current path during the charge-discharge process. Charge when the MOS tubes turn on, and discharge when they turn off, so as to realize the rectification.

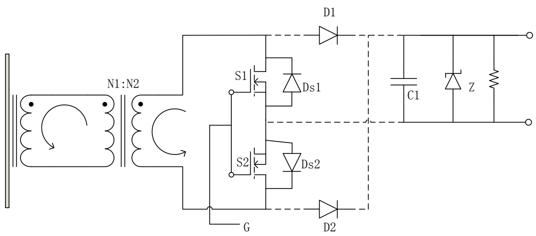
The operation mode conversion of the AC-DC conversion circuit is shown in Figure 6. In mode 1, $0<\omega t<\pi$, gating signal G=1, the MOS tube turns on, then inductor charges. In mode 2, $0<\omega t<\pi$, gating signal G=0, the MOS tube turns off, then inductor discharges. The power transfers from the inductor to the load. In mode 3, π<ωt<2π, gating signal G=1, the MOS tube turns on, then inductor charges reversely. Mode 4 is the same as mode 2. The diodes ensure that the current is in the same direction to the load, so as to realize the rectification.



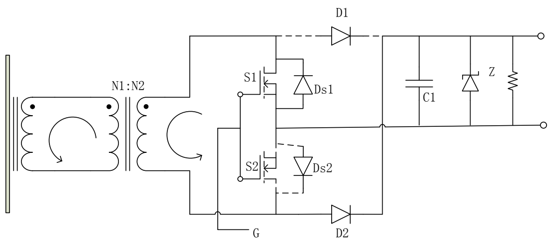
(a)mode 1



(b)mode 2



(c)mode 3



(d)mode 4

Fig. 6. Rectifier operation mode conversion

4. System Test and Result Analysis

In order to validate the effectiveness of the design of the induction power supply proposed, a prototype is produced and tested.

Set the transmission current to 5A, 10A, 15A, 20A, sequentially. Connect the magnetic core to the electronic load to test the output power. The result is shown in Figure 7.

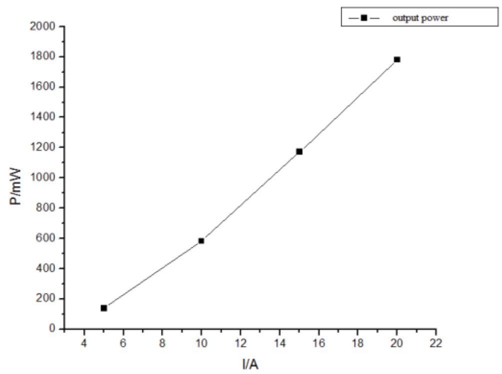


Fig. 7. Output power test of the magnetic core

The result shows that the output power of the magnetic core is close to 600mW when the primary current is 10A. Considering the loss of the power supply system, the output power is still more than 300mW, which can meet the power requirements of most of the online data acquisition devices.

Test the mode switching function of inductive power supply and the "black start". It is found that the system can work stably and can switch working mode rapidly in a wide range of primary current and load. In normal working mode, the power conversion efficiency of the system stays above 75%.

The power supply prototype is shown in Figure 8.

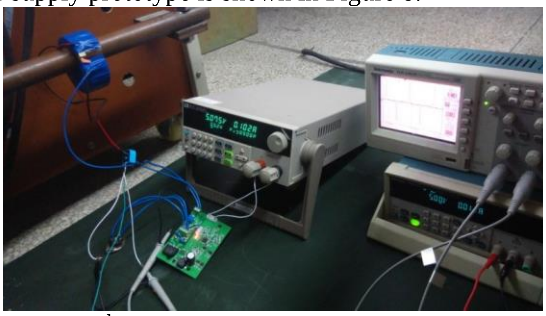


Fig. 8. Testing the power supply prototype

5. Conclusion

In this paper, a design scheme of a high conversion efficiency inductive power supply is proposed. A low-loss AC-DC converter circuit without rectifier bridge is designed, and a "black start" circuit is designed to cope with the power shortage. The power control strategy for different line states is made out to fit the backup battery. The system can supply power more than 300mW when the primary current is 10A, meeting the working conditions of online monitoring equipment. The system can be used for AC- DC conversion without a rectifier bridge. It can start immediately after line fault recovery, and can switch operation mode according to line and load conditions. The results indicate that the system can work in a wide current range, and can switch the working mode quickly to maintain high power conversion efficiency and ensure stable power supply. The design scheme of inductive power supply proposed in the paper will promote the improvement of the online monitoring, and promote the development of smart grid further.

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