

Research Article

Study on Power Supply System by Using CT in High-Voltage Transmission Lines

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Abstract: In online monitoring of the transmission line, its power supply is one of the key issues. This study presents a device using special transformer which can induce power to supply the high side circuitry. The front-end of the protection device includes output-power-control circuitry, which can take output-power limited to a small range. At the back side it contains rechargeable lithium batteries. By using the reasonable control strategy, it can provide a stable output-power at the transmission line current ranging from 40 to 1500A. And in the larger current the fever of transformer is not serious. Experiments show that the power supply system has the high reliability and efficiency.

Keywords: Output with stable voltage, power supply of CT, power control, transmission line

INTRODUCTION

With the comprehensive construction of the smart grid, there is a growing need for online monitoring devices working on the high voltage transmission lines such as photoelectric current transformer, cable temperature monitoring devices and so forth. Since these devices are installed at the high voltage side, it is impossible to supply power from ground which is a conventional way. Thus there is a need to develop a power supply that can meet the requirement of online monitoring devices at the high voltage side. Optical energy supply method has been studied by Banwell *et al.* (1993), in which optical energy can be transmitted to high voltage side from ground via optical fiber and then be converted to electric energy to supply the working circuit. This method is not suitable for devices working in the open country and has low energy efficiency and short service life. Zangl *et al.* (2008) studied the divider capacitor energy harvesting method in which isolation is needed between energy harvesting circuit and working circuit. Its output power is also limited by temperature, humidity and stray capacitance.

This study presents a device using special transformer which can induce power to supply the high voltage side circuit. The power quality of the grid would not be affected, because of the lower power consumption of high voltage side circuit and photoelectric devices. The device itself can be considered to be an isolated and contactless special-made induction power supply. This device, which

addresses the insulation problem of solar photovoltaic power supply, has great development prospect. Moreover, a power output control circuit is proposed to limit the output power of transformer core on secondary side within a smaller range. In this way, the transmission line could offer stable power to the load in a large current range.

METHODS AND MATERIALS

Principle analysis of CT power supply has been studied by Liu *et al.* (2010). The load equivalent model of transformer can be used to show the working diagram of CT coil. According to the law of electromagnetic induction (Zhou, 2007), it can be known that the expression of the instantaneous output voltage \dot{E}_2 on the secondary side of coil on unsaturated core is:

$$\dot{E}_2 = -j4.44fN_2\Phi_m \quad (1)$$

where,

\dot{E}_2 = Output voltage of secondary side

f = Current frequency

N_2 = The turn number of coil on the secondary side

Φ_m = The effective magnetic flux through the core

According to the law of total current (Zhou, 2007):

$$\Phi_m = B_m S = \mu H_m S \quad (2)$$

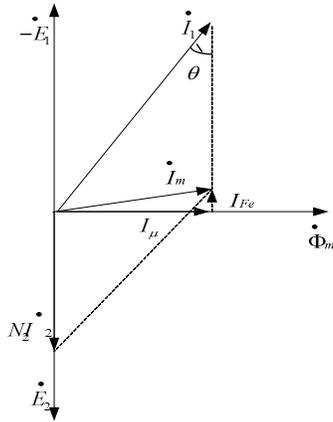


Fig. 1: Vector diagram of resistive load of coil

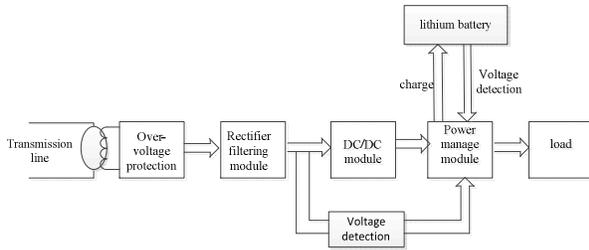


Fig. 2: Circuit block diagram of CT power supply system

$$H_m = \frac{\sqrt{2}N_1 I_\mu}{l} = \frac{\sqrt{2}I_\mu}{l} \quad (3)$$

where,

- Φ_m = The effective magnetic flux through the core
- B_m = The effective magnetic induction
- H_m = The effective magnetic field intensity
- S = The sectional area of core
- μ = Magnetic permeability of the core
- l = The magnetic circuit length
- N_1 = The turn number of coil on the secondary side
- I_μ = Magnetizing current of coil

According to the magnetic potential balance equation of the transformer, the turn number of coil on the primary side can be considered as one. I_m is divided into two parts: one is the magnetization component I_μ of the same phase with Φ and the other is the hysteresis loss component I_{Fc} of the same phase with the voltage E_2 . The vector diagram of the resistive load of the coil, disregarding the inductance and the coil resistance on the primary and secondary side, is shown as Fig. 1. According to the above formulae, disregarding the hysteresis loss component I_{Fc} of core, the output power of coil is given by:

$$P = E_2 I_2 \approx 4.44 f \mu S I_1 \cos \theta \frac{\sqrt{2} I_1 \sin \theta}{l} = 3.14 f \mu S I_1^2 \sin(2\theta) / l \quad (4)$$

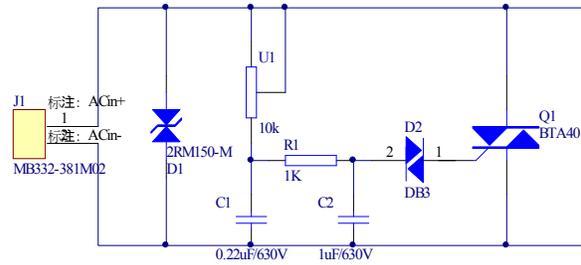


Fig. 3: Circuit diagram of overvoltage protection module

When the transformer core works in the linear region, μ can be regarded approximately as a fixed value. Then magnetizing current is $\sqrt{2}/2$ of current at primary side; when $\theta = 45^\circ$, $P_{max} = 3.14 f \mu S I_1^2 / l$. The changes of output power of the coil are summarized as follows: in linear region, when the magnetizing current is $\sqrt{2}/2$ of current at primary side, the maximum output power of coil is $3.14 f \mu S I_1^2 / l$. The load current of at the secondary side can be controlled so that magnetizing current is $\sqrt{2}/2$ of the current at primary side. At this time, the coil has the maximum output power. When the current at primary side is larger, the load current at the secondary side can be increased and θ decreased to control the output power of coil. By this means, the entire system will work in a state of low heat loss.

A CT power supply system in transmission line is designed by using the above principles. The circuit block diagram is shown as Fig. 2. As shown in Fig. 2, the AC voltage and current induced from the high-voltage transmission line go through the overvoltage protection module. The AC voltage is converted into a rectified voltage by rectifier module and supplied to DC/DC module. Then a 5V voltage is stably output after the conversion of DC voltage. There is a voltage detection module following the rectifier module, which is used to detect the voltage input into the DC/DC module and to provide data to the voltage management module. Power supply management module comes after DC/DC module, consisting of F320 SCM and related circuit. It is mainly used to collect the voltage detected by the voltage detection module for the following purposes: 1. to prevent the input voltage from being too large, which would burn the DC converter chip of DC/DC module. 2. The power supply management module adjusts the size of the PWM switch according to the size of the measured voltage value, so as to control the charging current of the lithium battery and provide enough voltage to load. The excess power would recharge the lithium battery.

The following are the circuit diagrams of each module and the working principles.

Overvoltage protection module and power control circuit: As shown in Fig. 3, the protection module is composed of protection circuit and output control

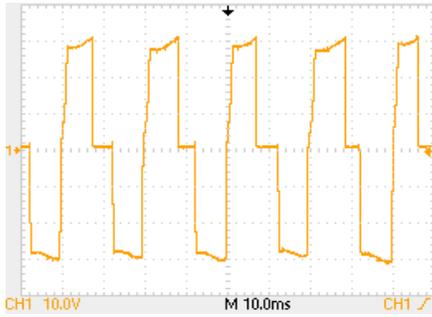


Fig. 4: Voltage waveform at 60A current at primary side



Fig. 5: Voltage waveform at 540A current primary side

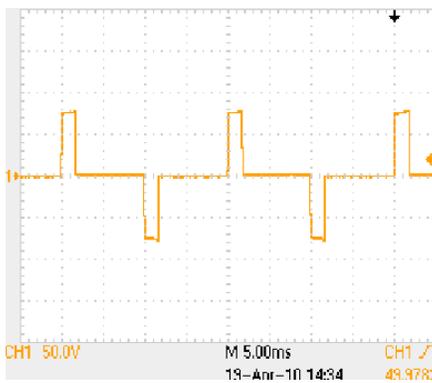


Fig. 6: Voltage waveform at 1100A current at primary side

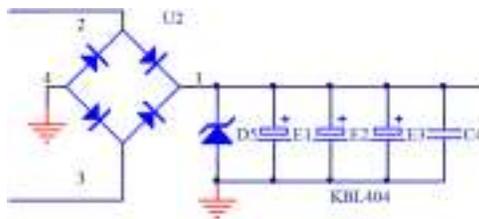


Fig. 7: Rectifying and filtering module

circuit. Where D1 is discharge tube whose function is to prevent the back-end circuit from the damage caused by lighting, short circuit and high induced current and voltage; U1 is a potentiometer, which can adjust the

size of its resistance; D2 is DB3 tube; Q1 is a triac, which has a bi-directional conduction function. The power output control circuit is used to control the conduction of triac and the current at the secondary side by controlling the size of potentiometer U1 and DB3 conduction. When the current of transmission line is large, with the increase of the conductive angle of triac, the current at the secondary side also increases and the phase angle θ decreases. Thus, the output power of coil is also reduced and limited within a small range. It can be seen that when the current of transmission line is large, due to the role of power control circuit, the output power of transformer would be reduced. Therefore, the core would not overheat. At the same time, the output power control circuit can also be used as a protection circuit. When the current of transmission line is large, the triac would start conducting, filtering out the high voltage spike at secondary side to reduce the output voltage and protect back-end circuit.

Figure 4 to 6 are, respectively the output voltage waveform at the secondary side for 60A, 540A and 1100A current at the primary side. It can be seen that when the transmission line current is large, the output voltage is limited to a small range. When the current is great than 1000A, the output power would not be too high, so the core would not overheat.

Rectifying and filtering module and DC/DC module:

The function of rectifying and filtering module is to convert the AC voltage output from overvoltage protection module into DC voltage. It consists of rectifier bridge and wave filtering circuit. Its circuit diagram is shown in Fig. 7.

U2 is the rectifier bridge, converting the AC voltage into DC voltage; the transient voltage suppression diode D5 limits the output voltage within a certain range, preventing a high output voltage from burning out the DC/DC converter chip. Following that is a wave filtering circuit, whose function is to reduce the output voltage ripple of the rectifier bridge and to filter out the high frequency spikes on the power supply.

DC/DC module could convert the variable DC voltage into a stable 5V DC voltage to supply the load and the rechargeable batteries. It consists of DC/DC converter chip and related circuits. Its circuit diagram is shown in Fig. 8.

A voltage detecting circuit is placed before DC/DC module. It is used to detect the voltage input into DC converter chip. Its VoltIn port is connected to F320 port of the power supply management module for AD conversion. The reference voltage V_{ref} is generated by SCM of power supply management module, by selecting the ratio of R4 and R11 to restrain the voltage value collected by CPU within a reasonable range. Thus, the voltage value input into DC/DC converter chip could be calculated by CPU. The principles of battery voltage detecting circuit and output voltage detecting circuit are the same as above.

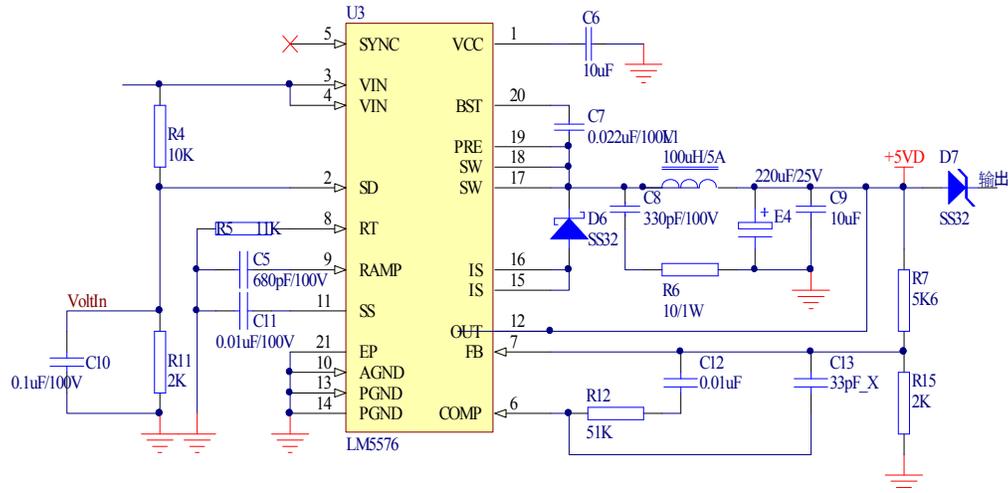


Fig. 8: DC/DC module

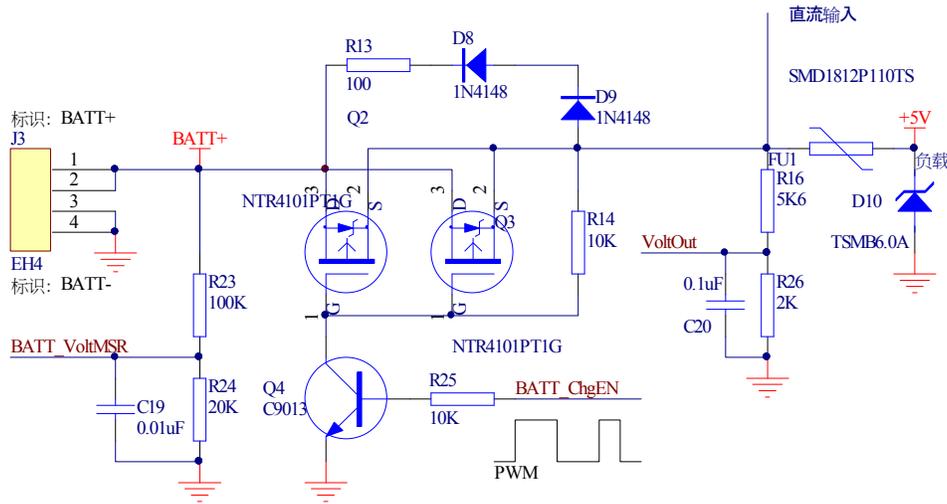


Fig. 9: Battery charging and discharging circuit

Power supply management module and battery charging and discharging circuit: The power supply management module is the control module of the whole device and is mainly used to receive the voltage value collected by the above circuits. It controls the charge or discharge of the lithium battery. It consists of F320 SCM and related circuits. The chip F320 contains 10-bit AD converter, which could detect the input voltage, battery voltage and output voltage. It is equipped with programmable counter array, which could output the PWM wave with variable duty cycle, so as to regulate the switch for charging or discharging.

The battery charging and discharging circuit consists of chargeable lithium battery and PWM-wave adjustment switch, etc. The circuit diagram is shown in Fig. 9.

The switching circuit is composed of triode Q4 and MOSFET Q3, which controls the switch on and off of MOSFET Q3 by controlling triode Q4. The

BATT_ChgEN port is connected to the output port of the PWM wave of SCM programmable counter array. In order to control the charging and discharging current, the PWM wave with variable duty cycle output from F320 chip is used to control the switch on and off time of the switch. A trickle charge circuit consists of R13, D8 and D9. The trickle charging is initiated when lithium batteries are not fit for high current charging. A battery voltage detecting circuit is designed at the battery port and is used for the real-time detection of battery voltage. The voltage of a charging battery might show a higher value than actual. So to reduce the error, we must first turn off the PWM switch and then measure for several times to obtain an average (Wu, 2009). An output voltage detecting circuit is placed at the output port and is used to detect the output current.

The BATT_ChgEN port is connected to the output port of the PWM wave of programmable counter array

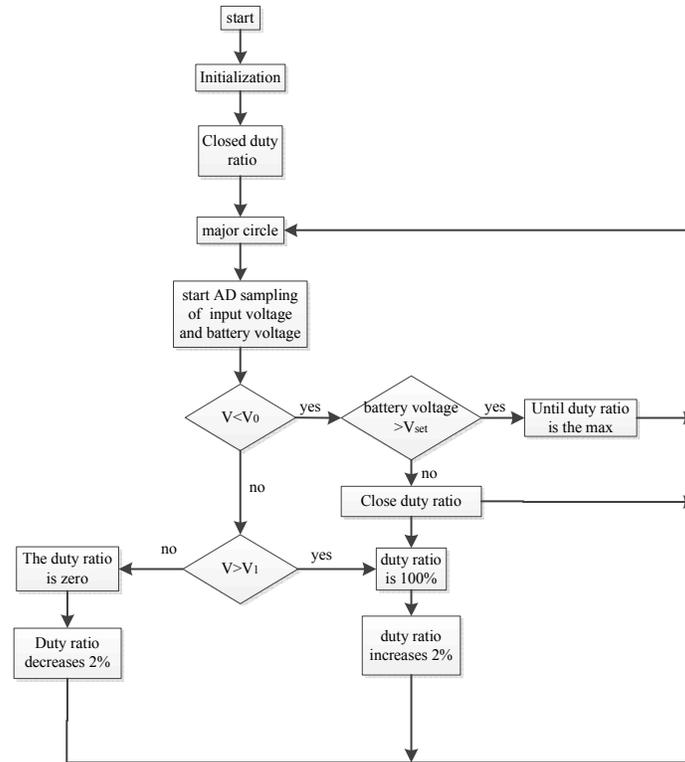


Fig. 10: Flowchart of power control program

and VoltOut port and BATT_VoltMSR port are respectively connected to the ports of AD converter of SCM. Then analog-to-digital conversion is possible.

The SCM in the power supply management module receives the data to control the switch for charging or discharging battery after calculation. It is responsible to ensure the smooth operating of the device.

Software configuration of power supply system: The software of the device is responsible for the charging and power supply management of the battery. The control and switching between different working states and the corresponding management strategies of the power system are realized by the SCM-based charge-discharge control circuit. The control signal is the voltage input into DC converter chip. When the current of transmission line is high, the control circuit detects the normal output voltage at the secondary side, then the charging circuit switch would be turned off first. The duty cycle of PWM wave would be increased slowly. That is to say, the charging current would be increased, until the output power of transformer has met the load power and the battery charging power. In the case of the empty load of transmission line, the output power cannot supply the load power. Thus the charging switch is fully turned on to let the battery to supply power to the load.

Its control flow is shown as Fig. 10. V_{bat} is the charging voltage of lithium battery, V is the voltage

before input to AD converter chip, V_0 , V_1 is the threshold voltage set according to the load power.

It can be seen from the flowchart that in the case of too small non-load current of the transmission line which cannot provide load power, the PWM duty cycle would be increased to the maximum. Thus the lithium battery would supply power to load until the battery can no longer afford or when the transmission line could provide sufficient power. When the current of the transmission line is large enough to provide the power greater than the load power, the SCM would detect the battery voltage. If the battery could be charged, the duty cycle of PWM would be increased slowly, that is, increasing the charging current (to the minimum output load power) to charge the battery.

EXPERIMENTAL RESULTS

This device was tested on a high-current generator. It could stably output 5V voltage when the current of the transmission line ranged from 40 to 1500A. Power higher than 1.5 W was provided when the current was small (40A). After long-time working under 1500A, the transformer did not overheat. This device has been manufactured and put into the operation on high-voltage transmission line to provide power to the online monitoring equipments (Fig. 11 and 12). So far it has been working stably and reliably.



Fig. 11: Picture of circuit board

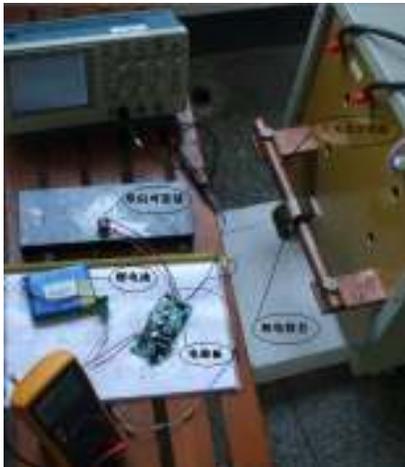


Fig. 12: Equipment commissioning

CONCLUSION

This study introduces a CT power supply device for high-voltage transmission line. It uses transformer to induce power to supply the circuit at secondary side. This device is designed with an output power control circuit to limit the output power at the secondary side

within a small range. The back-end contains a rechargeable lithium battery pack which can be charged or discharged according to reasonable control strategy. The experiment proved that this device can provide power higher than 1.5W when the current of transmission line varies from 40A to 1000A without overheating.

ACKNOWLEDGMENT

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