Self Powered Circuit with Composite Energy Storage for Monitoring Terminal in Distribution Network

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Abstract. In this paper, a self powered circuit with composite energy storage for monitoring terminal in distribution network is proposed, which consist of a rectifier circuit, DC/DC converter and composite energy storage. Firstly, the self powered circuit obtained energy by CT (Current Transformer) from the lines in distribution network. Then, the expected DC voltage was obtained by rectifier circuit and regulated by DC/DC converter. To enhance the power supply reliability, composite energy storage is applied, which is regulated by coordinated control. To verify the effectiveness, a simulation model was built in MATLAB, and the result are satisfactory.

1. Introduction
With the rapid development of economy and technology, the scale of power grids is becoming larger and larger, and the structure of power grids is becoming more and more complicated [1]. The increasing complexity of power grids has caused more faults. While, fault monitoring is an effective method to deal with the problems [2]. Because of the high voltage and high current in the power transmission and distribution lines, it is difficult to supply power to the monitoring terminal directly. Therefore, it is very important to transform voltage or current from high level to low level for application in monitoring terminal.

The main methods of self powered are CT power, capacitance voltage sharing power, photovoltaic cell power and laser power. In [3], a novel method based on self-power supply control for balancing capacitor static voltage was proposed. Because of the influence of self-power supplies on capacitor voltages, the method can keep the capacitor static voltage balanced by controlling the input characteristic of SMs(submodules) self-power supplies. The control signals of self-power supplies have a fixed frequency and duty ratio, and they can be determined based on capacitor voltage sorting results and self-power supply output support capacitor. In [4], a control design for hybrid photovoltaic-fuel cell with a storage terminal (HPFCS) is presented. These stand-alone systems are used close to the load. The HPFCS is formed of a Fuel cell generator (FCG), a photovoltaic generator (PVG), a storage battery and a supervisor associated to a DC Bus. A control is conceived to manage power flows. Priority is given to PVG as it satisfies the load requirements. To balance the power a FCG was used when the power provided by PVG is not enough. The storage terminal was used to store the enough of power produced by PVG. In [5], a two-way power supply system was given, which was completed by bus and laser. In order to solve the problems of short life and poor reliability of the laser, the fuzzy PID control algorithm is used to dynamically adjust the laser transmitting power.
according to the power demand of the signal acquisition system, so as to improve the service life of the laser.

CT power is a simple self-powered method with high energy conversion rate. Therefore, in the environment of high-voltage transmission lines, it is relatively effective by CT. However, most monitoring terminal circuits couldn’t work normally, when a small current flowed through the line. Hence, it is a problem to be solve that how to realize the self-powered supply of a small current monitoring terminal [6].

This paper proposed a self-powered circuit with composite energy storage for monitoring terminal in distribution network, which is consist of a rectifier circuit, DC/DC converter and composite energy storage. Firstly, the self-powered circuit obtained energy by CT (Current Transformer) from the lines in distribution network. Then, the expected DC voltage was obtained by rectifier circuit and regulated by DC/DC converter. The self-powered circuit proposed in the paper could work normally as long as the line current is greater than 2A.

2. Structure of Monitoring Terminal

The monitoring terminal structure is shown in Figure 1. The monitoring terminal contains self powered module, power grid monitoring device and collection modules. Firstly, self powered module supplies energy for power grid monitoring device. Then, power grid monitoring device transmits data to several collection modules. At the same time, collection modules will handle the transmitted data, and it means edge computing. All the collection modules could share the data. Finally, all the handled data would be transmitted to each user by 4G or 5G so that data visualization could be realized.

![Figure 1. Structure of monitoring terminal](image)

2.1. Design of self powered circuit

Self powered module provides the power supply for monitoring terminal. Therefore, it is very important to design a reliable power.

As is shown in Figure 2, it is the principle of PMSMT (power management system for monitoring terminal), the PMSMT contains self powered circuit, power management, GPS module, A/D module and CPU. Power management system consists of self powered circuit and power management. Also, power management system supplies energy for monitoring terminal which consists of GPS module, A/D module and CPU.
2.2. Principle block diagram design of self powered circuit

As is shown in Figure 3, it is the principle block diagram of self powered circuit. The self powered circuit contains four parts, including CT power circuit, rectifier circuit, DC/DC converter and composite energy storage. CT power circuit obtained induced current by CT from distribution network and supplied voltage to the input of next circuit. Rectifier circuit transmitted AC voltage to DC voltage and supplied DC voltage to the input of next circuit. DC/DC converter reduced the input voltage to the equipment demand voltage, then the circuit charged composite energy storage. Composite energy storage could supply enough energy to monitoring terminal by coordinated control.

\[ I_1 = \frac{N}{I_2} \quad (1) \]
\[ U_1 = I_2 R_i \quad (2) \]

2.3. Design of CT power circuit for monitoring terminal

As is shown in Figure 4, it is CT power circuit for monitoring terminal. CT power circuit mainly consists of CT and resistance \( R_i \). The current transformation ratio of CT is N/1 as (1). The output voltage is \( U_1 \) as (2).

In order to ensure that the self powered circuit work reliably when the lower limit of line current is 2A, the current transformation ratio of CT has been set as 2/1 in this paper.
2.4. Design of rectifier circuit for monitoring terminal

As is shown in Figure 5, it is rectifier circuit for monitoring terminal. The rectifier circuit mainly includes a rectifier bridge composed of four diodes, a filter capacitor [7]. However, due to the CT, the CT power circuit could be considered as a current source. In order to solve the voltage fluctuation, Zener diodes are used, which could limit the output voltage in a small range.

The selection of rectifier circuit filter capacitor in the following. In (3), \( R_2 \) represents the resistance in general rectifier circuit. \( T \) represents AC period.

\[
C_1 R_2 \geq 2.5T
\]  

(3)

2.5. Design of DC/DC converter for monitoring terminal

As is shown in Figure 6, it is DC/DC converter. DC/DC converter mainly contains 4 parts, including a GaN MOSFET, a diode \( VD_1 \), an inductance \( L \) and a capacitor \( C_2 \) [8].

GaN MOSFET is drove by PWM, and the duty cycle of PWM is decided by (4). In (4), \( U_o \) represents output voltage which is transmitted by DC/DC converter. \( U_i \) represents output voltage from rectifier circuit. \( D \) represents duty cycle. The selection of inductance is decided by (5). In (5), \( V I_s \) represents ripple current. \( f_s \) represents switching frequency. The selection of capacitor is decided by (6). In (6), \( VV \) represents ripple voltage. Generally, a margin of 1.5 times should be reserved when refer to the inductance or capacitor selection.

GaN MOSFET has the advantages of low loss, high frequency and high reliability, which can greatly improve the efficiency, power density and reliability of switching power supply. Among them, the advantage of high frequency will reduce the value of inductance and capacitor, and then volume of inductance and capacitor will be reduced.
Figure 6. DC/DC converter for monitoring terminal

\[ D = \frac{U_o}{U_i} \]  

\[ L = \frac{U_o}{\sqrt{f_s}} (1 - D) \]  

\[ C = \frac{U_o}{8Lnf_s} (1 - D) \]  

Usually, the desired voltage value may not be achieved by the DC/DC converter with theoretical value. Therefore, PI regulation should be used in the circuit to adjust the gap between output voltage and expected voltage dynamically. As is shown in Figure 7, it is PI regulation diagram of DC/DC converter. \( U_{ref} \) represents expected voltage.

Figure 7. PI regulation diagram of DC/DC converter

2.6. Design of composite energy storage

In this paper, composite energy storage consists of battery and super capacitor. As is shown in Figure 6, BA is battery and SC is super capacitor. The coordination control of composite energy storage is shown in Figure 8. The composite energy storage system adopts hysteresis control so that misjudge the occurrence of power grid state could be avoided.

In Figure 8, \( U_o \) represents the threshold of output voltage which is decided by ripple voltage. In order to judge the state of distribution network twice during a very short time, the paper gave \( 10T_e \) to the composite energy storage management system. If the two judgement results were all YES, super capacitor would be used to supply energy. If the two judgement results were all NO, battery would be used to supply energy. Composite energy storage would stay the last time state if the two judgement results were different.
3. Simulation analysis

The simulation of self powered circuit is shown in Figure 2. The voltage in grid side is 10kV. CT ratio N/1 is 2/1, expected voltage is 5V. As is shown in Figure 9, it is output voltage and current waveform of CT power circuit. The total simulation time is 2s. During the first 1s, the grid side was normal. During the second 1s, a ground fault occurred in the grid side. The current effective value of CT primary side is 2A, and the current effective value of CT secondary side is 1A. Therefore, it is a small current fault condition.

![Figure 9. Output voltage and current waveform of CT power circuit](image)

As is shown in Figure 10, it is output voltage waveform of self powered circuit with composite energy storage. It could be seen that output voltage stay at 5V during the full 2s. Therefore, the voltage supplied by composite energy storage is stable and can be used directly by monitoring terminal.
As is shown in Table 1, the switching frequency (Fs) of GaN MOSFET is 5 times that of Si MOSFET. The theoretical value of L and C were 3.125mH and 5.04mF respectively when Si MOSFET was used. The theoretical value of L and C were 0.625mH and 1.008mF respectively when GaN MOSFET was used.

As is shown in Table 2, when Si MOSFET was replaced by GaN MOSFET, the reduction ratio of theoretical values of L and C were all 80%. Therefore, the volume of L and C would be much smaller. Also, it is easier to install in distribution network in practical engineering.

| Fs(kHz) | L(mH)     | C(mF)  |
|---------|-----------|--------|
| Si MOSFET | 100 | 3.125  | 5.04  |
| GaN MOSFET | 500 | 0.625  | 1.008 |

| L(%) | C(%) |
|------|------|
| Reduce 80% | Reduce 80% |

4. Conclusion
This paper proposed a self powered circuit with composite energy storage for monitoring terminal in distribution network. This paper proposed a self powered circuit with composite energy storage for monitoring terminal in distribution network, which is consist of a rectifier circuit, DC/DC converter and composite energy storage. Firstly, the self powered circuit obtained energy by CT from the lines in distribution network. Then, the expected DC voltage was obtained by rectifier circuit and regulated by DC/DC converter. The self powered circuit proposed in the paper could work normally even if the line current is only 2A. The use of GaN MOSFET reduced greatly the volume and value of L, and so did C. The simulation verified that the self powered circuit proposed in this paper was effective.

5. References
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