Power supply for on-line monitoring device of power lines based on double-half ring core

Kaijin Xue[1], *Jieyu* Liu[2], *Naidi* Kang[2], *Yujia* Zhao[3], *Yan* Zhao[4] and *Donglai* Wang[4,*]

[1]State Grid Liaoning Information and Communication Company, Shenyang, Liaoning 110006, China
[2]State Grid Liaoning Marketing Service Center, Shenyang, Liaoning 110006, China
[3]State Grid Anshan Electric Power Supply Company, Anshan, Liaoning 114002, China
[4]School of Renewable Energy, Shenyang Institute of Engineering, Shenyang, Liaoning 110136, China

Abstract. In order to solve the problem of insufficient energy supply of the on-line monitoring device of the transmission line, a sensor energy acquisition scheme directly installed on the transmission line is proposed. In the current power supply, induction power supply is a kind of energy extraction method with better practical applicability. Since the monitoring devices and electronic equipment on the transmission line are often in a strong magnetic field and high voltage environment, designing a stable and reliable power supply is the guarantee for the stable operation of the monitoring devices and electronic equipment. This paper presents a structure of energy-absorbing iron core with two semi-circular magnetic cores, and studies the magnetic saturation problem in the inductive power supply and the design of the DC output circuit.

1 Introduction

With the rapid development of the power grid, a large number of transmission lines inevitably pass through regions with harsh climates and complex environments during work operation. The stable operation of transmission lines is extremely vulnerable to damage [1,2]. In order to achieve real-time monitoring of the transmission line operation status, it is necessary to use monitoring means to obtain relevant operating parameters, analyze the line operation status and further formulate transmission line maintenance strategies [3]. The importance of reliable operation of transmission lines has increasingly attracted people's attention. Domestic and foreign power research scholars have focused on monitoring and fault diagnosis of power line state parameters, and have made great progress [4]. However, solutions for power supply problems of electronic devices such as online monitoring devices are still not satisfactory. Since the monitoring device operates under special working conditions, the power supply of the monitoring device becomes a difficult problem in the field [5].

Currently, there are four main ways to supply power to the monitoring devices and electronic equipment on the transmission line: battery power supply, laser power supply, new energy supply, and induction power supply. The outstanding advantage of battery

* Corresponding author: donglai.wang@hotmail.com

supply compared to other energy supply methods is good stability, but under strong electromagnetic fields like transmission lines, the service life and performance of the battery will be greatly reduced [6]. The advantages of laser energy supply are high stability, good insulation effect, low noise, and not easy to be interfered by electromagnetic field. However, changes in ambient temperature often affect the output power and emission wavelength of the laser light source. Most of the new energy power supply is dominated by batteries and solar power. Solar power usually adopts a flat structure. The structure has a narrow light receiving surface and a low light absorption rate, which affects the output capacity of the solar power [7]. Induction power supply is based on the principle of electromagnetic induction. When the current flowing through the line causes a change in the electromagnetic field around the wire, the AC power is induced by the inductive power supply, and then converted to the back end after rectification, filtering, and voltage regulation circuit conversion. The monitoring device and the electronic equipment provide electrical energy. The advantage is that the energy is taken directly from the transmission line, which solves the problem of high and low voltage insulation isolation. However, the load of the power system is constantly changing, especially the influence of seasonal load and load that changes with time [8].

Compare the advantages and disadvantages of the above several different power supply methods. From the aspects of practicability and cost performance, it can be seen that the inductive power supply method is a more suitable energy supply method for providing electrical energy to various environmental online monitoring devices and electronic equipment in various regions. In this paper, based on the way of induction power supply, the problems of voltage dead zone and protection of large current impulse faced by the induction power supply are studied, and the improvement scheme is proposed.

2 Design of energy-absorbing components

The basic principle of induction power is Faraday electromagnetic induction. The structure of the induction power supply is shown in Figure 1 below. The energy source is composed of induction power module and processing circuit module. This article mainly discusses and simulates the induction power supply module and the processing circuit module, and designs a power supply suitable for the monitoring device.

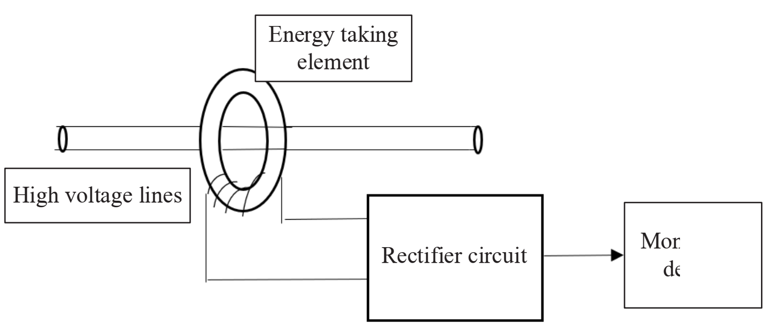

Fig. 1. Basic structure of the energy extraction device.

The choice of the core material for energy dissipation mainly depends on the magnitude of the current, and the magnitude of the current is determined by the core material of the energy dissipation transformer and the number of coil turns. Due to the magnetic saturation characteristics of the core material, when the current of the line is small, in order to avoid the energy-absorbing core entering the saturation state prematurely, the level of saturation magnetic induction is one of the main considerations. Compared with other ferromagnetic materials, the magnetic induction strength of silicon steel sheet under strong magnetic field is much higher than the cost performance and practicality. The magnetic saturation density of silicon steel sheet is about 1.8T. In this paper, 1T is selected for the following calculation. The output power and voltage of the induction power take-off device mainly depend on the material of the core, the size of the load, and the number of coil turns. The induced electromotive force in the coil is:

$$e=-\frac{\mathrm{d}\psi_B}{\mathrm{d}t}=-N\frac{\mathrm{d}\varphi}{\mathrm{d}t}=-\omega N\Phi_m\cos\omega t=E\sin\left(\omega t-\pi/2\right) \tag{1}$$

$$\boldsymbol{E}=\frac{\boldsymbol{E}_m}{\sqrt{2}}=\sqrt{2}\pi fN\Phi_m=4.44fN\Phi_m \tag{2}$$

where N is the number of turns of the power coil, $\boldsymbol{E}_m$ is the peak value of the electromotive force induced by the power coil, $\boldsymbol{E}$ is the effective value of the electromotive force induced by the power coil, and $\Phi_m$is the peak value of the flux linkage.

In this paper, when designing the iron core, in order to facilitate the installation, two semicircular magnetic cores are selected to be installed above the transmission line. However, due to the existence of a small air gap at the interface of the semicircular energy core, the magnetic resistance of the magnetic circuit will be changed. On the contrary, due to the existence of the air gap reluctance, the energy-absorbing magnet also avoids entering the magnetic saturation state prematurely. Therefore, when designing the iron core, a certain air gap needs to be designed.

The design method of the air gap is discussed below. The calculation formula of the main reactance of the coil is:

$$X_M=\omega L_M \tag{3}$$

where L_m is the inductance corresponding to the main reactance, namely the main inductance H. For L_m, there is:

$$L_M=W^2\Lambda_M \tag{4}$$

where W is the total number of turns of the iron core, and Λ_M is the magnetic derivative of the magnetic circuit. The expression of Λ_M is:

$$\Lambda_M=\Lambda_{M1}+\Lambda_{M2} \tag{5}$$

where Λ_{M1} is the track perpendicular to the cross-sectional area, Λ_{M2} is the main magnetic flux line except Λ_{M1}, which is generated by the edge and its shape is similar to a semi-arc.

$$\Lambda_{M1}=\mu_0\frac{S_Z}{\delta} \tag{6}$$

where S_Z is the intimate cross-sectional area, μ_0 is the vacuum permeability, and δ is the air gap length.

The factors affecting the maximum excitation current value are: the size and saturation magnetic induction strength of the iron core, the relative permeability of the iron core and other parameters. Suppose the intimate cross-sectional area s, the cross-sectional diameter is d, the height of the iron core is h, the effective magnetic circuit length is L, where L affects the consumption of materials, D affects the number of windings used in the coil winding, in order to reduce losses, according to the minimum core Principles to design the core size. Let c be a known quantity, the calculation method is as follows:

$$d+L=\frac{2s}{d}+\left(2+\pi\right)d+\pi c \tag{7}$$

$$d=\sqrt{2S/\left(2+\pi\right)} \tag{8}$$

$$h = S \Big/ \sqrt{2S/(2+\pi)} \tag{9}$$

$$L = \pi\left(c + \sqrt{2S/(2+\pi)}\right) \tag{10}$$

The voltage stabilizing element preselected in this paper is 78 series, so the output voltage of the DC terminal is about 15V, that is, the induced voltage is 40V. According to the formula of the induced voltage at no load, there are:

$$N = \frac{EL}{4.44 f \mu_0 \mu_r S \sqrt{2} I} = 525 \tag{11}$$

The above are the requirements for the core size material at the induction end. The cross-sectional area s=3cm^2, the core diameter d=24mm, the height h=21.6mm, the air gap=3.53mm, and the number of turns is 525.

3 Rectifier circuit design

After passing the front-end energy-absorbing magnetic core and the energy-absorbing coil, the output voltage and current are all alternating current. But devices such as monitoring devices require DC power. Therefore, it is necessary to convert the direct current of the alternating current induced by the energizing coil. The AC-DC conversion circuit requires a front-end impact protection circuit, a rectifier circuit, a filter circuit, and a voltage regulator circuit.

(1) Protection circuit. Considering that once the transmission line has a single-phase short circuit, two-phase short circuit and other line failures, or when it encounters a huge surge current caused by direct lightning, etc., the energy source will output a very large voltage value at this time. With sufficient protection, an anti-shock protection circuit composed of a transient suppression diode is directly connected in parallel after the output end of the front-end energy coil, which will clamp the surge voltage caused by short circuit or lightning in a safe voltage range. Therefore, an anti-shock protection circuit is required in the front section.

(2) Rectifier circuit. This article chooses bridge rectification. If a half-wave rectifier circuit is used, only the positive half-cycle waveform of the output voltage can be obtained, which contains a DC component. After passing through the full-wave rectifier circuit, the positive and negative half cycles are obtained, but the circuit still contains a DC component. Therefore, in order to filter out the DC component, this article selects the bridge rectifier circuit.

(3) Filter circuit. The filter circuit is mainly realized by the property that the voltage value at both ends of the capacitor and the current flowing through the inductor will not jump, and the capacitor and the load can be connected in parallel or the inductor and the load can be connected in series. The structure of the capacitor filter circuit is simple, and the filter effect is determined by the time constant. The higher the RC value, the smoother the voltage waveform obtained. Compared with the capacitor filter circuit, the use of an inductive filter circuit will reduce the load current and reduce the inrush current value of the rectifier diode. The output voltage value after the inductor filter is lower than the output voltage value of the rectifier circuit. In order to get a more ideal filtering effect, the filtering circuit in this paper chose LC-π type.

(4) Voltage regulator circuit. After the voltage value output from the energy extraction coil is adjusted by the rectifying and filtering circuit, the obtained voltage will still change with the change of the wire current and the size of the load. What the monitoring device and the electronic equipment on the transmission line each need is a stable DC voltage after processing by the voltage stabilizing circuit. The experiment chooses the switch integrated

voltage regulator of LM7815 series with wide range input. The voltage obtained by filtering and rectifying the voltage after 7815 voltage regulator processing is the DC voltage available for the monitoring device. The circuit provides a stable 15V DC voltage.

The circuit is shown in Fig. 2.

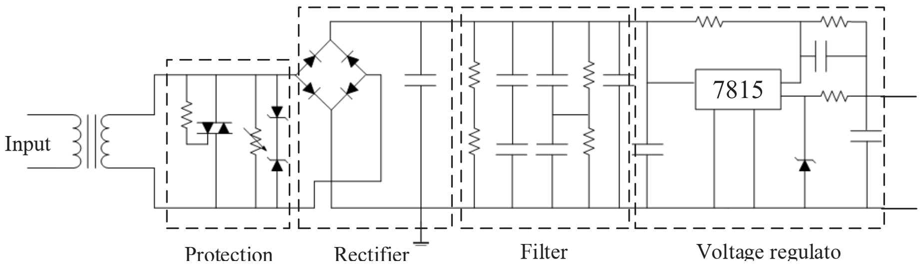

Fig. 2. Circuit diagram.

4 Conclusion

Induction power supply on the transmission line is a more economical and practical way to obtain power. This paper studies a power supply for monitoring equipment on the transmission line. The energy-supplying power supply adopts energy-absorbing transformers to induce energy from the transmission line to supply power to the online monitoring device. By reasonably selecting the length of the air gap and the wire parameters, the energy-consuming core can work in the unsaturated zone within the normal range of the primary current. An AC-DC converter circuit including a protection circuit, a rectifier circuit, a filter circuit, and a voltage stabilizing circuit is designed so that the energy induced by the iron core can be stably supplied to the sensor.

This paper was supported by the Key R&D Program of Liaoning Province (2018220017, 2019JH8/10100062, 2019JH8/10100066).

References

1. Q. Huang, J. Wang, S. Lu, X. Chen, L. Bai, Y. Dai, Y. Tian, S. Yan, ACS Applied Materials & Interfaces, **10**, 29 (2018)
2. S. Shahsavari, M. Saberi, Circuits Systems and Signal Processing, **38**, 3 (2019)
3. C. Lin, T. Ma, Z. Siwy, S. Balme, J. Hsu, J. Physical Chemistry Letters, **11**, 1 (2020)
4. G. Craven, D. He, A. Nitzan, Physical review letters, **121**, 24 (2018)
5. R. Ni, D. Xu, G. Wang, X. Gui, G. Zhang, H. Zhan, C. Li, IEEE Trans. Industrial Electronics, **63**, 2 (2016)
6. X. Yan, G. Wang, D. Deng, Plasmonics, **14**, 5 (2019)
7. U. Jurado, S. Pu, N. White, Nano Energy, **72**, 104701 (2020)
8. M. Jacek, J. Jaworski, Journal of Materials Engineering and Performance, **26**, 4 (2017)