Energy and Power Engineering, 2013, 5, 570-574
doi:10.4236/epe.2013.54B109 Published Online July 2013 (http://www.scirp.org/journal/epe)

Design of Power Supply for On-line Monitoring System of Transmission Lines

Kai Chen[1], Zi-jian Zhao[1], Yu-ning Zhang[1], Yang-chun Cheng[1], Yuan Dai[2]
[1]State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources,
Beijing Key Laboratory of High Voltage and EMC, North China Electric Power University, Beijing, China
[2]Guangdong Power Test & Research Institution, Guangzhou, Guangdong Province, China
Email: 570940746@qq.com

Received March, 2013

ABSTRACT

This paper uses CT to gain the energy directly from the high-voltage transmission line, to address the problem of power supply for monitoring system in high voltage side of transmission line. The draw-out power coil can induce voltage from the transmission line, using single-chip microcomputer to analog and output PMW wave to control the charging module, provides a stable 3.4 V DC voltage to the load, and solve the problem of easy saturating of core. The power supply based on this kind of draw-out power coil has undergone the overall testing, and it is verified-showing that it can properly work in a non-saturated status within the current range of 50 - 1000 A, and provide a stable output. The equipment also design protection circuit to improve the reliability to avid the impacts of the impulse current or short-circuit current. It effectively solves the problem of power supply for On-line Monitoring System of Transmission.

Keywords: Monitoring System; Power Supply of High-voltage Transmission Line; Draw-out Power Coil; Single-chip Microcomputer

1. Introduction

The monitoring devices need to be installed directly in the transmission lines, so how to provide electrical power for the devices is one of the key issues we need to resolve. The power supply of study has important practical value. Now the most widely used method is the solar energy [1], but this method is susceptible to affected by climatic conditions, and lack of long-term maintenance-free capacity. The laser energy has been applied in the electronic current transformers and active optical current transformer [2, 3], but such power is not suitable for work in the field. Using the capacitive bleeder is the use of a capacitor to obtain energy from the high-voltage transmission, but the stability and reliability of this method is poor, and the power of the method is limited [4]. The best way of power supply is using CT to take energy directly from the transmission lines. In this paper, a new power supply used in high-voltage buses is designed and verified by experiments.

2. Basic Schematic of CT Inductive Power

The basic schematic of the power supply is shown in **Figure 1**.

The basic principle of Using CT to obtain energy is based on the Faraday's law of electromagnetic induction. Within the current range of 50 - 1000 A, using CT to induce from the high-voltage transmission, then after rectifying, voltage reduction, it can finally output stable 3.4V-DC voltage for on-line monitoring equipment.

3. Basic Principle of CT Inductive Power

3.1. The Theoretical Analysis of Draw-out Coil

The draw-out coil works like a transformer, its no-load equivalent model is shown in **Figure 2**.

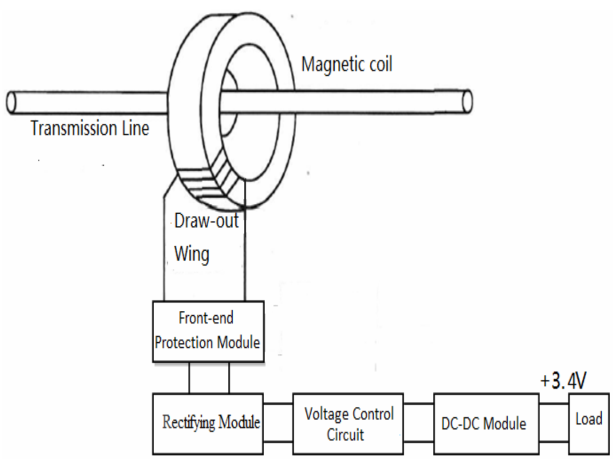

Figure 1. The basic schematic of the power supply.

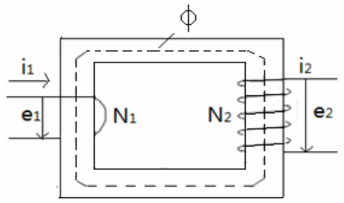

Figure 2. No-load equivalent model of draw-out coil.

According to the knowledge of the electromagnetic theory [5,6], the secondary voltage valid value is:

$$U_2 \approx E_2 = 4.44 f N_2 \Phi_m \quad (1)$$

where E_2 is the magnetic induction electromotive force RMS; f is the power frequency; N_2 is the secondary-side winding turns; Φ_m is the magnetic flux amplitude, the flux amplitude is:

$$\Phi_m = B_m S k \quad (2)$$

where B_m is saturation magnetic induction; k is laminated coefficient.

According to Ampere's circuital law:

$$H_m l = \sqrt{2} N_1 I_1 \quad (3)$$

where S is the cross-sectional area of the core; I is the average magnetic path length; I_1 is the exciting current; N is the primary winding turns, which takes one. The relation of magnetic induction peak and magnetic field strength peak is:

$$B_m = \mu_0 \mu_r H_m \quad (4)$$

where μ_0 is the vacuum permeability; μ_r is the relative permeability of magnetic core; H_m is the peak of the magnetic field strength. By the formulas (1)-(4) can be known:

$$E_2 = 4.44 f N_2 \Phi_m = 4.44 f N_2 \times \frac{\sqrt{2}\mu_0 \mu_r S k}{l} \times I_m \quad (5)$$

Form equation (5) we can be known that secondary-side output voltage of the coil is related to the primary side of the excitation current Im, and has no relation with the secondary-side current.

As is shown in **Figure 3**, from region 1 to region 4, the magnetic induction B is approximately proportional to field strength H, growing with the increasing of H. But in the saturation region, when Hm increases, Bm slows down or even not increases. The formulas (1) and (2) show that, If B_m does not change, the secondary-side voltage RMS E_2 unchanged. So E_2 does not grow with the increasing of wire current in the saturation region.

The literature [7] and experiment results show that the waveform of induced voltage distorts seriously and becomes into a narrow pulse waveform in deep saturation, which is a big challenge for the follow-up circuit. To solve this problem, to increase the magnetic saturation current ,the ways such as adding air gap to the power coil [8] and using feedback compensation control [7] have certain effects. But the air-gap width is hard to control and the structure is too complex, both of which have a bad effect on the reliability of the power.

3.2. Front-end Protection Module

When the transmission line being struck by lightning or short circuit, especially the lightning stroke, the relay protection device could not work timely, it will cause the lethal threat to the power apparatus circuit. The impulse current does not only electrical harm but also mechanical harm to the power apparatus. On the one hand, the impulse current can cause the draw-out coil inducing a transient high voltage. On the other hand, it can cause huge electric force to destroy the draw-out coil. In this paper, the double polarity transient suppression diode (TVS) and the voltage dependent resistor are paralleled as front-end protection, and filling with a soft buffer layer between the core and winding to reduce the impact of the electric force.

3.3. Voltage Control Circuit

The preceding analysis shows that, when the transmission-line current is higher than a certain value, the draw-out coil becomes saturated. The wave of secondary induced voltage become a peaked wave or even a high-amplitude pulse wave, so measures must be taken to limit the excessive voltage to prevent the DC-DC module from damage. Equation (5) shows that，when the draw-out core parameters and the turns of the secondary winding is a fixed value，the coil's secondary-side output voltage E_2 is only related to the primary side of the excitation current I_m. The higher the voltage E_2， the greater the excitation current I_m. In order to suppress the draw-out coil into saturation, we can reduce the secondary-side voltage of draw-out core to control the input voltage of the DC- DC circuit within the certain range.

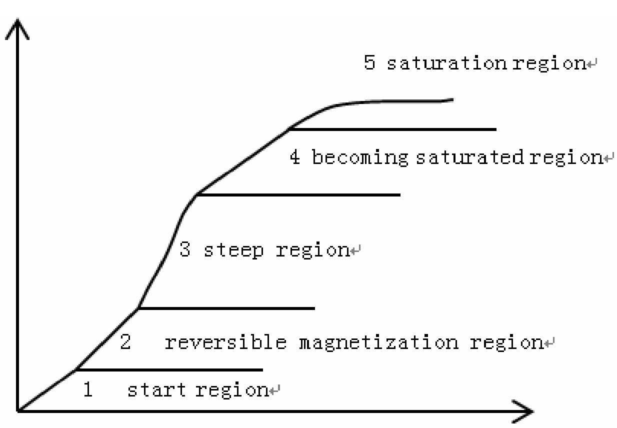

Figure 3. The magnetization curve of the magnetic material.

The voltage control circuit is shown in **Figure 4**, comprising a control signal circuit and a step-down circuit. Step-down circuit is mainly composed of NMOS transistor Q_1 and charge-storage capacitor C. When the DC-DC module input voltage is too high, Q_1 will work and discharge excess energy, to achieve the purpose of reducing voltage. Control signal circuit is constituted by the microcontroller of programmable counter array. When the voltage of the energy storage capacitor C exceeds the normal operating range, the Q_1 will be switched by the control of the microcontroller. Specifically, as shown in **Figure 4**, the normal operating range of energy-storage capacitor C voltage V_c is disposed as V_{c1}-V_{c2}. When V_c is higher than maximum normal operating voltage V_{c2}, the microcontroller outputs a high level signal to close the NMOS transistor Q_1. The excess energy is discharged through Q_1 and the load is powered by C, capacitor C supplies power for the load and its terminal voltage V_c decreases. When V_c is lower than minimum normal operating voltage V_{c1}, the control signal circuit have no output and the Q_1 open. The output power of the rectifier circuit directly supply to the load and charge-storage capacitor C.

The protection circuit includes a voltage regulator tube W_1, current limiting resistor R_1 and the grounding resistance R_2. When the voltage V_{in} exceed the breakdown voltage of W_1, W_1 is turned on, the current flowing through W_1 and producing a voltage drop on R_2. Therefore, the NMOS transistor Q_1 discharges the excess energy.

To verify whether the circuit can achieve the purpose of reducing voltage, we use the signal generator to replace the control circuit. It loop outputs different duty-cycle PWM wave to control the step-down circuit, using 47 Ω resistors R as the load. As shown in **Figure 5**, the transmission-line current is 200 A, after Q_1 is completely turned on, the voltage of R reduce from 30V to almost 0 V. As shown in **Figure 6**, when the transmission line current are 300 A, 400 A and 500 A,with the increase of the duty cycle of the control signal, the voltage across the resistor R gradually reduce. When the duty cycle of the control signal is about 90%, the voltage is about 10 V. The purpose of the step-down can be achieved.

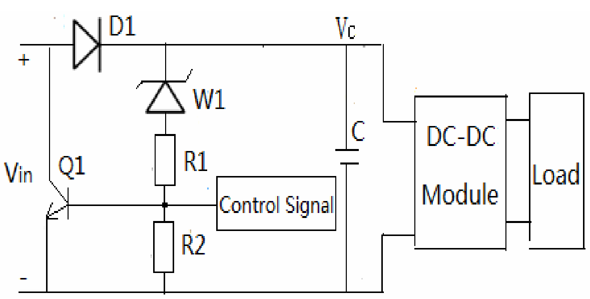

Figure 4. The voltage-control circuit.

4. Experimental Results and Analysis

4.1. Experimenting Platform

We choose the U93-MnZn ferrite U-shaped magnetic core which is produced by the Ferroxcube Company. after the calculation and experiments, the turns is chosen as 400, the diameter of enameled wire is chosen as 1mm.The draw-out coil can set in the transmission line with special design shell.

The experimenting platform is shown in **Figure 7**. The input of voltage regulator connect to 220V/50Hz AC, the current-generator output is short connecting for producing high current. It can change the output current of the current-generator by regulating the voltage regulator. For facilitating to measure the current of the draw-out coil,

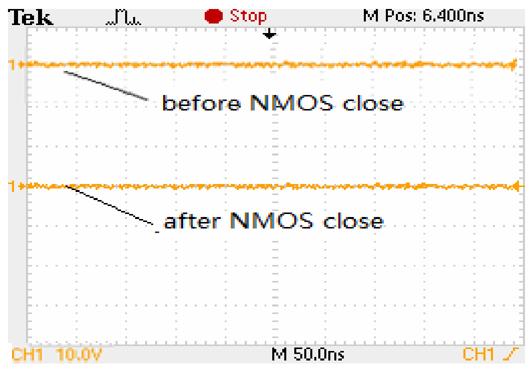

Figure 5. The voltage cross the load R.

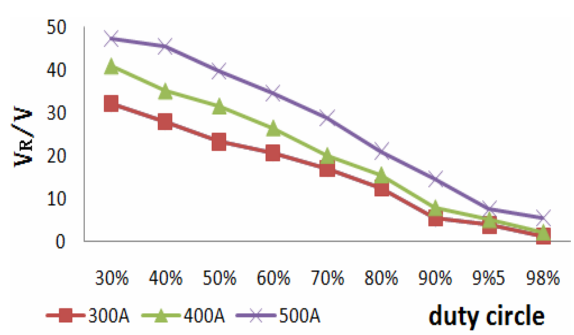

Figure 6. The relation diagram between the voltage of R and the duty cycle.

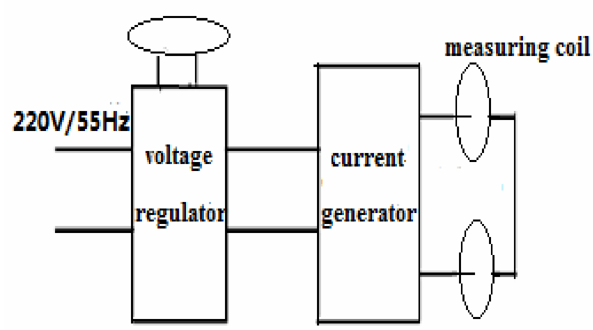

Figure 7. The platform diagram.

the high-accuracy current transformer is used to detect the current.

4.2. Testing Result and Analysis

When in start current 50 A, we need to test weather draw- out coil can provide enough power. We Use a variable resistor to simulate the changing load to test the coil output power. Experiments show that the coil output is related to the load. As is shown in **Figure 8**,with the current-generator output current I_1=50 A, when the load resister R is 150 Ω, the coil output power P_2 reach the maximum, as high as 653 mW. It can supply sufficient power for the load.

The design requirements of the draw-out power are that the starting current is 50 A, it can provide more than 500mW power the load (the normal operating power of the transmission line monitoring device with a GPS module is about 500 mW) and it can work stably within the range of 50 A to 1000 A of the transmission-line current.

Using 47 Ω resistors R as load, the power apparatus based on the above parameters is tested in the experiments. Form **Figure 9**, we can find that the maximum voltage of storage-capacitor C is 12.0 V, minimum voltage is 9.0V. When the NMOS transistor Q_1 close, the energy-charge capacitor C directly supply energy for load and its terminal voltage V_c decrease. When Q_1 open, the output power of the rectifier circuit directly supply to the load and charge capacitor C, the voltage V_c of C will increase. In **Table 1**, V_{max} is the maximum input voltage of DC-DC, V_{min} is the minimum voltage of DC-DC, V_{out} is the output voltage.

After the voltage-control circuit, DC-DC module input is 9.0 - 12.0 V and out a 3.4 V voltage within the range of 50 A to 1000 A bus current. With bus current 300A， the power apparatus continue working 300 minutes, the ripple wave within 300 minutes of DC-DC output voltage V_{out} is shown in **Figure10**. After the DC-DC module, the power apparatus can provide a stable 3.4 V voltage.

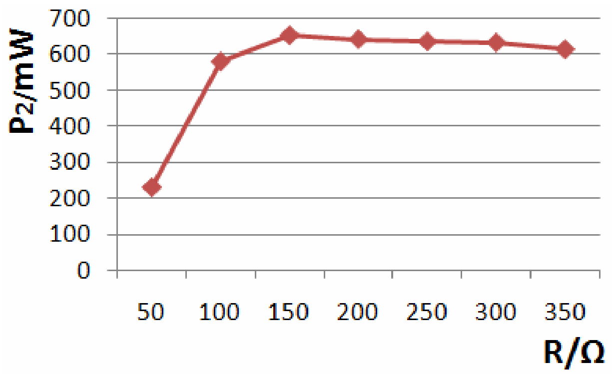

Figure 8. The relationship curve between the output power and the load.

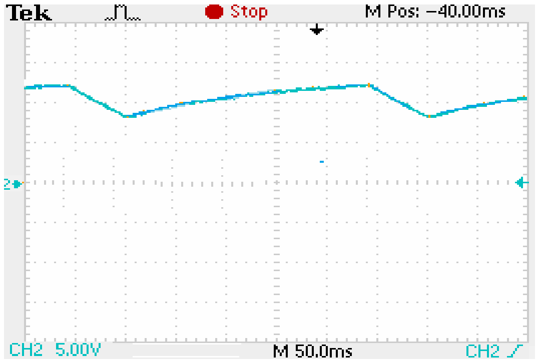

Figure 9. The voltage cross energy-shortage capacitor C.

Table 1. The output and input voltage of the DC-DC circuit.

Tramission-line current	V_{max} /V	V_{min} /V	V_{out} /V
50A	12.2V	8.8V	3.39V
100A	12.0V	9.0V	3.41V
200A	12.3V	9,1V	3.40V
400A	12.0V	9.1V	3.42V
600A	12.1V	8.9V	3.39V
800A	11.9V	9.0V	3.38V
1000A	12.0V	9.1V	3.40V

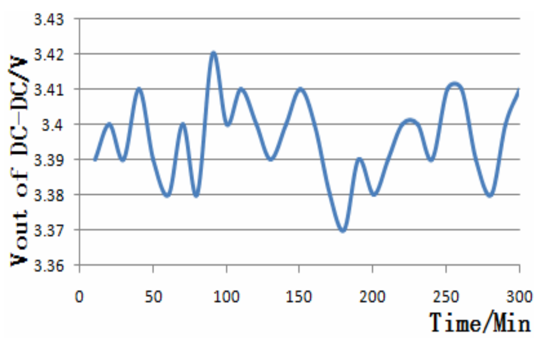

Figure 10. The ripple wave within 300 minutes of DC-DC output voltage.

5. Conclusions

In this paper, we study the issue about the power for the high-voltage on-line monitoring device. The analysis shows that using CT to induce energy is a low-cost, practical and viable way.

To save the problems of easily saturating and high-power consumption of the exiting power supply, the paper introduces a new design of the high-voltage-side induces power apparatus. A large number of experiments show that, the power apparatus of the paper can prevent the magnetic core from saturating in high current, steadily work in non-saturated and low-power consumption status within the range of 50 A to 1000 A transmission-line current.

REFERENCES

[1] S. B. Jiao, D. Liu, G. Zheng, *et al*., "On Line Insulator Contamination Monitoring System for Transmission Lines Based on Telemetry," *Automation of Electric Power Systems*, Vol. 28, No. 15, 2004, pp. 71-75.

[2] T. C. Banwell, R. C. Estes and L. A, Reith, *et al*., "Powering the Fiber Loop Optically-a Cost Analysis," *Journal of Light Wave Technology*, Vol. 11, No. 3, 1993, pp. 481-494. doi:10.1109/50.219583

[3] J. Song, P. G. Mclaren, D. J. Thomson, *et al*., "A Prototype Clamp-on Magneto-optical Current Transducer for Power System Metering and Relaying," *IEEE Trans on Power Delivery*, Vol. 10, No. 4, 1995, pp. 1764-1770. doi:10.1109/61.473382

[4] Z. Qian, "Power Supply for High Voltage Circuit of Active Electronic Current Transformer," *High Voltage Apparatus*, Vol. 40, No. 2, 2004, pp. 135-138.

[5] G.-Y. Qiu, Circuit, Beijing: Higher Education Press, 1999.

[6] Y-M Tang and N. Shi, "Electromechanics," Beijing: China Machine Press, 2002.

[7] L. Fu, "Research on Power Supply of Hybrid Fiber Current Transducer," Qinhuangdao: Yanshan University, 2004.

[8] Z. Wang, F. Zong, F. Wang, *et al*., Development of Power Supply in High Voltage Side of Transmission Lines," Power System and Clean Energy, Vol. 26, No. 6, 2010, pp. 24-27.