Design of Power Ripple Detection System for Carrier Module of Electric Energy Meter

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Abstract. DC power supply is usually obtained by rectification, filtering, voltage stabilization and other processes of municipal electricity. Due to the incomplete rectification or the existence of switching power supply, the output DC stability is superimposed with AC components, called ripple. The generation of ripple will bring noise, reduce the efficiency of power supply and affect the normal operation of the system. Strong ripple will cause the generation of surge voltage or current, and burn down electrical appliances and other equipment. This paper designs a detection device which can quickly and efficiently detect the ripple of carrier power supply. The experimental results show that the design system can help testers quickly judge whether the ripple of carrier module power supply meets the ripple voltage limit stipulated by Southern Power Grid Corporation, and is used to detect the ripple of power supply. Testing provides a new method of implementation.

1. Introduction

Generally, the power supplies used in products are divided into two categories: linear power supplies and switching power supplies. Generally speaking, the AC power is obtained by a multi-stage conversion process. In power production, AC power can be used to obtain DC power through rectifying, filtering, and stabilizing voltage. DC voltage can also be used to obtain AC power through inverter. During the AC-DC conversion process, because the filtering is not clean, the AC voltage is contained in the DC voltage, which causes ripple. Ripple is a complex clutter signal that fluctuates up and down around the output DC voltage. The ripple waveforms of different power sources are different.

Reference [1] is an improved circuit designed for a two-stage single-phase inverter that reduces the secondary ripple current while reducing the cut-off frequency of the voltage outer loop. Reference [2] is aimed at photovoltaic power generation systems. The LCL-T resonant network is introduced into a photovoltaic grid-connected inverter. When the switching frequency of the converter is equal to the resonant frequency, the low-frequency ripple in the output current of the photovoltaic cell can be effectively suppressed by the characteristics of the resonant network. Reference [3] proposed a new method based on the reverse current gain Ai (s) (input current vs. output current) model for analyzing the low-frequency ripple characteristics of DC-DC converters. Reference [4] uses an active filter to suppress power supply ripple, and introduces the structure and design points of the active filter.
Reference [5] proposed a method of using hybrid filters composed of passive filters and active filters to greatly reduce the current ripple of stable power supplies. Through analysis, we can see that the reference [1-5] is an optimized circuit designed from the perspective of reducing power supply ripple. Although good design methods and layout can reduce the influence of power supply ripple to a certain extent, it cannot completely eliminate the influence of power supply ripple, so precise detection equipment is still needed to detect the ripple value.

Q/CSG 1209003-2015 *Technical Specification for Single-phase Fee-controlled Electric Energy Meters* requires that the ripple Vp-p of the power supply should be less than 0.1%. In actual production, the ripple of the electric energy meter will not be tested in batches. The power supply ripple analysis is generally performed by means of an oscilloscope during sampling and testing. The test method is single, the level of automation is low, the workload is large, and it is susceptible to the size of the loop formed by the oscilloscope probe windings during the test.

The ripple detection system designed in reference [6] uses an oscilloscope with the Fourier analysis function to sample and analyze the ripple current of the actual prototype, and obtains experimental data and results that support theoretical analysis, but there are still some deviations. When using the oscilloscope for ripple voltage sampling, you need to hold the probe of the oscilloscope to touch the part to be measured, which results in a low level of automated testing. At the same time, the size of the contact loop and the artificial uncertainty will affect the accuracy of the ripple voltage sampling. As a result, there is a deviation in the sampled data at the source, and the superiority of the post-stage arithmetic circuit is difficult to compensate for the deviation caused by the randomness of the previous stage operation.

The power supply ripple detection system of carrier module based on microcontroller designed in this paper uses superior hardware circuits and advanced algorithm processing architecture. The automatic detection method can well solve the above problems. The device is pluggable, has a high level of test automation and is easy to carry, which greatly improves the test efficiency and accuracy level.

2. Research on power supply ripple mechanism
The power supply ripple of the electric energy meter carrier module port is due to the use of the BUCK circuit by the power supply of the carrier module. The switching characteristics of the BUCK circuit itself and the existence of dynamic characteristics devices such as inductors, capacitors and diodes are shown in Figure 1 below.

![Figure 1. Buck Circuit](image)

As shown in Figure 1 above, the inductor L and capacitor C form a low-pass filter, which has the same function as DC blocking high frequency, thereby suppressing the harmonic components of $Us$ from passing. The output voltage $Uo$ is the DC component plus a small ripple.

When input voltage in the BUCK circuit is 24V, the output voltage is 12V. The waveform of the output voltage monitored by the oscilloscope is shown in Figure 2 below. It can be seen that the ripple value in the figure is 25.2mW. If this power module is used on an electric energy meter as the power supply for the carrier module, it obviously does not meet the ripple design requirements.
The output voltage ripple $\Delta V_{\text{out}}$ is expressed as follows:

$$\Delta V_{\text{out}} = \frac{U_o}{f_s \times L} \times \left(1 - \frac{U_o}{U_s}\right) \times \left(\text{Resr} + \frac{1}{8 \times f_s \times C}\right)$$  \hspace{1cm} (1)

It can be seen from the formula that the factors that affect the ripple depend on the maximum operating frequency $f_s$ of the switch, the input voltage and output voltage, the inductance $L$, and the capacitance value $C$ in the BUCK circuit. Many parameters of the capacitor are temperature dependent [7]. $\text{Resr}$ represents the equivalent series resistance of the output capacitor. These factors together affect the ripple value.

For ceramic capacitors, the switching frequency impedance is dominated by the capacitor, and the output voltage ripple is mainly determined by the ceramic capacitor. To simplify the calculation, the output power ripple can be expressed as:

$$\Delta V_{\text{out}} = \left(1 - \frac{U_o}{U_s}\right) \times \left(\frac{U_o}{8 \times f_s \times 2 \times C}\right)$$  \hspace{1cm} (2)

For tantalum or electrolytic capacitors, the equivalent series resistance $\text{Resr}$ is dominant at the switching frequency. For simplicity, the output ripple $\Delta V_{\text{out}}$ can be approximated as:

$$\Delta V_{\text{out}} = \frac{U_o}{f_s \times L} \times \left(1 - \frac{U_o}{U_s}\right) \times \text{Resr}$$  \hspace{1cm} (3)

Through the analysis of the voltage ripple generation mechanism, it can be found that the types of components, manufacturing process, capacity, equivalent series resistance and other parameters in the circuit will affect the ripple voltage value. When designing the power supply, according to the specific circuit and component type, formulate some appropriate formulas to measure the ripple voltage value and reduce the ripple voltage.

This formula also provides a basis for the comparison between the theoretical analysis value of the ripple and the actual measurement.

3. Design of ripple detection system

The detection system is mainly composed of 6 parts: power module, carrier module power interface, filter conditioning circuit, signal amplification and conversion circuit, MCU main control circuit, and 485 interface circuit.
The power module provides energy for the device, so that the system can work normally. The carrier module power [8] interface is used to connect the voltage ripple of the carrier power to be detected. The filter circuit is mainly used to filter the DC voltage component and noise in other frequency bands [9], to obtain the accurate ripple voltage waveform as much as possible. The signal amplification and conversion circuit is mainly used to realize the ripple voltage amplification and A/D conversion, serial-parallel data conversion. The MCU main control circuit processes the received sample ripple signal and reproduces the ripple value. The 485 interface circuit is used for data exchange between the MCU main control circuit and the PC, and the ripple value is displayed on the host computer interface, as shown in Figure 3 below.

![Figure 3. System Block Diagram](image)

To realize the power supply ripple voltage detection, the circuit of each module needs to be cooperated one by one. The following is the introduction of the main module circuit principles.

3.1. Filtering and signal amplification circuit

The filter circuit is used to filter out unwanted clutter and obtain the ripple voltage to be measured. Since the ripple voltage is generally at the mV level, it is a small signal and is easy to be submerged, so it needs to be amplified by a signal amplifier circuit. The specific circuit is shown in Figure 5 below.

![Figure 4. Filter and Signal Amplifier Circuit](image)
In Figure 4, C12 is a filter capacitor with a value of 0.1uF, which can filter 12V DC and low frequency clutter from the power supply of the carrier module.

The signal amplifier circuit is composed of three AD817 op amp chips, R8 and R30 play the role of voltage division. The first AD817 is used for voltage follow-up and isolation [10-12], which isolates the front stage and the rear stage, and outputs a ripple signal with the same value as the divided voltage of the previous stage signal. The second AD817 constitutes a reverse proportional operational amplifier circuit, so that the output voltage is -5 times the input voltage. The third AD817 constitutes a forward adder circuit. The TL431 chip outputs a 2.5V standard voltage value. After the addition operation with the output of the previous stage AD817, the operation result is output.

3.2. A/D conversion processing circuit

The module circuit consists of a high-speed A/D conversion circuit and a data buffer circuit, which completes the functions of data acquisition, processing and conversion. The ADS830 high-speed A/D chip realizes high-speed analog signal sampling, converts the analog signal into a digital signal, and outputs an eight-bit digital signal in parallel to the IDT7205 chip for buffering and then transmits it to the MCU main control chip. The circuit schematic is shown in Figure 5 below.

![Circuit Diagram](image)

**Figure 5. A/D Conversion Processing Circuit**

4. System software design

The completeness of a device's function depends on the cooperation between hardware and software. If you compare a hardware circuit to a human body, software can be called a human way of thinking, controlling a person's behavioral pattern. On the basis of hardware and corresponding software programs, corresponding functions can be realized. Both software defects [13] and hardware defects [14] affect the overall performance of the entire system.

During the data processing of the software design process, the concept of training set was used, the learning idea of learning neural network was introduced, and the standard signal source was used to output small signal waveforms from small to large. The standard waveform is sampled by this system, and the ripple coefficient is continuously adjusted through multiple learning, so that the acquired waveform and the input standard waveform are perfectly matched. The training process flowchart is shown in Figure 6 below.
Figure 6. Learning Process Flow Chart

This process is the ripple coefficient value calibration. Before using this system to test the ripple, the calibration must be performed first to reduce the influence of uncertain factors on the accuracy of the ripple test value.

The calibrated device is used to detect the power supply ripple value of the actual circuit, and the power supply ripple value is displayed in real time. And compare it with whether the ripple value exceeds the limit, determine whether the power module design in the circuit is qualified, whether it meets the requirements of the power ripple range, and achieve the purpose of quantitative calculation of power ripple and qualitative analysis.

5. Systematic experimental research
The PCB soldering board and appearance of the device are shown in Figure 7 below.

Figure 7. PCB Soldering Board and Appearance of the Device
In Figure 7, the board 1 and the board 2 are connected by a plug-in unit and placed in a structural member. During the test, a signal generator is selected as the standard ripple source and injected into the circuit under test. The test results are compared with the standard ripple signal waveform to determine whether the measured ripple signal is accurately detected by software parameter calibration. Use the waveform generator to output a 10mV sine wave signal with a duty cycle of 50% and a frequency of 1 kHz, with an offset of 10mV. The waveform diagram is shown in Figure 8 below.

![Figure 8. Signal Generator Output Waveform Setting](image)

Next, connect the standard ripple signal to the input port of the carrier power supply of the detection device. The comparison between the standard ripple signal measured with an oscilloscope and the ripple waveform on the side of the detection device is shown in Figure 12 below.

![Figure 9. Output Waveform of Oscilloscope](image)
As shown in Figure 9 above, cyan is the standard ripple signal output by the signal generator, and the blue waveform is the ripple value measured by the oscilloscope at the input end of the ripple detection device. The two waveform diagrams are basically the same when compared. Use the host computer interface MODBUS to connect to the ripple detection equipment and set the parameters through the 485 bus. The waveform amplitude detection result can be displayed through the MODBUS interface, as shown in the red marked area in Figure 10 below.

![Image](image_url)  
**Figure 10.** Ripple Value Detected at MODBUS Interface

By adjusting the signal generator to output standard signals of different amplitudes to simulate the power supply ripple, it can be found that the ripple value displayed on the host computer interface changes with the input ripple value. Record the ripple value measured by the test device. The comparison results are shown in Table 1 below.

| Signal generator output value (mV) | Detection device output value (mV) | Absolute error (mV) |
|-----------------------------------|-----------------------------------|--------------------|
| 10                                | 9.0667                            | 0.9333             |
| 11                                | 9.8801                            | 1.1199             |
| 12                                | 10.8452                           | 1.1548             |
| 13                                | 12.1161                           | 0.8839             |
| 14                                | 13.0023                           | 0.9977             |
| 15                                | 13.9081                           | 1.0919             |

It can be seen from Table 1 that the ripple value measured by this device is very close to the standard ripple signal value, excluding the effect of signal offset, it can be considered that this indication is the ripple value. The experimental results show that this system can accurately, conveniently, quickly and real-timely detect the ripple changes and realize the power ripple detection function.

6. **Conclusion**

With the rapid development of information technology, the industrial structure is bound to undergo drastic changes, and modular design ideas are widely used. The future development trend of the power industry is bound to realize modular product portfolios. The reliability and compatibility requirements between modules will be higher. The emergence of this device will help to detect the power performance of each module, reduce the potential failure rate, improve the reliability of the product, and improve the
power management module of the product. It has played a certain role in promoting the development of the entire industry.

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