Research and Design of Harmonic Measurement Instrument for High-Voltage Transmission Lines Based on Field Strength Method

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Abstract. Along with the development of new energy technology, more and more power equipment such as inverters are used in power grids. The power injected into the grid by inverters contains a large number of harmonics, which seriously affects the quality of power emitted from public outlets. At present, inside the substation, voltage harmonics of high-voltage transmission lines can only be measured indirectly with the help of CVT/PT cabinets; outside the substation, the measurement of voltage harmonics of high-voltage lines is not possible due to the absence of CVT/PT cabinets installed. Therefore, a harmonic measuring instrument based on the field strength method is designed to detect the voltage harmonic content of the power grid more conveniently and accurately.The voltage harmonic signal is obtained directly through the field strength method principle, and the FFT technology is used to perform harmonic analysis on the collected grid voltage signal, and the isolation technology is used to make the measured voltage level between 10 kV and 220 kV. After the actual test, the measurement accuracy meets the B-level measurement accuracy stipulated by GB/T19862-2016 standard, which solves the problems of traditional measurement and improves the utilization of electric power transportation more.

Keyword: Eelectric field coupling · Harmonic detection · Wireless radio frequency · Field strength method

1 Field Strength Method for Obtaining Harmonic Signals

The electric field of the transmission line is a low-frequency alternating electric field, the wavelength is much larger than the geometry of the measuring instrument, so the calculation of its electric field can be done with the help of electromagnetic field theory, using the mirror method equivalent charge [1]. The electric field strength is expressed as a function [2].

$$E = E_x \sin(\omega t + \varphi_x)x_0 + E_y \sin(\omega t + \varphi_y)y_0 \tag{1}$$

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Style (1): there are $\varphi_x \neq \varphi_y$, that is, the electric field intensity synthesized at any point is a rotating elliptical field. In practice, when considering a single-phase conductor and neglecting the effect of the charge generated on the other two phases of the conductor, the field strength is determined by the line's own charge only, i.e. $E_\mathrm{i} \approx \frac{Q_i}{2\pi\varepsilon R_i}$.

The error in the calculation is usually no more than 0.5%. Therefore, a point in space $P(x_i, y)$ is chosen to be at a point with the same horizontal coordinate as that wire $x - i$, see Fig. 1.

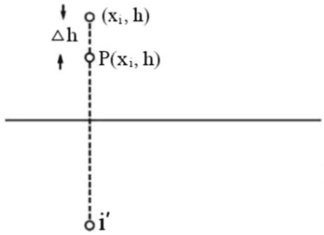

Fig. 1. Vertical distribution of the field strength of the conductors

$$E_{px} = \frac{Q}{2\pi\varepsilon}\left[\frac{x^2}{x^2 + (h-y)^2} - \frac{x^2}{x^2 + (h+y)^2}\right] \tag{2}$$

$$E_{py} = \frac{Q}{2\pi\varepsilon}\left[\frac{h-y}{x^2 + (h-y)^2} - \frac{h+y}{x^2 + (h+y)^2}\right] \tag{3}$$

When $x = 0$, there are $E_{px} = 0$, $E_{py} = \frac{Q}{2\pi\varepsilon}[\frac{1}{(h-y)} - \frac{1}{(h+y)}]$.

Suppose the voltage transient value of the high-voltage transmission line is $u_i = u_1 \cos(\omega t + \varphi) + u_2 \cos(3\omega t)$, note that the vertical distance between the point P and the wire is $\Delta h = h - y \geq R$, according to the principle of superposition can be obtained at the point $P(0, y)$ the field strength transient value is

$$\begin{cases} E_{px} = 0 \\ E_{py} = \frac{u_1}{\ln\frac{2h}{R}}(\frac{1}{\Delta h} - \frac{1}{2y + \Delta h})\cos(\omega t + \varphi) + \frac{u_2}{\ln\frac{2h}{R}}(\frac{1}{\Delta h} - \frac{1}{2y + \Delta h})\cos(3\omega t) \\ |E_p| = \sqrt{E_{px}^2 + E_{py}^2} = \sqrt{\frac{1}{\ln\frac{2h}{R}}(\frac{1}{\Delta h} - \frac{1}{2y+\Delta h})^2(u_1\cos(\omega t + \varphi) + u_2\cos(3\omega t))} \end{cases} \tag{4}$$

There are two points in the electric field, assuming that the vertical distance between the two points and the wire is Δh_1, Δh_2, and the ground is zero potential, the potential of P_1 is expressed as

$$U_1 = \int_{h-\Delta h_1}^{h} E_p d\Delta h = \frac{1}{\ln\frac{2h}{R}}(u_1\cos(\omega t + \varphi) + u_2\cos(3\omega t))\ln\frac{h}{h - \Delta h_1} \tag{5}$$

P_2 The electric potential of

$$U_2 = \int_{h-\Delta h_2}^{h} E_p d\Delta h = \frac{1}{\ln\frac{2h}{R}}(u_1\cos(\omega t+\varphi)+u_2\cos(3\omega t))\ln\frac{h}{h-\Delta h_2} \tag{6}$$

P_1 The voltage difference between P_2 and

$$U = U_1 - U_2 = \frac{1}{\ln\frac{2h}{R}}(u_1\cos(\omega t+\varphi)+u_2\cos(3\omega t))\ln\frac{h-\Delta h_1}{h-\Delta h_2} \tag{7}$$

Let $U_m = \frac{1}{\ln\frac{2h}{R}}\ln\frac{h-\Delta h_1}{h-\Delta h_2}$,
then $U = U_m[u_1\cos(\omega t+\varphi)+u_2\cos(3\omega t)]$.

Equation (7) shows that in the space of two points and the wire distance to maintain a constant situation, the two points between the voltage difference signal amplitude value and the corresponding high-voltage line voltage signal is proportional to the relationship. Therefore, the field strength method is used to obtain the voltage difference signal at two points in the vertical direction near the high-voltage line, and then analyze the harmonic content of the high-voltage line.

2 Design of Harmonic Detector

High voltage transmission line harmonic detector consists of: a harmonic measurement sensor and a handheld receiver device, which transmits data via radio frequency between the detection sensor and the handheld receiver device.

2.1 Design of Harmonic Measurement Sensor

The principle block diagram of the harmonic measurement sensor is shown in Fig. 2.

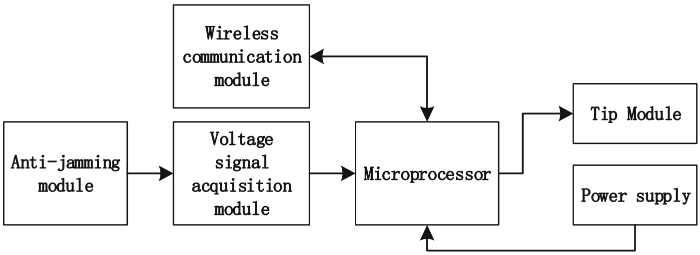

Fig. 2. Block diagram of the principle structure of the harmonic measurement sensor

2.1.1 Anti-interference Module

The interference problem of high-voltage strong magnetic field is solved by using shielding and high-frequency modulation technology [3], and the communication distance under high-voltage strong magnetic field conditions reaches more than 20 m. Using the principle of equalizing voltage, a circular shield is used to solve the problem of harmonic detection sensor tip discharge of portable high-voltage line harmonic detector.

2.1.2 Voltage Signal Acquisition Module

Bring the harmonic measurement sensor electrode close to the high-voltage transmission line with a handheld insulated operating rod, and the voltage signal acquisition circuit design is shown in Fig. 3.

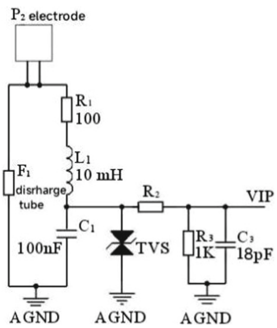

Fig. 3. Voltage signal acquisition circuit

If the harmonic measurement sensor is put into the electric field, according to the electric field theory, a certain amount of charge will be induced on the sensor electrode, Causes stray capacitance between the electrode conductor of the harmonic measurement sensor and the high-voltage transmission line.

The capacitors C_1,C_2 and C_3 form a series circuit, according to the principle of series impedance divider, thus the voltage signal consistent with the harmonic content of the high-voltage transmission line can be coupled at both ends of the voltage divider capacitor C_1. When the electrode touches or approaches the wire, a voltage signal with the same frequency and phase as the line signal will be induced at both ends of the electrode, and then a voltage signal of moderate amplitude will be obtained through the voltage divider capacitor for subsequent circuit acquisition and processing.

The equivalent circuit for acquiring the alternating voltage signal in Fig. 3 is shown in Fig. 4. The capacitor $C_{\_G}$ represents the equivalent capacitance generated by the electrode, and the capacitor $C_{\_F}$ represents the voltage divider capacitance of $C_1 \sim C_3$ in Fig. 3.

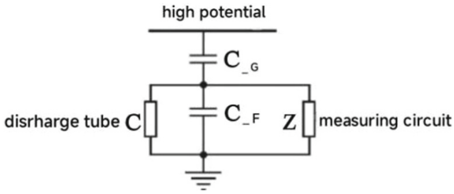

Fig. 4. Equivalent circuit for alternating voltage signal acquisition

2.1.3 Anti-aliasing Filter Circuit

Considering the standard FFT transformation requires the number of sample points per cycle to be 2^n, the processing speed of the chip and the maximum time interval of the conversion of the A/D module, $f_s = 6400$ Hz is selected. Identified as CFA-based 6th-order Butterworth low-pass filter[4], two third-order filters are designed from Fig. 5, and then two sections of the third-order low-pass filter are cascaded to obtain the 6th-order Butterworth low-pass filter.

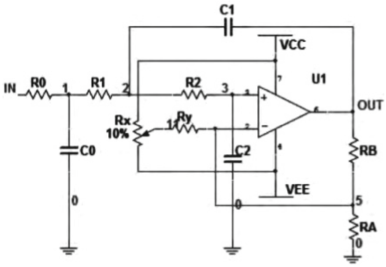

Fig. 5. Third-order low-pass filter improvement circuit improvement circuit

2.1.4 Wireless Communication Module

Using electric field coupled wireless RF transmission of harmonic information, the flow block diagram is shown in Fig. 6. Electric field coupled no RF technology to alternating electric field as a carrier of energy wireless transmission, first by the original side and vice side of a variety of plate components, and then with a number of coupling capacitors to increase the channel of energy transmission.

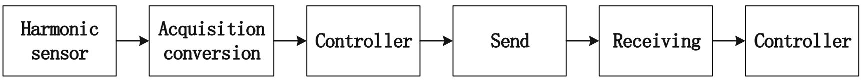

Fig. 6. Wireless RF flow block diagram

2.1.5 Prompt Module

Using two two-color light-emitting diodes and a buzzer, when the power is on an indicator light green, when coupled to the electric field signal two indicators light green, when the electric field signal is too strong two indicators light red, buzzer continuous sound.

2.2 Design of Handheld Receiver Device

The handheld receiver device mainly completes the functions of data reception, analysis and calculation, display of results, storage and query. The structure is illustrated in Fig. 7.

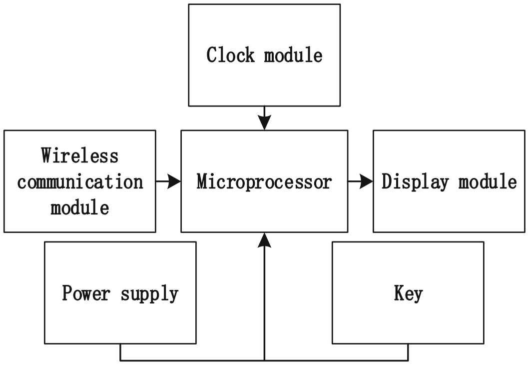

Fig. 7. Block diagram of the principle structure of the handheld receiver

3 Software Implementation Methods for Systems

3.1 Analysis of Voltage Harmonics Algorithms

The article's calculation of the harmonic components is the use of the Fourier algorithm[5]. The basic principle of the FFT algorithm is to decompose the DFT of a long sequence into the DFT of a shorter sequence one at a time.This system uses the time-extracted FFT algorithm, i.e. the base 2- FFT transformation.

3.2 Components of a Harmonic Detection System

The system mainly consists of a voltage acquisition module, waveform change circuit, A/D conversion circuit, microcontroller, etc. The structure diagram of the system is shown in Fig. 8.

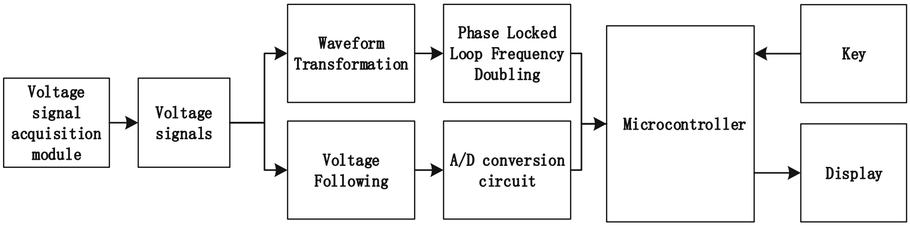

Fig. 8. System architecture diagram

The working principle is that the voltage signal is collected by the voltage acquisition module, then the signal is sent to the AD574 to complete the A/D conversion, the sampled data is read by the microcontroller and the voltage data is saved. Once a cycle of 32 samples has been taken, the harmonic value is obtained by the FFT algorithm, and the harmonic value is displayed according to the keypad.

3.3 Implementation of a Harmonic Detection System

The main function of the system is data acquisition and processing. The main control flow diagram is shown in Fig. 9.

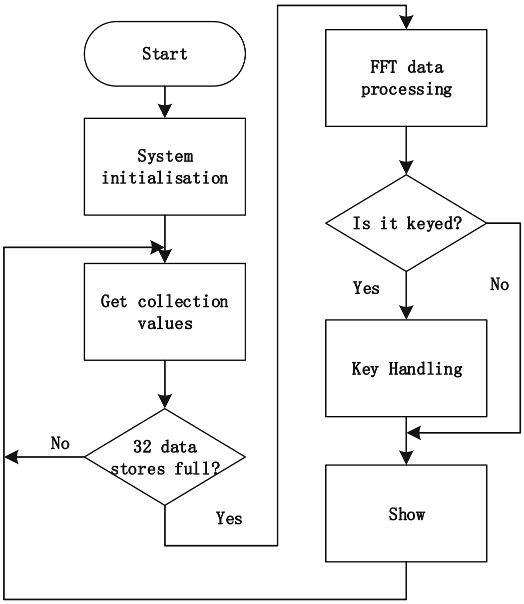

Fig. 9. Main control flow chart

4 Comparison of Experimental Data

Multifunctional three-phase electrical measuring instrument calibration device, the results of which are shown in Table 1.

Table 1. Odd harmonic measurement data

Data	Harmonic content/%	Measurement of harmonic content %	Absolute error
3	15	15.11	0.11
5	10	9.89	-0.11
7	5	5.02	0.02
9	3	3.17	0.17
11	3	2.98	-0.02
13	2	2.07	0.07
15	1	1.25	0.25

Generally only odd harmonics are analysed in the study of harmonics in power grids, because odd harmonics cause more harm than even harmonics.Therefore only the individual odd harmonic components are covered in the analysis of the data in the table above. When the data are analysed on this basis, there are large individual deviations, but none of the absolute errors exceed 0.5%, the errors being caused by the lack of strict synchronous acquisition. The accuracy was measured experimentally at 0.5 level, which meets the requirements of the national standard.

5 Conclusion

Through a combination of theoretical analysis, hardware design and experimental measurement, the field strength method and FFT are proposed to achieve the detection of voltage harmonics of high-voltage transmission lines, and a harmonic measuring instrument based on the field strength method is also designed, and the results show that the harmonic measuring instrument can measure the harmonic content of high-voltage transmission lines more accurately by comparing the measurement data of this instrument with the actual measurement results. The harmonic detector overcomes the traditional harmonic detection only for the station transmission line voltage harmonics detection, measurement accuracy is low and other problems, easy to use, not only for the substation station harmonics, but also for the substation station outside the harmonic condition can also be detected, has important significance for understanding the transmission line harmonics, has a very good promotion and application value.

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