A Transmission Tower Voltage and Discharge Condition Monitoring Method

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Abstract. A kind voltage stability of the transmission tower and discharge state monitoring method is introduced in this paper. The system structure and module function of the method is expounded and the key module circuit is explained, and the implementation principle of this method and the matters needing attention are analyzed detailed. This method is different from traditional measurement method that no need to install and monitor near high-voltage transmission lines, and it is safe and convenient to monitor transmission status of towers in real time.

1. Introduction

The stability of the power system focuses on the behaviours of the power system under conditions such as sudden changes in the load or generator, and short circuits in the transmission line [1]. Power systems stability includes static stability and transient stability. Among them, static stability means that the system can maintain its own stability during the entire power running process. System operation needs to be constantly interfered by external factors, and ensuring its own stability is the basis and premise. Therefore, it is important to strengthen static stability. In addition, for transient stability, it is mainly aimed at the stability of the system after being subjected to external interference. Since this stability needs to face a series of uncertainties, it is relatively difficult. However, many measures will be adopted in the specific work [2].

With the continuous development of economy, all walks of life have put forward higher requirements for the quality of power supply. The stable operation of the line has become the key to the reliable operation of the power grid. With the increase in the size of the grid interconnection, a large number of new stability issues continue to emerge. How to prevent a system-wide stable accident from causing a chain reaction due to the failure of a certain device or line is extremely important when the network structure is relatively weak. Once the stability of the power system is destroyed, huge economic losses and catastrophic consequences will be inevitably caused [3].

At present, the instruments for monitoring the operational status of iron towers are mainly focused on the monitoring of transmission tower voltages, currents, tilting of towers, and lightning currents have been developed domestically, which can detect line problems in advance and ensure reliable operation of the lines. However, the method of monitoring the operational stability of the line is relatively simple.

In view of the above situation, an indirect method for the detection of voltage stability and discharge state of transmission lines is proposed in this paper. In this method, the operator is not directly close to the high-voltage wire, which has the advantages of convenient installation, simple measurement, and low investment cost once.
2. The Principle of Transmission Tower Voltage and Discharge Monitoring

Transmission towers serve to support the overhead transmission line conductors and ground lines and to make them and their distance from the earth and the tower meet the requirements of electrical insulation safety and power frequency electromagnetic field constraints. The transmission line is suspended on the tower by a tensile insulator, and the insulator must be able to withstand the voltage of the line and insulate it from the tower. During the power transmission process, under the alternating voltage, a harmonic magnetic field is formed around the transmission line, that is, a primary field. The tower body forms a resonant voltage under the action of a harmonic magnetic field. When the power transmission tower is in stable operation, the formation of the resonant voltage of the tower is also relatively stable. In a certain period of time, the overall characteristics of the resonant voltage will not fluctuate significantly. The erection of a rigid support structure for transmission lines also serves to prevent corona discharge and the danger of inducing an electrostatic field to humans.

Since the discharge signal of the tower is mainly the electromagnetic field signal with high frequency components, the signal distribution of the tower and the electromagnetic signal are compared and then the calculation and analysis are compared. The original signal of the tower itself is extracted and restored, and the voltage stability and discharge conditions of the transmission tower are obtained.

The device mainly includes a solar power supply module, a tower signal acquisition module, an interference signal acquisition module, an operation processing module, and a GPRS wireless communication module. The tower signal acquisition module is used to collect the voltage of the tower body, perform basic filtering on the signal and further calculate and analyze the signal status of the tower body. The interference signal acquisition module uses a loop antenna to collect background interference electromagnetic field signals in the analysis space. The operation and processing module calculates the voltage and discharge conditions of the tower by comparing the characteristics of the two signals, and finally sends the calculated result to the terminal through the GPRS wireless communication module. The voltage regulation module system structure is shown in Figure 1.

![Figure 1. Voltage regulation module system structure](image)

3. Solar Power Module

Because the system is operating outdoors, it is difficult to use traditional power supply wiring for complex terrain, and using battery power needs to be periodically replaced and suitable for long-term monitoring needs. The solar power generation technology has the advantages of wide distribution of solar energy resources, small geographical restrictions, no mechanical parts, no noise, and good stability, as well as simple maintenance and low maintenance costs [4-5]. Through comprehensive consideration, the system uses solar energy for power supply. The power supply module is mainly divided into three parts: solar panels, batteries, and controllers. Solar panels are used to absorb solar radiation, convert solar radiation into electrical energy through photoelectric effects, and store energy in batteries. The controller controls the charging and discharging process of the battery, stores electric energy during the day and provides discharge at night and monitors and controls the battery power at
the same time to avoid overcharge or over discharge of the battery. Generally, the battery is charged to about 90%, and the remaining discharge capacity is 5% to 20% to ensure long-term stable operation of the power supply module. The solar power supply module structure is shown in Figure 2.

![Solar power supply module structure](image)

**Figure 2.** Solar power supply module structure

4. The Signal Acquisition Module

The signal acquisition module consists of a signal sensor, a pre-filter circuit, and an analog-to-digital conversion circuit. Mainly used to filter out the broadcast signal in the space, mobile phone signals, etc., where the background noise signal sensor uses multiple loop antenna loops for signal reception. The filter circuit and the antenna as an important part of the sampling module play an important role in the entire system, and careful and reasonable design of their parameters has a very important significance for the overall performance of the system.

4.1. Background Noise Antenna

The system uses a multi-turn antenna composed of multiple ring antennas for signal reception. The greatest advantage of a circular magnetic field antenna is that it receives only part of the energy of the magnetic field in the electromagnetic wave and converts it into a current signal that can be collected. The biggest advantage that this kind of antenna brings to the system is that it cannot obtain the strong electromagnetic interference caused by the high voltage electric field formed in the space around the high-voltage transmission line. Because of the use of bipolar or long-line antennas in such a strong electric field environment, most signals will be buried in strong electromagnetic interference noise, which is not conducive to the effective extraction of noise signals by the system.

Multi-frequency antenna refers to a wide-band antenna that contains three or more working frequency bands in one antenna band. Because the system's background noise sampling range is wide 10kHz-20 MHz, it is difficult to use a single antenna to meet the full-bandwidth reliable reception, so the use of multi-frequency antenna for signal reception, each sub-antenna corresponds to signals in different frequency bands, so as to achieve reliable reception of signals in the entire frequency band of 10 kHz to 20 MHz. The receiving frequencies by secondary antenna of multi-frequency antenna are shown in Table 1.

| Secondary Antenna   | Frequency          |
|---------------------|--------------------|
| 1 secondary antenna | 10kHz-220kHz       |
| 2 secondary antennas| 190kHz-2MHz        |
| 3 secondary antennas| 1.9MHz-20MHz       |

4.2. Pre-Filtering Module

The pre-filter module performs preliminary filtering on the output signal of the signal sensor and uses an LC low-pass filter circuit. The filter module is a filter circuit composed of a capacitor, an inductor, and a resistor, and can form a low-impedance bypass for the main sub-harmonic waves. The LC filter
is a passive filter and does not require additional power. The system uses an inverted L-type filter and is suitable for filtering high-frequency signals with low input impedance and large output impedance. The LC filter circuit is shown in Figure 3.

\[
\frac{1}{sC} = \frac{1}{sL + \frac{1}{sC}} = \frac{1}{L\omega_0^2 + \frac{1}{R_L} s + 1}
\]

where \( R_L \) is load impedance and \( \omega_0 = \frac{1}{LC} \) is resonant frequency. The capacitance and inductance are calculated by the following formula, \( C = \frac{1}{2\pi f_c R} \) and \( L = \frac{R}{2\pi f_c} \), where, \( f_c \) is the cut off frequency of the signal, \( R = \frac{L}{C} \) is the load resistance. The inductor is made of a non-destructive magnetic core and made of enamelled wire. The digital bridge is used to measure the nominal inductance, and the capacitor uses a high-frequency ceramic dielectric capacitor. The filter module is installed in the metal shield box, and the installation position is as close to the antenna as possible. At the same time, the ground terminal is reserved on the metal box for reliable grounding.

4.3. A/D Conversion
As a core device for acquisition, an AD9268 analog-to-digital conversion chip is used in the analog-to-digital conversion circuit. HMC960 is used as the front end a programmable gain amplifier to ensure optimal sampling performance over a wide range of voltages in this system. The HMC960 is a digitally programmable dual-channel variable-gain amplifier that supports discrete gain steps of 0 to 40 dB in steps of 0.5 dB with high bandwidth and supports 0-100 MHz. The device uses a glitch-free architecture with excellent smoothing gain transition performance. The device's matched gain path provides excellent orthogonal balance over a wide signal bandwidth, is suitable for interfacing with sensors, and drives high sampling rate analog-to-digital converters.

The AD9268 is a dual, 16-bit, 125 MSPS analog-to-digital converter (ADC) with 650MHz bandwidth. It features a proprietary differential input that maintains excellent signal-to-noise ratio at input frequencies up to 300Hz. In this system, we measure the frequency signal of 20Hz-50MHz. According to the Nyquist sampling law, the sampling rate of the sampling rate should not be less than twice the maximum frequency of the signal. The original continuous signal can be completely reconstructed from the sampling sample, i.e. the sampling rate. To meet more than 40MHz, the chip meets the requirements. The functional composition of the sampling module is shown in Figure 4.
The HMC960 and AD9268 chips form a programmable gain analog-to-digital conversion system. The pre-filter module's pre-filtered signal is further amplified and sampled, and the sampled data result is submitted to the arithmetic processing module for data analysis.

### 5. Arithmetic Processing Module

#### 5.1. Digital Signal Processing Chip
Digital signal processing is the core of real-time signal processing. Compared with ordinary microprocessors, it is optimized for signal processing, instruction systems, and processor architectures to accommodate numerically intensive real-time processing. The system operation and processing module uses a digital signal processing chip ADSP21060 [4]. The chip uses Super Harvard architecture with four independent buses, an instruction cycle of 25ns, and an arithmetic unit capable of 32-bit fixed-point and 32-bit or 40-bit floating point operations. It is a high-performance floating-point DSP chip. Its main features include: (1) Operation speeds of 40 MIPS and 80 MFLOPS up to 120 MFLOPS. Each instruction is completed in one cycle; (2) 2 sets of serial ports and 6 sets of link ports. Each serial port can work in full duplex with a maximum transmission rate of 40 Mbit/s and a word length from 3 bits to 32 bits. (3) The 1024-point complex FFT operation time is 0.46 ms[5, 6]. The calculated speed at 40MHz operating frequency is shown in Table 2.

|                         | 0.46ms | 18221 cycles |
|-------------------------|--------|--------------|
| 1024-Pt Complex FFT (Radix4, with Digit Reverse) |        |              |
| FIR Filter (per Tap)    | 25ns   | 1 cycle      |
| IIR Filter (per Biquad) | 100ns  | 4 cycles     |
| Divide (y/x)            | 150ns  | 6 cycles     |
| Inverse Square Root (1/x)| 225ns  | 9 cycles     |
| DMA Transfer Rate       | 240Mbytes/s |

This system uses ADSP21060 to carry on the FFT operation to the collected signal, the 40 MIPS operation speed, the single-channel 0.14ms 1024-point complex FFT operation time completely satisfies the high performance requirement that the system carries on the fast processing analysis to the signal.

#### 5.2. Signal Analysis Algorithm
After the signal undergoes a fast Fourier transform, the amplitude of the corresponding frequency can be obtained to continue further analysis of the amplitude-frequency characteristics of the signal. When the sampling frequency is \(F_s\), the sampling signal frequency \(f\), the number of sampling points is \(N\), \(F_s\) is generally \(2^n\) times of \(f\), \(n\) is a positive integer, and the resolution of the sampled signal is \(F_s/N\), for example, \(F_s = 40MHz\), \(N = 1024\), \(f = 20MHz\), with a resolution of \(1024MHz/1024 = 1Hz\). The resolution increases with the number of sampling points. The first point
is the DC component. The amplitude $K$ obtained from the Fourier transform is converted into the signal amplitude formula, DC component amplitude $= K/N$, AC component amplitude $= K/(N/2)$[7-9].

By comparing the amplitude-frequency characteristics of the tower signal sampling module and the interference signal acquisition module, the system removes the background interference signals of the same component from the tower signal to obtain the voltage signal of the tower. By analyzing the frequency spectrum characteristics of the frequency range of 20-500Hz, monitoring the changes in the unit time, determine the operating stability of the transmission tower; by analyzing the frequency spectrum characteristics of the 100 kHz-20MHz frequency band, comparing with the characteristics of typical discharge spectrum, the discharge conditions and discharge types of transmission lines were analyzed.

5.3. Voltage Stability Algorithm

After the signal acquisition is completed, the arithmetic processor extracts the amplitude of the power frequency component in the analysis signal. At the same time, the amplitude storage is stored in the data memory of the operation processor. The arithmetic processor calculates the data stability parameter through a specific formula, which is used as a judgment basis for the overall voltage stability of the tower.

The signal stability parameter $D_{sta}$ is then obtained by dividing the amplitude standard deviation by the amplitude average. The closer the value is to 0, the more stable the data is within a specified period of time. $D_{sta} = \text{stdev}(X_1, X_2, \ldots X_n) / \bar{X}$.

Where, $\text{stdev}(X_1, X_2, \ldots X_n) = \sqrt{\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \cdots (x_n - \bar{x})^2}{n-1}}$, $\bar{x} = \frac{x_1 + x_2 + \cdots x_n}{n}$.

6. GPRS Wireless Communication Module

The on-line monitoring system of power transmission towers, in order to solve the cable-based monitoring equipment, is susceptible to strong electric field signal interference, especially in the more difficult and complicated terrain of the mountainous areas, the laying of cables is difficult. Therefore, using GPRS wireless communication, the resulting data is transmitted to the monitoring background. The system uses the SIM908 module for data transmission. The SIM908 is a quad-band GSM/GPRS low-power module that integrates GPS navigation technology. GPRS can transfer module data to the server through the mobile network. GPS supports global positioning, enabling seamless tracking of different assets wherever and whenever GSM and GPS signals are covered. GPS positioning accuracy, positioning accuracy: <2.5 meters CEP. With RS232, UART communication interface, using AT commands to control. The AT command is a string ending with AT as the first character. Each instruction has a corresponding return for success. The quick debugging and configuration can be realized by using the serial debugging assistant, or supporting software.

The SIM908 module sends the positioning data together with the voltage stability parameters and discharge conditions to the background terminal. Through the background software, the distribution of the transmission towers in the map can be viewed in real time and the operation status of each transmission tower can be checked. The system will further analyze the background data in order to evaluate the overall operation of transmission lines on transmission towers.

7. Conclusion

The stability of the power system is the basis and prerequisite for improving the operation of the power company. The structure of the power system is complex and it is of great significance to adopt scientific measures to monitor the power grid for safe and stable operation of the power grid. The core idea of this method is to extract the signal characteristics of the iron tower itself from the background noise by collecting the spectral characteristics of the signal of the contrast tower and the spatial background signal, and indirectly determine the voltage status and discharge status of the iron tower through waveform analysis. In this way, effective and convenient on-line monitoring of the operational stability of power transmission towers is realized. The method avoids the installation of
high-altitude operations and can quickly establish a monitoring network for the operation of high-voltage lines under the condition that each high-voltage tower is used as a monitoring point. With high sensitivity and light weight, it can effectively judge whether the equipment is operating normally. It is an on-line monitoring method suitable for reference by power departments and research institutes.

8. References
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