Research on EME of real-time monitoring system

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Abstract. With the increase of the number of substations, the precision of electromagnetic environment parameters is higher. At present, there are many defects in the electromagnetic environment measuring system, such as the nonstandard data and the difficult reutilization. And many circuits with self-scale are controlled by switch, it has a great impact on the switching time and the service life of the device. A method of magnetic field range smooth switching is provided in this paper which is based on the magneto resistivity and the control of MCU, applying this method to the monitoring system which has functions of distributed data, real time data display, data storage and unified management etc.

1. Introduction
As the rapid development of smart grid construction, the number of high-tension transmission lines and smart substations is increasing day by day. However, with the enhanced awareness of human rights, the disputes caused by electromagnetic environment have hindered the development of electric power industry. Therefore, it is of great significance to study the real-time monitoring system measuring the magnetic field strength of substations [1].

In order to implement monitoring task and to improve the measurement result of wide dynamic range of magnetic field, particular attention should be paid to the influence of measurement accuracy, the real-time measurement and the cost of the measurement range switching method in the measurement process. Therefore, the factors should be comprehensively considered in the design process of monitoring systems [2].

1) The interference caused by magnetic field measurement circuit will cause low measuring precision of traditional measurement.
2) The frequent use of range switch circuit cause more failure rates.
3) The switching of magnetic field range is real-time to make it feasible to automatic switching.
4) The goal is to achieve accurate measurement and to reduce the cost of component.

According to key points mentioned above, this paper studies an electromagnetic environment of real-time monitoring system (EME-RTMS) which can realize the automatic and smooth translation of magnetic range at low cost and high accuracy. Meanwhile, EME-RTMS has powerful ability of data process and analysis. It supports not only database searching but also online analysis of users' submitting data via a user-friendly interface.

2. Electromagnetic environment of real-time monitoring system
EME-RTMS provide possible pathway for displaying real-time information of electromagnetic environment parameter for people living near substation and providing unified entrance for monitoring
data. The system is easy to be built, and easy to expand the site [3, 4]. The system is composed of three modules such as monitoring station, real-time data management and users. The monitoring station module completes data gathering and processing. The data finally is transferred to PC by wireless transmission module. In the real-time data management module, the PC stores data into database and then the computer deals with the data and displays the information to the analyst in real-time. In the user module, the PC can choose different content and models to display in user’s view in outdoor display systems. Three modules work together to complete the complexity of EME-RTMS functions, which provides an effective way for real-time monitor and analysis and display.

![Diagram of EME-RTMS System](image)

**Figure 1. The structure diagram EME-RTMS**

The topology of EME-RTMS is shown in Figure 2. An open wireless network is adopted as the solution to network buildup. C/S structure is generally based on a small scale network environment, and pays more attention to the process. It can be verified with multi-level permission, and has a strong control ability of information security. Therefore, C/S structure is more suitable for the presence of the network transmission. For the monitoring center of transmission network which need remote monitoring and data management, B/S structure can break the limitation of hardware environment and realize the integration of heterogeneous systems and data sharing between users [5]. With the application requirements of EME-RTMS, the system is developed with hybrid architectures of C/S and B/S.
The web site of the monitoring center adopts the Browser/Server structure. A convenient user interface is provided by web browser. Application server is responsible for application logic centralized management when a request arrives at the server. The outdoor display system uses Client/Server, with presenting the user interface in the client and executing the application on the server.

3. Design of the circuit of magnetic-field measurement

The functional modules of the magnetic-field measurement’s circuit, including the collecting, conditioning, sampling and processing of the signal-flow are given.

The data of EME-RTMS comes from the monitoring terminal, which can accurately collect and deal with magnetic field information through strict adjust circuit and insulate circuit. The field intensity varies to a large extent in actual monitoring. It is the keystone that the function, automatic adjustment and adaptation of magnetic field range, could be realized by monitoring terminal. Taking the width of magnetic field measured and measurement of weak magnetic, we use Magnetoresistance Effects to detect reluctance, which is converted into electrical signals by means of an electric bridge [6].

The sensor converts the collected magnetic field value to the voltage. Two mutually exclusive circuits is designed for multi-level amplification and amplitude limiting of filtering. Then the voltage will be calculated and analyzed by build-in function on MCU. Model analyses and results are sent to server through Bluetooth module.
Magnetic Sensor Filtering First Stage LNA PGA STM32 Communication

Figure 3. Circuit diagram of magnetic field measurement

3.1. The signal sampling circuit
In this paper, according to the requirements of signal acquisition in low-intensity magnetic field, HMC1001, a magnetoresistive sensor, is proposed. HMC1001 is of small size, low cost, high sensitivity. And it has set / reset current interface, which can eliminate the magnetic interference and decrease the influence of the temperature drift, nonlinear error and loss of signal.

Resistance of NiFe
Randomly Distributed of Magnetic Regions

Figure 5. The distribution of magnetic regions in disturbing magnetic fields

Figure 4. The using process of set / reset current interface

When the magnetoresistive sensor is exposed to the interfering magnetic field, the sensor element would be randomly divided into some magnetic regions with different directions, which leads to degradation of sensitivity, as shown in Figure 5. There will be a high-intensity magnetic field by pulse current through set / reset current when the peak current is higher than the minimum required one. The magnetic field can realign these magnetic regions in unitary direction, which can ensure value sensitive, accurate and reproducible. Just like Figure 6 [7].

Figure 6. The distribution of magnetic regions in setting magnetic fields
Most low-magnetic sensors will be affected by large magnetic interference (>4-20gauss) which may result in the decay of the output signals. To counteract the trend and reduced interference, the magnetic switch technology can be applied on the reluctance bridge. Set/reset current belt achieves the goal of higher sensitiveness and smaller measure error. The pulse current timing trigger is suggested, which generate set/reset current and then generate a magnetic field. The pulse current reduce external magnetic field and increase the reliability of monitoring parameters. Its PWM can be shortened to 2µs and the average power consumption is less than 1mA (DC) during continuous pulse.

![Figure 7. Timing set/reset circuit](image)

3.2. Multi-level amplifier circuit

There are some disadvantages to the traditional instrument of detected hardware circuit board. They has complex structure and limited range switching magnification, and can’t realize smooth switching between different ranges. They will greatly influence the reliability and accuracy of the measured results. The design adopts programmable gain amplifier PGA with ARM+ in this paper and achieve a smooth switching of 7 ranges of data acquisition by software programming of STM32 [8].

The smooth handoff of EME-RTMS is showed in below, and the PGA switching range in magnetic field loops is put forward as an example. Figure 3 shows the structure of the circuits in the information of magnetic field acquisition. The sampled analog signals are conversion to digital quantity. Voltage will get through multiple independent paths in order to amplify the output voltage and limit amplitude filtering. In this paper, a single-directional magnetic field circuit is used for the analysis. The voltage analysis and calculation have been made by functionality and the built-in deployed applications. The analysis results are given out by communication module and show later.

According to the characteristics of magnetic field sensor output, the output voltage is from 0 to 10mV at external magnetic field flux of 200μT and Output voltage 10mV. EME-RTMS uses STM32 containing a 12-bit conversion ADC and input voltage ranging 0-3.3V. According to AD transform of least significant bit (LSB) definition, we can get a formula as follows.

\[
\text{LSB} = \frac{V_{\text{ref}}}{2^n} = \frac{3.3}{2^{12}} \approx 0.805mV
\]
The minimum voltage ADC module can be resolved is 0.805mV. So single below this voltage cannot be collected by STM32. Therefore, in order to achieve the smooth switching in the small range, there is amplification to process the voltage signals of and the magnetic field sensor. In this paper, the AD620 operational amplifier is used as the first stage of the acquisition voltage with the magnifying power of 150x. Then we will get the range of voltage from 0 to 1.5V.

In order to get the highest precision, the amplitude of voltage signal should match the dynamic range of ADC conversion voltage in STM32. Therefore, it is necessary to magnify sensor output signal by PGA and ensure that the input voltage of ADC is around 2.0V. Thereby heightened the accuracy rating of measure results. TI's PGA281 chip is used to realize magnify binary gain from 1V/V to 128V/V. Multi-dichotomy is adopted to decide the data and we will get Table 1.

**Table 1. PGA gain.**

| magnetic field intensity | the output voltage of first stage amplifies | PGA gain. | PGA out voltage |
|-------------------------|--------------------------------------------|-----------|----------------|
| 100μT<B≤200μT           | 0.75V-1.5V                                 | p         | 1.5V-3V        |
| 50μT<B≤100μT            | 0.375V-0.75V                               | 4         | 1.5V-3V        |
| 25μT<B≤50μT             | 0.1875V-0.375V                             | 8         | 1.5V-3V        |
| 12.5μT<B≤25μT           | 0.0937V-0.1875V                            | 16        | 1.5V-3V        |
| 6.25μT<B≤12.5μT         | 0.0468V-0.0937V                            | 32        | 1.5V-3V        |
| 3.12μT<B≤6.25μT         | 0.0234V-0.0468V                            | 64        | 1.5V-3V        |
| 1.56μT<B≤3.12μT         | 0.0117V-0.0234V                            | 128       | 1.5V-3V        |
| B≤1.5625μT              | 0V-0.0117V                                 | 128       | 0.0V-1.5V      |

4. Verifying test
Optimal effects could be reached by calibrated sensor’s output to ensure good measuring accuracy and linearity [9].
We calibrate the system through the magnetic environment calibration laboratory. Through the frequency electric field generator and the industrial frequency magnetic field generator, we can 10 standard values and monitored values can be obtained by device. Then monitored values and standard values are compared, and the relative errors between them are analyzed. And we will get the demarcate function. For example, some records of power-frequency magnetic fields are taken as shown in Table 2.

**Table 2. Original data of frequency magnetic field.**

| Standard of the magnetic field(μT) | Monitoring of the magnetic field(μT) |
|------------------------------------|-------------------------------------|
| 1.038                              | 1.022                               |
| 4.632                              | 4.574                               |
| 9.785                              | 9.821                               |
| 23.419                             | 23.178                              |
| 32.818                             | 32.699                              |
| 46.844                             | 46.797                              |
| 52.427                             | 52.506                              |
| 63.026                             | 63.173                              |
| 80.471                             | 80.730                              |
| 100.075                            | 100.459                             |

In order to get the calibration curve in EME-RTMS, Table 2 records the values made in this article. The relationship between standard magnetic field values and the monitored ones is linear. And by
means of least square method, the regression equation for the two kinds of values to transform each other is derived.

The binary regression equations were achieved:

\[ f(x) = kx + b \]  

where \( f(x_i) = y_i \). Argument is denoted with \( x \) and offset is \( b \). \( k \) is stood for the magnification of \( x \) to \( f(x) \), \( y \) was regarded as dependent variables. And calculator is carried out through least square fitting method.

\[
\begin{align*}
\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y}) &= \sum_{i=1}^{n} x_i y_i - n \bar{x} \bar{y} \\
\sum_{i=1}^{n} (x_i - \bar{x})^2 &= \sum_{i=1}^{n} x_i^2 - n \bar{x}^2 \\
b &= \bar{y} - k \bar{x}
\end{align*}
\]

In the Table 2, the fitting equations of standard values and monitored values were obtained.

\[ f(x) = 0.9972x + 0.02789 \]

As is shown in Table 3, according to magnetic compatibility testing, the result has high linearity. And the experiments demonstrate that the relative error of measurement is within 1%. The test results show that the EME-RTMS provides the desired measurement range and sensitivity with good linearity.

**Table 3.** Calibrated data of frequency electric field

| Standard of the magnetic field(μT) | Monitoring of the magnetic field(μT) | error(μT) | error(%) |
|-----------------------------------|-------------------------------------|-----------|----------|
| 1.038                             | 1.022                               | 0.009     | 0.870    |
| 4.632                             | 4.574                               | -0.043    | -0.927   |
| 9.785                             | 9.821                               | 0.036     | 0.372    |
| 23.419                            | 23.178                              | -0.278    | -1.187   |
| 32.818                            | 32.699                              | -0.183    | -0.557   |
| 46.844                            | 46.797                              | -0.150    | -0.321   |
| 52.427                            | 52.506                              | -0.040    | -0.077   |
| 63.026                            | 63.173                              | -0.002    | -0.003   |
| 80.471                            | 80.730                              | 0.061     | 0.076    |
| 100.075                           | 100.459                             | 0.131     | 0.131    |
EME-RTMS has already carried out in demonstration projects of one substation which is proved good and reliable by operation testing. The system of data transmission intuitive, accurate, reliable, economical and efficient to meet the needs of site monitoring.

5. Conclusion
EME-RTMS mainly works on the real-time measurement and data processing in substation. Through a series of works such as system demands analysis, circuit design, test design, etc, this system basically adopts a testing method which applies to magnetoresistive sensor for weak magnetic field. This method using pulse current loop to reduce the peripheral circuit influence deals with the problem of switch power delay and reduce the influence of high frequency. The application results show that EME-RTMS can realize accurate measurement from 0.01μT to 2000μT. The system is simple and reliable, and it possesses merits of high sensitivity and low cost. It also can realize the function of data acquisition, process and transmission, realize real-time dynamically display. It is convenient for the users to secondarily use. And the real-time storing data, real-time display, and using of multimedia are realized.

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