Journal of Computers Vol. 30 No. 1, 2019, pp. 237-244
doi:10.3966/199115992019023001022

Power Network Monitoring System Based on Power Signal Calculation and Analysis

Gen-ping Wang[1*], You-de Ruan[2]

[1]School of Mechanical and Electrical Engineering, Shenzhen Polytechnic, Shenzhen 518055, China
gpwang@szpt.edu.cn

[2] Industrial Training Centre, Shenzhen Polytechnic, Shenzhen 518055, China
ruyude01@szpt.edu.cn

Received 1 August 2018; Revised 1 September 2018; Accepted 1 October 2018

Abstract. In the power network monitoring system, the voltage signal and the current signal sampled can be transmitted to the cloud server through the public network as long as a voltage sampling apparatus and a current sampling apparatus are installed in the main switch board of power distribution network. The cloud server ascertained the state of device in the power distribution network, such as when to switch on and off the device and how about the energy consumption, by conducting mathematical contrast between the relevant signal characteristic quantities extracted via mathematical calculation and analysis and the relevant characteristic quantities of the operating device in the power distribution network. The operating state data of related device can be transmitted to the device manager or user through the public network. With extremely low investment on the whole system and extremely simple engineering installation, it has a broad application prospect. The experiment proves the validity of power network monitoring system technology.

Keywords: calculation and analysis, device state, power network monitoring system, signal characteristic quantity

1 Introduction

In power operation, or in industrial production, sometimes the operating state of electric device requires special attention. All the following information, including when to switch on and off the device, how about the energy consumption and whether there is any sign of failure, are very important.

Currently, there are many methods to monitor some electric device [1-3]. Sensors are usually installed at the points of device concerned or the points of signals concerned and the detected signals are transmitted to the monitoring center through a communication protocol or network, in order to realize the monitoring of the device state or system concerned. Usually real-time device monitoring systems similar to the industrial Ethernet protocol standards are adopted as the regular monitoring systems, which generally contain 3 layers of communication network, including the physical layer, the data link layer and the application layer [4-6]. There are other methods, such as wireless network monitoring system, etc. With the development of the intellectual technology, some new intelligent monitoring technologies have emerged in the network environment, such as, the computer vision in AI consisting of "low-level perceptive" and "high-level cognitive" technologies, which is mainly applied in video monitoring of system, face recognition, medical image analysis, automatic driving and robot monitoring, etc [7-8].

According to the different way of priori knowledge utilization, the process of monitoring method for the operating state of device can be divided into: the method based on quantitative model, the method based on the qualitative model and the method based on the data driving [9-10]. All these methods are to establish models or extract the operating characteristics of the device based on the priori history data,

* Corresponding Author

and make real-time judgment of the operating state of the device by analyzing the sample data of the system according to these models or operating characteristics.

The power network monitoring system adopted in this paper is different from the general monitoring system, in which there is no need for the arrangement of numerous sensors in each specific device or the construction of signal transmission networks for numerous sensors, but only needs to sample the real-time voltage signals and current signals in the main power switches of numerous devices, then these voltage signals and current signals are mathematically processed and analyzed, the signal characteristic quantities of the device operation are extracted and finally the operating state of each device installed in the main power switch, such as when to switch on and off the device, how about the energy consumption and whether there is any sign of failure, etc., is judged according to the different characteristic quantities of power signals.

2 Extraction of Characteristic Quantities of Power Signals in the Power Network Monitoring System

In fact, the operation of any device has its own characteristics, which will certainly be reflected in the fluctuation of the power signals of the power distribution system that it uses. Based on this thought, the power signals of the power distribution system can be mathematically decomposed and analyzed, the signal fluctuation characteristics caused by device can be extracted, and then the operating state of each device can be judged.

Setting g_m as a set of expansion functions in the power signal space X, the arbitrary power signal x∈ X can be expressed as formula (1):

$$\theta(t) = \sum_{m=1}^{M} a_m g_m \tag{1}$$

In formula (1), a_m is the coefficient of the expansion functions and M is of the number of the expansion functions.

In the formula, the signal expansion function g_m can actually represent the main characteristic of the power system disturbance signal. The expansion function, which can express the main characteristic of the power system disturbance signal, is also the power signal disturbance characteristic function. By extracting these characteristic signals, we can know what kinds of device are operating in the system and how they are operating through analysis and in turn, the energy consumption and the quality of electric energy in this region can be analyzed.

Below is an example of acquirement of fluctuation characteristic value of a voltage or current signal:

Supposing the sampled voltage or current signal is $f(t)$, $\theta(t)$ is the selected wavelet basis function, *is the convolution operator. $\Psi^{(1)}$ and $\Psi^{(2)}$ are the first derivative function and the second derivative function respectively.

Conduct calculation with the following formulas:

$$f(t) * \theta(t) = \int f(\tau)\theta(t-\tau)d\tau$$

$$W^{(1)} f(t) = f(t) * \Psi^{(1)}(t)$$

$$= \frac{d}{dt}(f(t) * \theta(t))$$

$$W^{(2)} f(t) = f(t) * \Psi^{(2)}(t)$$

$$= \frac{d^2}{dt^2}(f(t) * \theta(t))$$

Assuming the sampling signal is f(t), based on the results calculated from wavelets, it can be seen correspondingly from the Fig. 1.

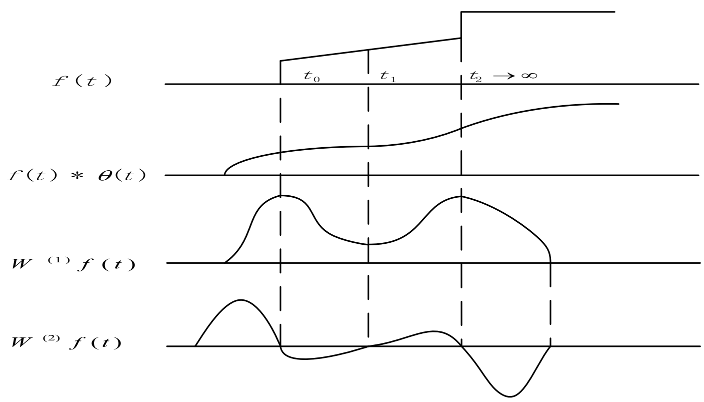

Fig. 1. Power signal and results obtained from decomposition calculation

It can be observed from the above figure that, the fluctuation characteristic values (fluctuation starting time T_{PQD}, fluctuation duration L_{PQD} and fluctuation amplitude S_{PQD}) of voltage or current signals can be acquired through the aforesaid calculation and analysis.

Acquirement of starting time: in the results of separate convolution calculation of the voltage or current signals and the first and the second derivative function of wavelet basis functions, the first corresponding point of time of the maximum value for the convolution calculation of voltage or current signals and the first derivative function of wavelet basis functions, which is also the zero point for the convolution calculation of voltage or current signals and the second derivative function of wavelet basis functions, is the point of stating time of fluctuation of power signal T_{PQD}; the next (the second) corresponding point is the point of fluctuation end time, and the difference between the first and the second points of time is the fluctuation duration L_{PQD}; the maximum value of the first derivative function of voltage or current signals and wavelet basis functions is defined as the fluctuation amplitude S_{PQD}.

In this way, the fluctuation characteristic values (fluctuation starting time T_{PQD}, fluctuation duration L_{PQD} and fluctuation amplitude S_{PQD}) of voltage or current signals can be obtained completely.

3 System Composition and Realization of Monitoring Functions

3.1 System Composition

See Fig. 2 Composition of Power Network Monitoring System for the composition diagram of the power network monitoring system. The current and voltage sensors dispersed in power grid, cloud server and various types of manager and user communication terminals compose the power network monitoring system of electric devices via the ubiquitous Internet systems. Among them, the current and voltage sampling apparatus is responsible for collecting the power signals from electric device of each power grid, the cloud server is in charge of the calculation and analysis of the power signals, and the calculation results are transmitted to the relevant users through the mobile network.

3.2 Judgment of the Monitoring System to the Operating State of Device

After the current and voltage sampling signals are sent to the server of the system through the voltage and current sensors installed in the main power switch, the server obtains the relevant characteristic quantities through the calculation and analysis of the signals. The specific process is shown in Chapter 2. Based on these characteristic quantities, the server can judge the operating state of the device through calculation and analysis.

Supposing the extracted current fluctuation characteristic quantities are I_{spec-l} (l=1,2,3,......) respectively, the voltage fluctuation characteristic quantities are U_{spec-l} (l=1,2,3,......), the other electrical characteristic quantities are E_{spec-l} (l=1,2,3,......); the referenced current fluctuation characteristic quantities corresponding to a default device are $I_{object-l}$ (l=1,2,3,......), the referenced voltage fluctuation characteristic quantities corresponding to a default device are $U_{object-l}$ (l=1,2,3,......), and the other referenced fluctuation characteristic quantities corresponding to a default device are $E_{object-l}$ (l=1,2,3,......), in which $I_{object-l}$, $U_{object-l}$ and $E_{object-l}$ can be gained by training the device by means of off-line learning or online learning.

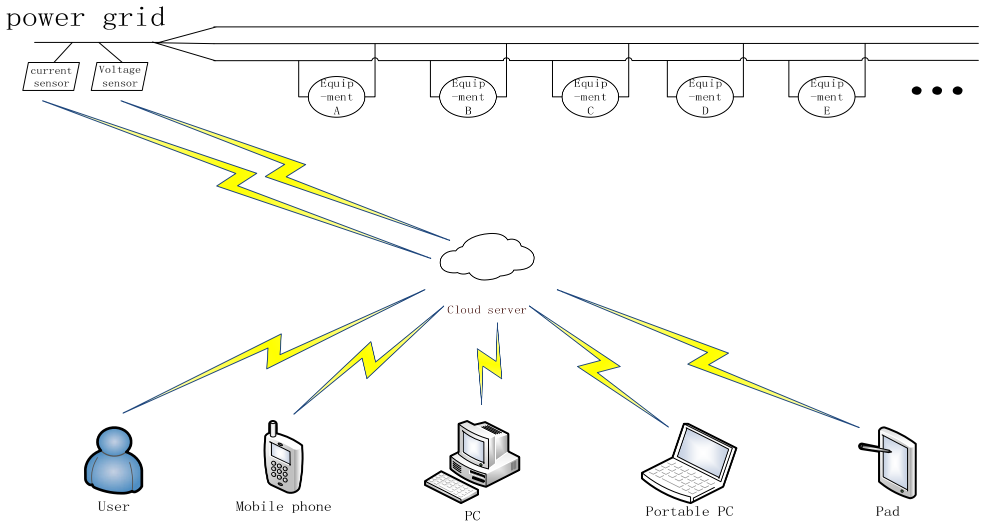

Fig. 2. Composition of Power Network Monitoring System

Finally, the real-time operating state of each related device can be judged by the calculation with formula (2) as shown below:

$$J_i = \min \sum_{l=1}^{n} \left(\lambda_{Il} (I_{spec-l} - I_{object-l})^2 + \lambda_{Ul} (U_{spec-l} - U_{object-l})^2 + \lambda_{El} (E_{spec-l} - E_{object-l})^2 \right) \quad \textbf{(2)}$$

In the formula (2), i expresses the device i, n means that the device n adopts n characteristic quantities for calculation and analysis, and λ_{Il}, λ_{Ul} and λ_{El} are respectively the weights of relevant characteristic quantities in the calculation and analysis. If the cumulative sum corresponding to the device i is the smallest, the fluctuation is caused by the device i, Σ means the accumulation of square differences after the real-time characteristic quantity of power signals selected is subtracted by the target value of characteristic quantity of the device. If the accumulated value of square differences corresponding to certain device is smaller than a set threshold value, it can be judged that the fluctuation is caused by the device i.

After determining which device causes the fluctuation of signals, the operating state and energy consumption of the relevant device can be accurately judged.

As shown in Fig. 2, the managers and users of the device can access to and view the data of the electric device sent by the cloud server, such as the operating state and the energy consumption, etc., by computer or mobile terminal.

4 Experiment and Conclusion

A voltage sensor and a current sensor were installed in the laboratory's main switchboard. Three electric devices were adopted in the experiment, a computer, a printer and an oscilloscope respectively. The current sensor and the voltage sensor transmitting the instantaneously sampled current and voltage signals to the server which judges the state of these three electric devices by extracting characteristic quantities and calculating the characteristic quantities with the formula ().

The characteristic quantities of the power signals selected were the current jump value in the instant of the device being switched on Ip, the time for the switching current signal to regress to stability T and the frequency spectrum of the current signal f.

Formula (2) was simplified according to the actual situation. Finally, formula (3) below was selected to judge the calculation formula of the device causing the fluctuation of power signals. When the value of formula (3) in the calculated result is less than a certain threshold value, the operating state of the device is judged to have occurred.

$$J_i = \min \sum_{l=1}^{3} \left(\left| Ip_{spec-l} - Ip_{object-l} \right| + \left| T_{spec-l} - T_{object-l} \right| + \left| f_{spec-l} - f_{object-l} \right| \right) \quad \textbf{(3)}$$

Table 1 to Table 3 below show the experimental data and related calculation results:

Table 1. Experimental data and calculation results of oscilloscope state changing from switching off to switching on (set s=1, the threshold value to judge the oscilloscope switching on)

Operating state of device i	Object current jump peak value Ip_{object}	Object value of current recovery time T_{object}	Object value of 150HZ frequency spectrum f_{object}	Current jump peak value calculated through real-time detection Ip	Current jump recovery time value calculated through real-time detection T	150HZ frequency spectrum value calculated through real-time detection f	Synthetic calculation deviation value	Judgment of device state
Oscilloscope from switching off to switching on	9.51A	5.50ms	0.065	10.13A	5.3ms	0.64	0.821	yes
Computer from switching off to switching on	1.31A	1.20ms	0.213	1.28A	5.3ms	0.64	3.069	no
Printer from switching off to switching on	3.15A	7.70ms	0.028	3.12A	5.3ms	0.64	9.992	no

Calculation and judgment process:

$$J_{Oscilloscope} = \sum_{l=1}^{3} \left(\left|10.13-9.51\right| + \left|5.3-5.5\right| + \left|0.064-0.065\right| \right) = 0.821$$

$$J_{computer} = \sum_{l=1}^{3} \left(\left|10.13-1.31\right| + \left|5.3-1.2\right| + \left|0.064-0.213\right| \right) = 13.069$$

$$J_{printer} = \sum_{l=1}^{3} \left(\left|10.13-3.15\right| + \left|5.3-7.7\right| + \left|0.64-0.028\right| \right) = 9.992$$

$$J_i = \min(J_{oscilloscope}, J_{computer}, J_{printer}) = 0.821 < s$$

i=oscilloscope, so the judgment is that the oscilloscope state changing from switching off to switching on has occurred

Table 2. Experimental data and calculation results of computer state changing from switching off to switching on (set c=1, the threshold value to judge the computer switching on)

Operating state of device i	Object current jump peak value Ip_{object}	Object value of current recovery time T_{object}	Object value of 150HZ frequency spectrum f_{object}	Current jump peak value calculated through real-time detection Ip	Current jump recovery time value calculated through real-time detection T	150HZ frequency spectrum value calculated through real-time detection f	Synthetic calculation deviation value	Judgment of device state
Oscilloscope from switching off to switching on	9.51A	5.50ms	0.065	1.340A	1.21ms	0.219	12.496	no

Table 2. Experimental data and calculation results of computer state changing from switching off to switching on (set c=1, the threshold value to judge the computer switching on) (continue)

Operating state of device i	Object current jump peak value Ip_{object}	Object value of current recovery time T_{object}	Object value of 150HZ frequency spectrum f_{object}	Current jump peak value calculated through real-time detection Ip	Current jump recovery time value calculated through real-time detection T	150HZ frequency spectrum value calculated through real-time detection f	Synthetic calculation deviation value	Judgment of device state
Computer from switching off to switching on	1.31A	1.20ms	0.213	1.340A	1.21ms	0.219	0.224	yes
Printer from switching off to switching on	3.15A	7.70ms	0.028	1.340A	1.21ms	0.219	8.491	no

Calculation and judgment process:

$$J_{Oscilloscope} = \sum_{l=1}^{3}\left(|1.34-9.51|+|1.21-5.5|+|0.029-0.065|\right)=12.496$$

$$J_{computer} = \sum_{l=1}^{3}\left(|1.34-1.31|+|1.21-1.2|+|0.029-0.213|\right)=0.224$$

$$J_{printer} = \sum_{l=1}^{3}\left(|1.34-3.15|+|1.21-7.7|+|0.219-0.028|\right)=8.491$$

$$J_i = \min(J_{oscilloscope}, J_{computer}, J_{printer}) = 0.224 < c$$

i=computer, so the judgment is that the computer state changing from switching off to switching on has occurred

Table 3. Experimental data and calculation results of printer state changing from switching off to switching on (set p=1, the threshold value to judge the printer switching on)

Operating state of device i	Object current jump peak value Ip_{object}	Object value of current recovery time T_{object}	Object value of 150HZ frequency spectrum f_{object}	Current jump peak value calculated through real-time detection Ip	Current jump recovery time value calculated through real-time detection T	150HZ frequency spectrum value calculated through real-time detection f	Synthetic calculation deviation value	Judgment of device state
Oscilloscope from switching off to switching on	9.51A	5.50ms	0.065	3.12A	7.72ms	0.029	8.636	no
Computer from switching off to switching on	1.31A	1.20ms	0.213	3.12A	7.72ms	0.029	8.514	no
Printer from switching off to switching on	3.15A	7.70ms	0.028	3.12A	7.72ms	0.029	0.09	yes

Calculation and judgment process:

$$J_{Oscilloscope} = \sum_{l=1}^{3}\left(|3.12-9.51|+|7.72-5.5|+|0.029-0.065|\right)=8.636$$

$$J_{computer} = \sum_{l=1}^{3}\left(|3.12-1.31|+|7.72-1.2|+|0.029-0.213|\right)=8.514$$

$$J_{printer} = \sum_{l=1}^{3}\left(|3.12-3.15|+|7.72-7.7|+|0.029-0.028|\right)=0.09$$

$$J_i = \min(J_{oscilloscope}, J_{computer}, J_{printer}) = 0.09 < p$$

i=printer, so the judgment is that the printer state changing from switching off to switching on has occurred

According to the actual situation, a threshold value is set for the comprehensive calculation value. If the calculation value is less than this threshold value, the device state is judged to be occurred. It can be seen from the experimental results that the comprehensive calculation value can accurately judge the operating state of the related device.

Although this experiment is simple, it proves the validity of power network monitoring system technology and thought.

In the power network monitoring system, the operating state of each related device can be judged by calculation and analysis of the current and voltage values obtained by sampling as long as a voltage sensor and a current sensor are installed in the power switch of power distribution network, so as to realize monitoring the state of each device in the power distribution network. In this method, the investment is extremely low (just need a voltage sensor and a current sensor), the installation is extremely simple and the communication networks can take advantage of public networks directly, so it is easily constructed with low cost. Therefore, the power network monitoring system has a great potential in application.

Considering the further popularization and development of the power network monitoring system, the work efforts that we still need to make in technical researches include (1) research on automatic learning and extraction technology of power signal characteristics of devices; (2) research on fast calculation method for signal processing; and (3) research on more effective signal characteristic judgment mechanism.

Acknowledgements

This research was supported by Shenzhen science and technology innovation committee, under the project “Research on fine calculation and analysis for power signals in power system”, project number: JCYJ20160429112213821.

And the author gratefully acknowledges the contributions of YAO Jingchang for his work on the experiment and the original version of this document.

References

[1] G. May, B. Stahl, M. Taisch, D. Kiritsis, Energy management in manufacturing: from literature review to a conceptual framework, Journal of Cleaner Production 167(2017) 1464-1489.

[2] S.A.S. Amiril, E.A. Rahim, S. Syahrullail, A review on ionic liquids as sustainable lubricants in manufacturing and engineering: Recent research, performance, and applications, Journal of Cleaner Production 168(2017) 1571-1589.

[3] N. Finnerty, R. Sterling, D. Coakley, M. Keane, An energy management maturity model for multi-site industrial organisations with a global presence, Journal of Cleaner Production1 67(2017) 1232-1250.

[4] P.K. Senyo, E. Addae, R. Boateng, Cloud computing research: a review of research themes, frameworks, methods and future research directions, International Journal of Information Management 38(1)(2018) 128-139.

[5] Z. Yan, J. Liu, L.T. Yang, N.V. Chawla, Big data fusion in Internet of Things, Information Fusion 40(2018) 32-33.

[6] A. Gameros, S. Lowth, D. Axinte, A. Nagy-Sochacki, O. Craig, H.R. Siller, State-of-the-art in fixture systems for the manufacture and assembly of rigid components: a review, International Journal of Machine Tools and Manufacture123 (2017)1-21.

[7] C.-J. Kuo, K.-C. Ting, Y.-C. Chen, D.-L. Yang, H.-M. Chen, Automatic machine state prediction in the era of Industry 4.0: case study of machines in a spring factory, Journal of Systems Architecture 81(2017) 44-53.

[8] A. Kalair, N. Abas, A.R. Kalair, Z. Saleem, N. Khan, Review of harmonic analysis, modeling and mitigation techniques, Renewable and Sustainable Energy Reviews 78(2017) 1152-1187.

[9] L. Li, M. Liu, W. Shen, G. Cheng, An expert knowledge-based dynamic maintenance task assignment model using discrete

stress–strength interference theory, Knowledge-Based Systems 131(2017) 135-148.

[10] M.S. Mahmoud, N.M. Alyazidi, M.I. Abouheaf, Adaptive intelligent techniques for microgrid control systems: a survey, International Journal of Electrical Power and Energy Systems 90(2017) 292-305.