Review of Online Condition Monitoring in Power Systems.

Rituparna Mukherjee, Susmita Dhar Mukherjee, Abhishek Dhar, Promit Kumar Saha, Sujay Bhowmik, Arunima Mahapatra

Department of Electrical Engineering, Swami Vivekananda University, Barrackpore, Kolkata, West Bengal, 700121, India

**Corresponding Author*

***Abstract*—As a means of detecting and assisting maintenance of power equipment, on-line condition monitoring(CM) has been widely used in power generation, transmission, substation, distribution, consumption and other fields in the past few decades. This paper reviews current on-line condition monitoring techniques and development trends of condition monitoring. In the context of 'Ubiquitous Internet of things', online condition monitoring is surely a promising way towards reliable protection of electrical equipment. However, in spite of obvious progress and undoubted benefits, the on-line condition monitoring system has also experienced a large number of practical problems in the application process such as generally low data availability and reliability. Furthermore, statistics on relative standards show a dramatic blank in international standards of on-line condition monitoring. Therefore, there is an urgent need that the international standards for condition monitoring should be set up as soon as possible. Corresponding areas for further research are also presented such as uncertainty evaluation, error modeling and evaluation system based on sequential control. It is intended that this review will provide the basis for future developments of safe and reliable on-line condition monitoring system.**

***Index Terms*--On-line condition monitoring; protection; standards; review.**

I. INTRODUCTION

In recent years, the power industry has undergone rapid growth and a large amount of power equipment has flooded into the power system. How to ensure the safe and reliable operation of various types of power equipment has become a difficult problem in the whole industry. As a means of detecting and assisting maintenance of power equipment, online condition monitoring has been widely used in power generation, transmission, substation, distribution, consumption and other fields in the past few decades [1]. The condition monitoring has a great many benefits and these advantages can be listed as follows [2]:

1) It can limit the repairing costs of equipment.
2) It can reduce the cost during maintaining period of equipment for it can detect the impending faults and intercept it.
3) Quality of supply and safety of persons are affected by limiting the probability of destructive failure.
4) It can limit the extremity of any damage incurred and reduce repair activities.
5) It can detect failure of the root causes and provide a better fault diagnosis system.

In the context of 'Ubiquitous Internet of things', on-line condition monitoring is surely a promising way towards reliable protection of electrical equipment. However, in spite of obvious progress and undoubted benefits, the on-line condition monitoring system has also experienced a large number of practical problems in the application process such as generally low data availability and reliability [3]. Furthermore, statistics on CM-related standards at home and abroad show a dramatic blank in international standards of CM. Especially, there was no epidemic standard about on-line monitoring. As a result, there is an urgent need that the international standards for condition monitoring should be set up as soon as possible.

This paper reviews current on-line condition monitoring techniques, (i.e. dissolved gases in oil analysis(DGA) [4], partial discharge [5], etc.) and development trends of condition monitoring. Next, the current problems existing in practical applications and the deficiency in international standards correspondingly are emphasized. To help establish a comprehensive architecture of on-line monitoring, further research fields are presented such as uncertainty evaluation, error modeling and evaluation system based on sequential control [6].

II. ON-LINE CONDITION MONITORING TECHNIQUES AND DEVELOPING TRENDS

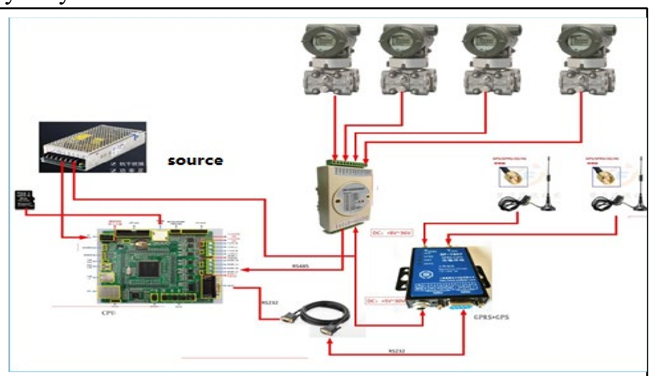
Taking the on-line condition monitoring of transformers as an example, generally different types of faults of transformer are classified as external faults and internal faults [7]. Various condition monitoring techniques can be classified as table I:

TABLE I. TYPES OF DIFFERENT DIAGNOSTIC TECHNIQUES

Methods	**Different Diagnostic Techniques**	
	Test	***Use at:***
Thermal analysis	Continuously measured as a function of temperature	Manufactures
Vibration analysis	Health condition of core and windings	Many research labs
Dissolved Gas Analysis (DGA)	Arcing, Ageing of oil & paper	Transported and used on site, laboratories
Partial Discharge	Identification of the insulation system	Mainly utilities
Frequency Response Analysis	The terminals of a transformer winding	Laboratories

Currently, apart from transformers which have realized comprehensive condition monitoring such as DGA and core grounding current, almost every important electrical apparatus in the power system has realized the on-line condition monitoring: the arrester has realized the full current and resistive current state monitoring of the leakage current; power cables and overhead lines have been monitored comprehensively in aspects of temperature and channels; substations have realized infrared temperature monitoring[8].

As more and more on-line monitoring methods of nonelectrical quantity like vibration, ultrasound and pressure flourish these years, on-line condition monitoring system is experiencing a tremendous transformation swiftly. Traditionally, an on-line condition monitoring system used to be centralized, designed for one detached electrical apparatus with single parameter, usually measuring electrical quantity only.



pressure sensing online monitoring system of GIS

Figure 1. Example of modern condition monitoring system

Nowadays, it has been integrated, usually acquiring multiple parameters, with multiple physical quantities, and most importantly, networked using Internet of Things. Some

examples of applications in State grid corporation of China are listed as follows: visualization terminal monitoring platform of transmission line channel, pressure sensing online monitoring system of GIS gas and intelligent analysis system of distribution station area operating state.

III. CURRENT PROBLEMS IN PRACTICAL APPLICATIONS

Taking the statistics of the state monitoring (online) device operation of a provincial company in the State Grid in 2014 as an example, the state monitoring system has covered 110kV to 1000kV substation and transmission equipment. The on-line monitoring device of substation equipment mainly includes: SF6 gas pressure, partial discharge of circuit breaker, partial discharge of transformer, insulation monitoring of metal oxide arrester, grounding current of iron core, DGA and micro water, etc. On-line monitoring devices for transmission equipment mainly include: wire sag monitoring, micro-meteorological monitoring, site contamination monitoring, breeze vibration monitoring, wire temperature monitoring, wire dancing, tower tilt monitoring, ice monitoring, image monitoring, video monitoring, etc. A total of 365 sets of devices.

According to statistics, in the case of maintenance, the real-time access rate of monitoring devices is only 81% on average, and the access rates of different types of monitoring devices are very different. Visible condition monitoring system data availability is generally not high.

Taking the relatively stable operation of the transformer DGA monitoring system as an example, the provincial company installed a total of 847 sets of transformer DGA monitoring devices. The running statistics of a certain week showed that 67 sets of devices could not operate normally due to faults. Among them, the failure of network protocol conversion of carrier gas under voltage and internal and external network disconnection is the main fault. It can be seen that the quality of condition monitoring devices is generally not satisfying [9].

From the above status quo, it is easy to find some severe problems in the field of condition monitoring:

1) *lack of basic theoretical support;*
2) *lack of system planning; 3) lack of system evaluation;*
4) lack of application strategies.

In addition, the lack of relevant standard construction has made the problem even more serious. It is no doubt that these problems seriously restrict the healthy development of power equipment condition monitoring technology.

With regard to the existing standards related to condition monitoring, we have conducted research and statistics on relevant standards at home and abroad. The statistics are as Table II [10].

Among them, there are only four technical standards

1) IEEE 1129-1992 - IEEE Recommended Practice for related to IEEE (including standards, technical guidelines, and Monitoring and Instrumentation of Turbine Generators. recommended guide):

TABLE II. EXISTING STANDARDS FOR CONDITION MONITORIN

	Electric generation	Electric transmission	Electric transformation	Electric distribution	Electric consumption
IEC Standard	2	×	1	×	1
IEEE Standard , Recommended practice or Guide	1	3	×	×	×
CIGRE technical report	6	4	8	4	2
National Standard(China)	4	7	6	8	1
Industrial Standard(China)	12	28	41	25	13
Enterprise Standard(China)	2	36	47	5	×

2) IEEE 400.3-2006 - IEEE Guide for Partial Discharge Testing of Shielded Power Cable Systems in a Field Environment.

3) P2797 - Guide for Forecast and Early Warning of Icing on Overhead Transmission Lines in Micro-Topographic Areas.

4) IEEE 1718-2012 - IEEE Guide for Temperature Monitoring of Cable Systems.

Although there are a total of 26 technical reports related to online monitoring of CIGRE power equipment, only 2 items directly related to monitoring devices (or technologies) are:

1) Use of Equipment built-in Automatic Testing: SelfChecking and Monitoring with a View to improving Reliability；
2) Guide for Application of Direct Real-Time Monitoring Systems.

The other 24 items are related to equipment category: 6 generators, 4 transformers, 3 substations, 4 transmission lines, 2 power quality, 1 switch cabinet, 1 shunt reactor, protection and automation device. 1 item, high voltage insulation. There are only four IEC related standards, namely TC2 power generation, TC10 power transformation and TC9 power consumption. The construction of China's corporate standards, industry standards and national standards are also shown in Table II.

Although the construction of standards in the fields of transmission, transmission, transformation, distribution, use and other fields is slightly different, it can be seen that the standards of condition monitoring are still concentrated in the power industry and enterprises, and it is almost a blank in international standards. Therefore, it is urgent to establish a corresponding standard system at the IEC level.

IV. SYSTEM ARCHITECTURE AND FURTHER RESEARCH

Under such circumstances, we try to build a 3-layer system architecture of on-line monitoring system from top-level design.

1) *Ground level：Basic definition, theory and method of condition monitoring system*
2) *Relation level：Relationship between equipment and system in condition monitoring*
3) *Junction level：Specific application of the relationship layer*

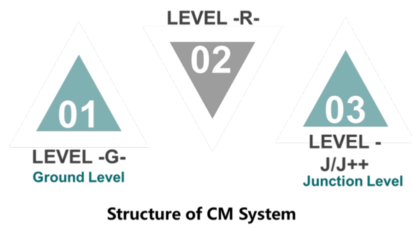


Figure 2. Three-layer design and Definition

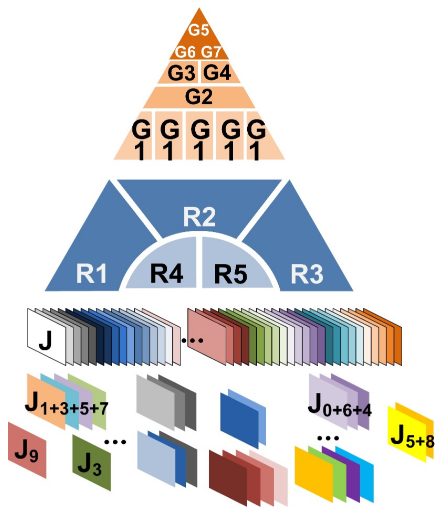


Figure 3. Application of 3-Layer Design

The specific mapping method of the actual application level is that after the object to be monitored is modeled and mapped, the processed and fitted data are obtained through transformation. Thus, the ground level to the relation level to the application level is a three-layer structure from the basic elements to the specific relationship to the specific application.

Furthermore, to make up for the deficiency in basic theoretical support and system evaluation [11], further research should focus on but not be limited to the following relevant sub-topics:

A. Research based on measurement, including: error theory, adaptation range and limitations of test methods:

Firstly, the error modeling of the condition monitoring system should be carried out, including the general model of the measurement chain of the state monitoring system and the error abstract modeling of different links of the measurement chain [12].

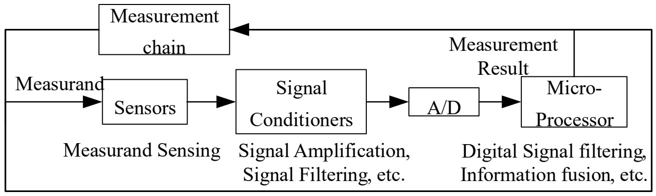


Figure 4. Measurement chain

B. System uncertainty research;

Then the uncertainty of the condition monitoring system should be evaluated: the measured probability density distribution law, the uncertainty chain transfer model of the measurement chain, the measurement chain uncertainty evaluation method based on the measurement uncertainty guide (GUM), based on Monte Carol (MCM) measurement chain uncertainty evaluation method.

C. Research on evaluation system based on time series control

As many on-line monitoring data have strong nonlinear properties, it is difficult for the conventional mathematical model to grasp its fluctuation trend. However, large amount of data with timestamp is meaningful only if the time series is thoroughly exploited. So the overall quality evaluation should be performed based on the evaluation factors on the time series, and the evaluation model needs to be established by the corresponding overall quality evaluation criteria [13].

After Carrying out the construction of relevant standards for power system condition monitoring, hopefully several breakthroughs and objectives could be fulfilled [14]:.

1) Real-time:

Mastering operating condition and status of power equipment;

2) Accuracy:

Analyzing defects and faults in power equipment; *3) Prediction:*

Discovering condition change trend of power equipment; *4) Economical efficiency:*

Avoiding excessive operation and maintenance for power equipment.

V. CONCLUSION

In order to address the more and more extensive on-line condition monitoring in power system in the context of ‘Ubiquitous Internet of things’, this paper concludes that:

1) With the development of information technology and measuring techniques, on-line condition monitoring system is extending from single parameter to multiple parameters, from electrical quantity to multiple physical quantities, from isolated to comprehensive, from centralized to networked, Internet of Things.

2) The extension of on-line condition monitoring has also brought up a higher requirement for every measurement and information transfer link, but current system can barely meet up with the qualifications. What’s worse, there is almost none international standard in this field.

3) A 3-layer design of on-line monitoring system is proposed and further research in the following areas are strengthened: research based on measurement; system uncertainty research; research on evaluation system based on time series control.

REFERENCES

[1] Dhingra Arvind Singh Khushdeep , Kumar Deepak“ Condition Monitoring of Power Transformer: A Review”2008 IEEE

[2] Zhang GuangMing1, Jiang GuoLian1, Xie ZhiXun1, “Techniques of Online Monitoring and Diagnosis for Transformer, “The International Conference on Advanced Power System Automation and Protection, vol. 2., 2011, pp.68-73.

[3] D. H. Shroff and A. W. Stannett, “Review of paper aging in power transformers,” in Proc. Inst. Elect. Eng. C, vol. 132, no. 6, pp. 312–319, 1985.

[4] G. Apostolakis, S. Garribba and G. Volta, Synthesis and Analysis Methods for Safety and Reliable Studies. New York: Plenum Publishing, 1980, ch. 17.

[5] M. Pertl, “Observability and decision support for supervision of distributed power system control,” Ph.D. dissertation, Dept. Elect. Eng., Technical University of Denmark., Lyngby, Capital, 2018.

[6] Patel, N., Vora, D. and Basera, A.S. 2019. Health Condition Monitoring of Transformer: A Review. Asian Journal For Convergence In Technology (AJCT). Apr. 2019

[7] S. Tenbohlen and F. Figel, "On-line condition monitoring of power transformers," 2000 IEEE Power Engineering Society Winter Meeting. Conference Proceedings (Cat. No.00CH37077), Singapore, 2000, pp. 2211-2216 vol.3.

[8] Y. Liu et al., "Novel and Necessary Structure of Overall On-Line Monitoring for Power System," 2018 China International Conference on Electricity Distribution (CICED), Tianjin, 2018, pp. 1671-1675.

[9] Communication Networks and Systems in Substations, IEC Standard 61850, 2004.

[10] A. Setayeshmehr, A. Akbari, H. Borsi and E. Gockenbach, "On-line monitoring and diagnoses of power transformer bushings," in IEEE Transactions on Dielectrics and Electrical Insulation, vol. 13, no. 3, pp. 608-615, June 2006.

[11] H. Zangl, T. Bretterklieber and G. Brasseur, "A Feasibility Study on Autonomous Online Condition Monitoring of High-Voltage Overhead Power Lines," in IEEE Transactions on Instrumentation and Measurement, vol. 58, no. 5, pp. 1789-1796, May 2009.

[12] Y. Tian, P.L. Lewin, A.E. Davies, “Comparison of on-line partial discharge detection methods for HV cable joints”, IEEE Trans. Dielectr. Electr. Insul., 9 (2002), pp. 604-615

[13] Raymond, Wong Jee Keen, Hazlee Azil Illias, and Hazlie Mokhlis. "Partial discharge classifications: Review of recent progress." Measurement 68 (2015): 164-181.

[14] Lemke, E. "A critical review of partial-discharge models." IEEE Electrical Insulation Magazine 28.6 (2012): 11-16.