STUDY ON OVERHEAD TRANSMISSION LINE ON-LINE MONITORING TECHNOLOGY

by

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Original scientific paper
DOI:10.2298/TSCI151214024Y

This paper introduces a new idea for overhead transmission line online monitoring. The basis of the paper has been developed upon years of research conducted by power engineers, and a new advanced transmission line safe operation monitoring system is proposed successfully. Furthermore, we used artificial neural network for diagnosis examples, to prove the feasibility and effectiveness of the advanced transmission line safe operation system.

Key words: *overhead transmission lines, sensor technology, online monitoring, remote video monitoring, artificial neural network*

Introduction

In recent decades since the Reform and Opening Up policies of late 1970s, Chinese power industry has rapidly developed, yet the power grid construction lagged seriously behind. Due to the lack of transmission capacity, transmission faults frequency occurred consecutively. They are very unbalanced between power grids and power source development. To solve the problem of power supply in the first half of 21st century, hydropower, thermal power and green energy must be developed as alternate energy sources. To maintain sustainable economic and social development, it is necessary that China constructs the national energy transmission channel and power grid. With power grid development and power toward the market and smart grid startup, engineers pay more and more attention to power grid safe operation and power supply reliability. The necessity for developing power transmission line online monitoring and fault diagnosis technology to promote advance transmission operation (ATO) technology has emerged. It is important to realize optimization of transmission system and to protect normal power transmission.

Development of intelligent transmission lines

For grid security, reliability, economic efficiency and environmental-friendliness, power quality, adaption of development of electricity market, and so on, it is necessary to build the smart grid. The transmission network is the backbone of power grid, the ATO tech-

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nology of intelligent grid does the research on the transmission line about online monitoring, assessment diagnosis and decision-making to achieve the transmission line's condition monitoring, assessment of intelligence, and to speed up the state maintenance of the transmission line, life cycle management and intelligent disaster prevention.

Transmission line on-line monitoring system

The transmission line is an important part of the grid. After years of research, power engineers developed a new type of high-level transmission line safe operation monitoring system [1]. This system includes weather monitoring on capacity-increase of transmission line, safe operation, insulator, icing, *etc*. At the same time, the remote video monitoring device is introduced. The system adopts advanced sensors, through high-speed communication networks, taking on-line monitoring of the transmission line's state. The system can also control safe operation state of transmission line in real time.

To ensure safe operation of the transmission line, it is necessary that all kinds of sensor probes are installed on the detection hot of transmission line tower directly, to obtain the operation monitoring signal [2], as shown in fig. 1.

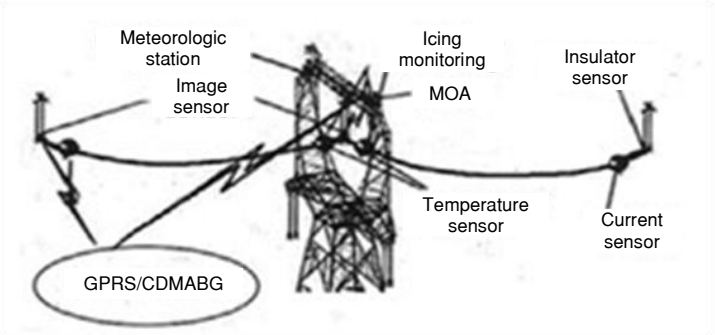


Figure 1. Diagram of sensing device installed

The sensor features are crucial for online monitoring. This means that the transmission line state makes comprehensive monitoring (wire temperature, current strength) and environmental conditions (temperature, sunlight, *etc.*). The online monitoring equipment mainly contains the infrared sensor of measuring temperature, the transformer of measuring current, the sensor of monitoring environmental change, and monitoring insulator pollution flashover, ice force sensors, remote video device, *etc*. Figure 1 is the weather station measuring the operating conditions of transmission line (including temperature, humidity, sunshine, wind speed, *etc.*).

Transmission lines dynamic capacity-increase and safe monitoring

The U. S. Electric Power Research Institute (EPRI) developed in 1996 a real-time temperature dynamic line stability capacity monitoring system, which follows actual weather conditions and equipment. The system includes a computer module and a thermal model. The thermal model consists of transformers, cables, overhead line, isolation switch and other equipment [3]. The model takes into account real-time weather conditions, equipment temperature parameters, electrical load and other related factors. This monitoring equipment includes a small meteorological observatory, wire laxity and temperature sensor and digitalized data units, *etc*.

At present, the steel cored aluminum wire (ACSR) and steel cored alloy strand wire are adopted widely in China. Under the temperature of normal operation, two factors are considered, namely heating to mechanical strength and connecting to wire on the line. According to the design rules, the line temperature limit is 70 ℃. It is important that transmission capacity is improved, and to ensure line structure and safe operation. We know that wire mechanical strength is almost invariable in line temperature 70 ℃~90 ℃. As the line temperature rises from 70 ℃ to 80 ℃ or 90 ℃, the line transmission capacity can be increased. For example, JL/G3A-400/55 ACSR (ambient temperature 40 ℃; voltage 500 KV; standard span for 400 M; wind speed 0.5 M/S~35 M/S; sunshine 100 W/m^2; endothermic coefficient 0.95) as shown in tab. 1.

Table 1. Transmission lines dynamic capacity-increase data (Operation wire temperature 70 ℃; current 5000 A; 2360 MW）

Measurement data	Wire temperature	Operation Current (A)	Capacity (MW)
July 2nd, 2013	80 ℃	5600	2780
June 15th, 2014	89 ℃	6200	3110

It is obvious that transmission capacity can be fully used when wire temperature is raised suitably and the mechanical strength of the cable is almost unchanged. Therefore, to improve conductor allowable temperature can give full play to the line transmission capacity, and it may have a economic and social benefits, in the protection of the transmission line safety and capacity-increase. In view of this, the corresponding temperature sensor, the current sensors and other monitoring equipment are installed on transmission lines, and will greatly enhance the transmission lines' safe operation.

Transmission line insulator flashover Monitoring

The insulators are used to support the wire. The insulator must have both, good electrical properties and enough mechanical strength. It is very important that the quality of insulator is sufficient for safe operation. There are two kinds of insulator electrical faults: flashover and breakdown. The insulator flashover occurs on the surface, and burn marks are visible. Usually, this does not effect in loss of insulation performance. The breakdown occurs are of internal nature. The insulator flashover discharges between iron cap and iron pin ceramic, the trace cannot be seen, but the insulation has been lost, and it may be completely destroyed due to arcing. For breakdown, the discharge traces of iron legs and burnt situation should be paid great attention [4]. Transmission line insulator flashover in operation can cause blackout accidents, and can seriously affect the power grid stability and reliability. Currently, the domain experts proposed online insulator flashover monitoring in order to early diagnose any probability of flashover occurrence, and to make assessment and identification. The prevention methods and measures are thus determined timely.

Owing to the insulator, flashover has been a hidden danger of transmission line. The question is how to detect insulator pollution degree and take preventive measures. The CIGRE recommended maximum leakage current method (I_h law) [5]. The leakage current can reflect the comprehensive factors such as voltage, climate and pollution. It can judge the formation of pollution flashover. The measurement of leakage current is relatively convenient, and is especially suitable for online monitoring. In the insulator leakage current online monitoring, the current sensor is installed on the insulator, it can real-time monitor the leakage

current. Before insulator flashover, the common leakage current sensor technology provided that max leakage current is a dynamic value (I_h). According to the on-set record, numerical and laboratory measures, I_h value may be determined. The relevant literature supposes alarm of leakage current is 40 mA. The signal that sensor measures is sent to monitoring center through GPRS/CDMA/3G network. Based on information of leakage current, expert system makes assessment of the insulator pollution degree, and sends the warning notification of insulator flashover.

Transmission lines icing monitoring

At the end of the 20th century, IEEE launched a research about transmission line icing. With the development of sensor technology and communication technology, a variety of sensors are installed on the transmission line, with a task to transmit the monitoring signal to the monitoring center through wireless communication network. Transmission line online monitoring can be divided into imaging method, mechanics model method, gravimetric method and artificial neural network method.

The transmission line icing is widely distributed in China [6], but the dancing amplitude of wire icing is very large. It can lead to phase flashover, equipment damage, line outage, even in broken wires, towers collapse and other serious accidents. The transmission line icing disaster can cause an extremely bad influence on power supply, resulting in significant economic losses. Owing to the complexity of regional distribution of transmission line, bad environment and difficult maintenance, we use transmission lines icing online monitoring and early warning systems. This system can reduce reliance on human resources and decrease financial burdens. It can record the icing parameter information accurately and timely, and provide real data for the line safety, anti-ice transformation. According to the principle of icing online monitoring, we can adopt imaging method, weighing method and other monitoring tools. The imaging method of transmission line icing online monitoring is to install a remote video device on the tower pole, to collect pictures. Using line inherent geometry, the icing area is calculated, then translated into an equivalent to its thickness. This method is simple, the icing situation can be observed directly under the harsh climate and environment. Since the camera can only observe conditions near the icing, the collectable information is limited. Under the conditions of thicker snow, the camera may be snow-covered, and the whole monitoring results are affected. At this time, the weighing method is used most widely in power system. Namely, the tension sensor is installed in the transmission lines to replace the ball type ring. In order to measure the wire quality of the whole vertical span, and minus the wire quality through the process of elimination, to obtain the icing quality eventually, and then converted to the equivalent icing thickness with 0.9 g/cm [4]. This method is direct and simple and relatively reliable. The artificial neural network (ANN) method is to use previous icing data [7], such as ambient temperature, humidity, wind speed, wind direction, rainfall and other factors, to train ANN sample, and then the collected data is input into the ANN sample that has been trained. It can obtain the icing thickness. The transmission line video surveillance system, which consists of the high-performance cameras, low-power PTZ and special sensors, may monitor the transmission lines icing by the help of GPRS/CDMA scene video image.

It is necessary that integrated control system is set-up. In the icing hit areas, it consists of monitoring and early warning, melting ice and so on. It can increase the level of safety in grid operation. In addition, the transmission line design standard is improved appropriately in heavy ice. Due to the new melting ice technology being applied, the icing hazards and losses are reduced.

Transmission line operation control system

China's rapid growth in power transmission line makes inspection line workload more complex. At present, manual inspection is still the main method, but it is completely not suitable for the needs of smart grid development.

Remote video monitoring

Transmission line remote visual monitoring system is created through installation in tower multiple cameras. Remote video surveillance is an open system which adopts B/S (Browser/Server) way, the structure of the remote video site includes the image monitoring unit, wireless communication unit and the monitoring center unit. The key technology within the system includes microcontroller, image sensor, image acquisition, digital image compression, remote transmission protocol and so on. The microcontroller is the core device to complete the initialization in video processing chip and JPEG image compression coding chip. It receives the control command of remote monitoring terminal, and processes the related affairs according to the command.

Transmission line digital remote video monitoring system is installed in the tower with multiple types of cameras. It monitors different objects, and obtains the scene image by computer control display (computer control display, CCD) high-performance image sensor (camera). The analog video signal is digitalized by dedicated video processing chip (*e. g.*, SAA71, FPGA series). On site monitoring signal is collected through the video image compressing and coding process, then the signal is sent to monitoring center through GPRS/CDMA/3G. The remote visual monitoring system realizes the operation of the transmission line and the surrounding environment all-weather monitor. According to the visual image information the operator may monitor tower pole and line's real time situation, to grasp the field device operation condition, and enhance the safety performance of transmission lines. The system can protect the line reliability comprehensively. It can reduce greatly the labor intensity of line patrol operators. Transmission line digital remote video monitoring system has increasingly played an irreplaceable role in the management of transmission lines operation. Its application improves the efficiency of the operators greatly. It is imporpant that digital remote video monitoring system solves the unified control for transmission line. The monitoring center should strive to build a unified communications platform based on IEC61850 standard, and establish a unified and open remote video monitoring integration platform. The plug-and-play method is successful in transmission line online unified management of the monitoring data, it provides reliable support and upgrade of smart grid development.

Remote wireless communication

Nowadays, high voltage transmission lines safe operation system applies the sensor that is installed in transmission line's various parts, to obtain the monitoring signal. The signal realizes remote data and image transmission based on wireless communication network GPRS/CDMA/3G. Wireless communication technology sends the monitoring signal to the on-site monitoring center. It effectively completes the real-time transmission of monitoring data, which includes wire operation temperature, environment conditions, insulator leakage current, wire icing video monitoring and so on. At the same time, the system can realize automated inspection of remote equipment. Thus, the system would understand transmission line operation conditions, and improve line reliability. During the operation, the maintenance of the equipment can be overhauled in the power sector, no need the communication sector,

and the security guaranteed. And then power engineers can control the transmission line operation any time.

With the development of GPRS technology, it has become the first choice of the wireless transmission channel in the fault location system, transmission and distribution monitoring system and so on. Using GPRS wireless communication technology, we can secure remote transmission line and equipment of data signal gathering and the information transmission question of control monitoring. Through GPRS technology, we integrate the transmission line safe operation online monitoring technology, combine artificial intelligence fault diagnosis technique and establish an information-monitoring platform. It can enable real-time monitoring of transmission line. The safe operation level of transmission line and intelligent management capabilities will thus be increased greatly. In short, wide application of wireless communication technology is an important step towards development of smart grid.

Transmission line artificial neural network

The ANN is used to monitor the transmission line's safe operation conditions [8]. The monitoring and control center of transmission line online monitoring system receive the information through GPRS/CDMA/3G, the Artificial neural network analyses and assesses transmission lines safe operation and makes diagnosis, sending warning notifications of transmission line faults that may not be observed.

Development of artificial neural network

The artificial neural network is becoming a satisfactory tool for the transmission line on-line monitoring. A better TLMANN topology has been determined, as shown on fig. 2.

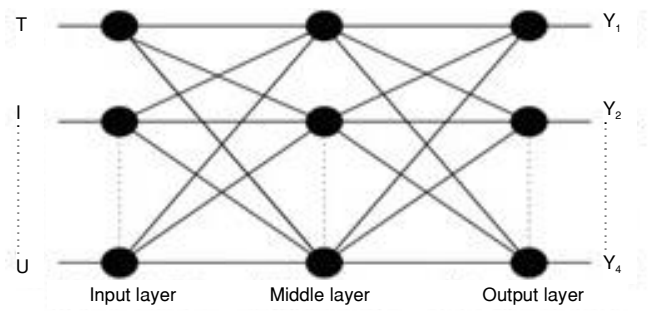


Figure 2. Diagram of TLMANN construction

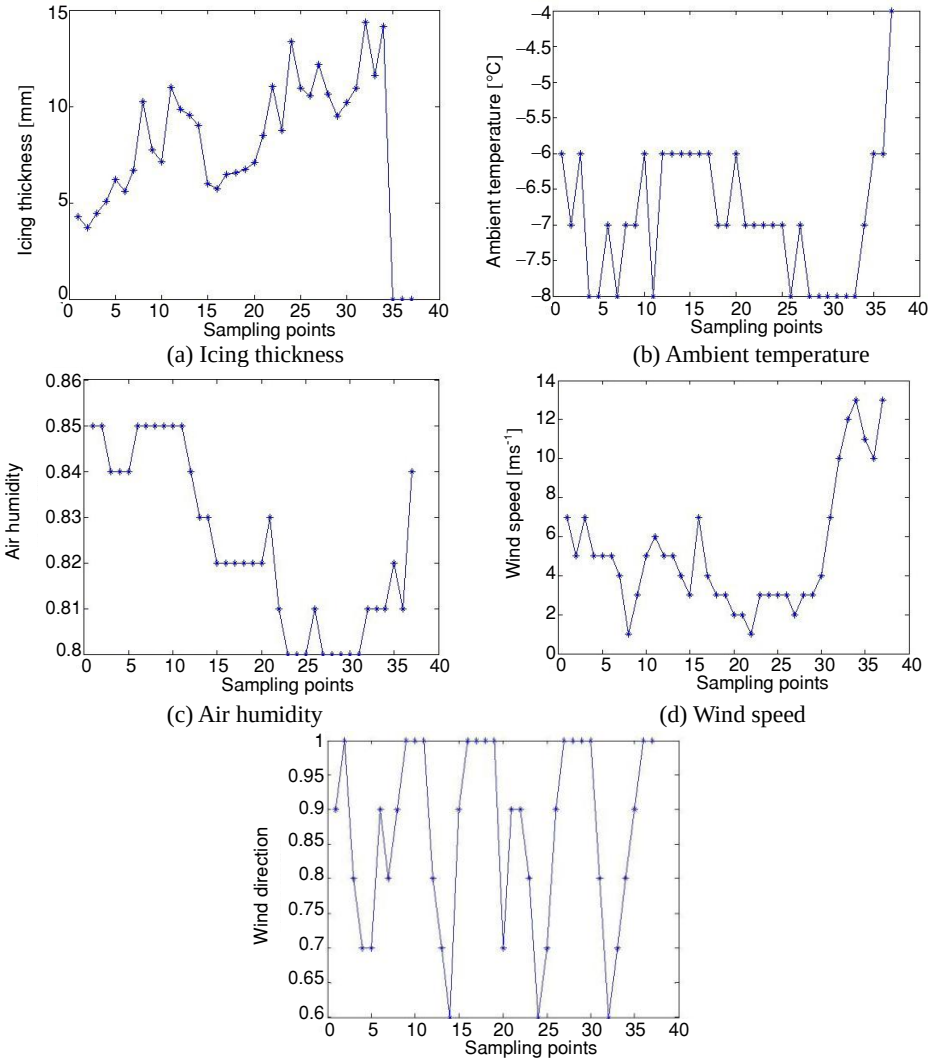
The TLMANN network is a complex structure including many extensively connected nodes as simple information elements. It consists of input layer, hidden layer and output layer [9]. The input layer node receives the input signal from the external source. In view of the special position of the temperature, current, voltage in transmission line (*i. e.* T, I, U), we choose T, I, U as the characteristic input elements to the nodes of the corresponding input layer for TLMANN. Otherwise, we introduce the grey relational theory in TLMANN train. After the module that is identified as the input node, these information are transmitted forward to each hidden layer node through network. Subsequently, this ANN sample is trained the number of hidden layer nodes up to 256, and then, it is set to the output node after the activation function of the hidden layer node work on (there are 4 nodes selected for the output layer of TLMANN, which responds to operating transmission line four common situation). Finally, the output signal is provided by the output layer nodes. The error back-propagation learning algorithm is used for TLMANN sample training. In the transmission line online monitoring, with the possible fault and the alarm signal to regard as input characteristics data to train ANN sample. After the sample training, it is possible to determine the nature of fault and the degree of seriousness in real-time, based on alarm signal. The out-

put information of the TLMANN through the output layer nodes corresponds to different fault status: with the values of Y range from 0 to 1, when the values of Y1, Y2, Y3, Y4 is greater than 0.5, the fault has been in existence. The more the value is closer to 1, the more serious transmission line fault is.

Transmission line Artificial Neural Network (TLMANN) can implement on-line monitoring and fault diagnosis for transmission line. We have developed the TLMANN system successfully. At present, it can monitor line operation. Its trend is almost perfect.

Artificial neural network diagnosis examples

Example 1. From February 27, 2013 to March 1, 2013, the transmission line online monitoring data in XinZhou Electric Power Company are shown in fig. 3. These data are icing thickness, ambient temperature, air humidity, wind speed and wind direction[10].



(a) Icing thickness (b) Ambient temperature (c) Air humidity (d) Wind speed (e) Wind direction

Figure 3. Transmission Line Monitoring Data

According to the online monitoring data, the incidence among icing thickness and meteorological factors can be obtained by the TLMANN system, as shown in tab. 2.

Table 2. The incidence among icing thickness and meteorological factors

Meteorological factors	Ambient temperature	Air humidity	Wind speed	Wind direction
TLMANN system analysis	0.9145	0.7529	0.9023	0.7193

Table 2 shows that the incidence among icing thickness and meteorological factors are relatively large. TLMANN system indicates that there is a larger correlation among these four parameters and wire icing. The descending orders of the incidence are ambient temperature, wind speed, air humidity and wind direction. This indicates that the ambient temperature is the main meteorological factor affecting the wire icing in this ice time.

Example 2. Shanghai Electric Power Design Institute has put the diagnosis system that is linked with TLMANN system into practice; test examples are given as below.

The table provides the online-measured leakage current date of the tested transmission line of FXBX220/100 which is carried out by the Shanghai Power Bureau in June 2010, as shown in tab. 3.

Table 3. Current leakage sampling data

Insulator number	315	377	365
Assigned numbers	11259N	11217N	11298N
Leakage current	50 (mA)	<30(mA)	290 (mA)
Environmental temperature	36 ℃		
Environment humidity	79%		
Voltage level	220（kV）		
Installation date	June 2008		

TLMANN diagnosis result: 365 # insulator Y3 value 0.9175; 365 # Insulator problems (the more serious nature of the fault); 365 # insulators should be replaced; 315 # insulators Y3 value 0.6172, 315# insulator pollution should be cleaned; 377 # insulator Y1 value 0.8175 is the normal operating range.

On-site experts opinion: 365 # insulator serious damage, take measures: replacement of insulators; 315 # insulators should be cleaned.

Conclusions

To summarize, power transmission line online monitoring system research, development and application is a new topic in power system. It adopts advanced sensor technology, such as wire dynamic capacity-increase and safe operation, insulator flashover, wire icing, remote video monitoring, *etc*. Further practice shows that the transmission lines dancing, anti-theft alarm, bird induced damage, *etc*, on-line monitoring is very effective means of transmission lines monitoring. Observing from researchers' perspective, it has great potential. Online monitoring system can make warning notifications for transmission line's early hidden

faults. It can make full range monitoring for transmission lines daily safe operation and transmission line automated patrol. In recent years, with in-depth study of the smart grid, in order to promote power system automation, to protect transmission line security, stability, reliability, must reduce the accident rate. Therefore, we should introduce advanced technology and promote transmission line online monitoring technology actively, before the overhead line design and installing. At the same time, power network operation management ability and social economic benefits are increased.

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Paper submitted: December 14, 2015
Paper revised: December 17, 2015
Paper accepted: December 28, 2015