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A smart grid needs smart monitoring

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Abstract

Over the past few decades, the electricity consumption has experienced phenomenal growth across the world. This may impose heavy load on power plants such as cables, as many of them are approaching the designed life consequently resulting in the reduction of reliability of power networks. The constraint imposed by aged power cables on increased customer demand on supply reliability has become a bottleneck in the operation of electricity networks. Therefore, smart monitoring plays a crucial role in improving the reliability of power network.

This paper aims to discuss the importance of smart condition monitoring, taking power cable as an example, in smart grid. The paper introduces smart monitoring and asset management in smart grid in details and presents a physical configuration of on-line cable condition monitoring system. Partial discharge diagnosis is selected as an example in the paper to explain the benefits when smart monitoring is applied.

Keywords: Smart grid, asset management, condition monitoring, smart monitoring, power cables

1. Introduction

Due to improvement in living standards and industrialization across the world especially in developing countries, the demand for electricity has increased significantly in recent years. As power plant items usually have a higher failure rate during their early life (0-5 years) due to manufacturing and installation problems and when they age, failures of power plants threatens the reliability of network in both developing and developed countries. In addition, the constraint imposed by the aged power plants on increased customer demand in electricity usage and reliability has become a bottleneck of traditional power networks. Therefore, condition monitoring, a solution to monitor the operating conditions and to diagnose equipment incipient failure, has been recognised as an important element of the Smart Grid concept. Through advanced communication network, as illustrated in Figure 1, which is made available in the smart grid, smart monitoring can be enabled. A smart condition monitoring system, which monitors real-time condition and diagnoses fault automatically, is a key solution to improve reliability of the smart grid. The condition monitoring system monitors and collects the condition information of power plants by using sensors to trigger reports to local or remote control centres. Meanwhile, smart monitoring system statistically processes collected data for maintenance, operation and scheduling purposes in asset management and can provide early warning messages when potential danger occurs in equipment. On-line condition monitoring provides information which is essential to enable network operators to identify imminent failures and to assess real-time condition. The structure of smart grid and benefits brought by condition monitoring and asset management are shown in Fig. 1.

Smart grid requires an integrated view of the complete asset base to more effectively manage assets, to

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increase reliability and to mitigate environmental impacts [1]. The integrated view of smart grid can magnify the weakness in the network, therefore helps to maximise plants' service life, defer network investment and replacement as well as improve the efficiency of electrical network. Smart monitoring and the resultant smart asset management can form an integral part of the life cycle management of power plant assets [2]. It helps to make decisions with a limited amount of asset performance data. Through the communication of smart grid and various installed smart sensors, system operating data and other relevant data can provide sufficient help for asset managers to improve the performance data and to make decisions. However, a significant challenge in implementing the smart monitoring is the huge growth in the quantity and quality of condition monitoring data. This has been partially due to improved sensor technology but principally from advances in signal processing and data communications technology and capacity. The resulting information overload increasingly needs the smart applications such as 'data mining' techniques [2].

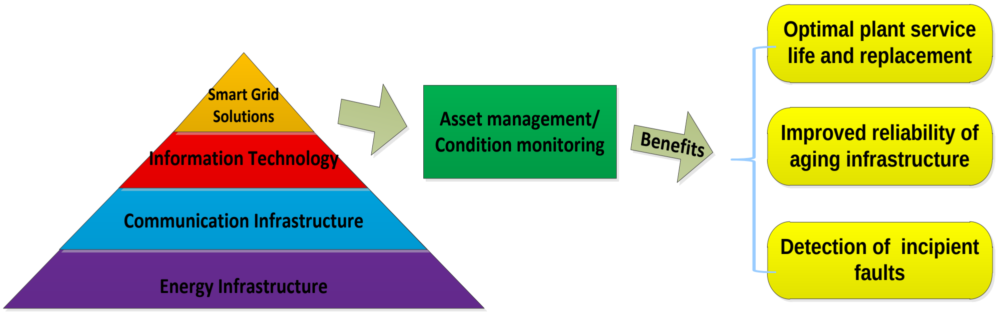


Fig. 1. Basic structure of smart grid and benefits brought by condition monitoring and asset management

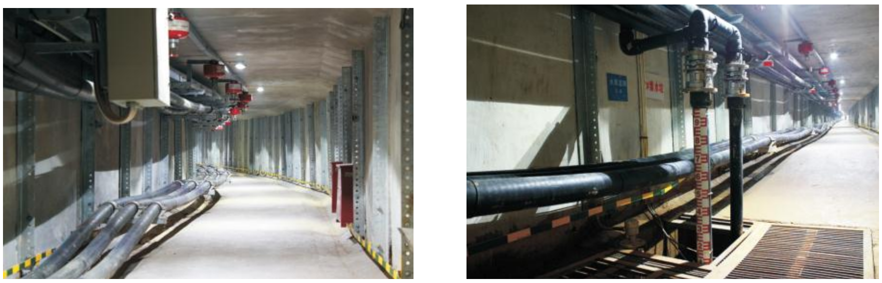


Fig. 2. Underground cables in the cable tunnel

2. Physical Configuration of an On-Line Cable Monitoring System

In this paper, power cables are selected to demonstrate the role smart monitoring plays in smart grid.

The adoption of underground power cables has experienced phenomenal growth due to the reliability and aesthetics concerns. However, directly buried cables, and those installed in conduit and duct are prone to damage by third parties and it is difficult to locate any faults when they occur. To ensure a higher reliability for strategically important circuits, an increasing number of High Voltage (HV) cables are now installed in cable tunnels. Fig. 2 shows pictures of cable tunnels developed with the condition monitoring systems investigated by the present authors' research team. Even though the failure rate is reduced in cable tunnels, possible faults such as breakdown in cable insulation or insulation in joint, earthing fault caused by damage of sheath or oversheath (rodent bite), water ingress in cable or link box and faults due to poor workmanship still threaten the safety of power cables in cable tunnel and reliability of power network. As loss of service of these important circuits would result in significantly adverse social and economic impacts, it is crucial to use on-line cable condition monitoring system to monitor the operational conditions of cables, environment and human activities in the tunnel to diagnose incipient cable fault and avoids third party damage.

On-line condition monitoring is the real-time monitoring for the conditions of components of power cables such as insulation or cable sheath at operating voltage. With the communication of the data acquisition and processing system, the measurable data can be processed automatically while cable failures can be diagnosed intelligently. In addition, with the rapid development of electronic and communication technique, especially the enhancement in computing and sensor technology, condition monitoring system can deal with huge capacity of collected data and real-time signal processing. A typical configuration of an on-line cable condition monitoring system is shown in Fig. 3.

It can be seen in Fig. 3, through computer processing, subsystems in the application centre listed in the figure can analyse measurable data automatically. With established knowledge base, the condition assessment of power cables can be achieved using knowledge rules which either has been established, or to be acquired in an autonomous manner from the smart monitoring system through self-learning.

2.1. Partial discharge monitoring subsystem

Partial discharge (PD) is one of the wide used diagnosis methods in power industry to assess cable conditions and can provide an early warning of cable components. It enables maintenance to plan repair and replacement of cables to be carried out timely. For many years, incipient partial discharge faults in power cables have been identified through off-line investigation techniques. In the smart grid era, on-line monitoring will be required for strategically important cable circuits to allow proactive asset management of the cable network to be carried out. Continuous on-line monitoring systems are being installed with aims of reducing unexpected failures and prioritising cable replacement programmes, due to its capability of identifying faults prior to failure while the cable is in service. Fig. 4 shows the schematic diagram of PD monitoring and results display for PD measurement.

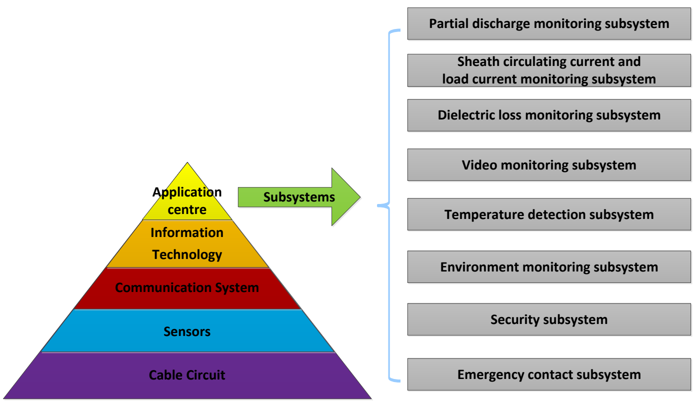
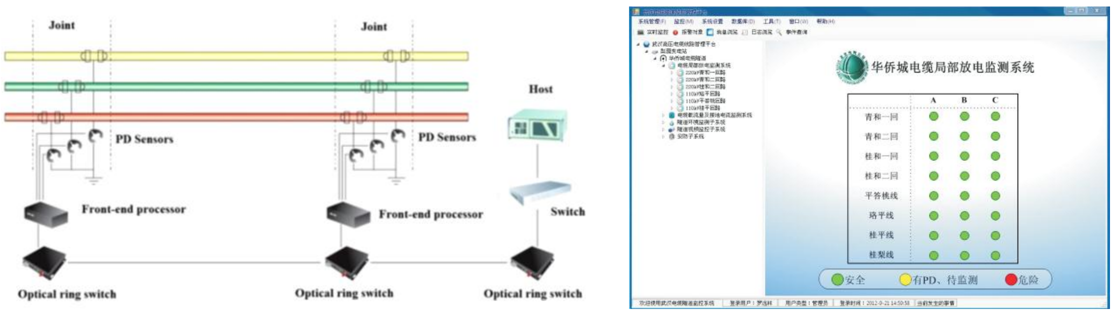


Fig. 3. Physical configuration of cable condition monitoring system



(a) (b)

Fig. 4. Diagrams of PD on-line monitoring system: (a) Configuration of PD monitoring and (b) Results display of the 8 cable circuits in a cable tunnel. Each of the three phases of the circuits are given a button in the diagram with “green” showing healthy condition, “yellow” warning sign meaning low level of PD and “red” signify alarms of imminent failure.

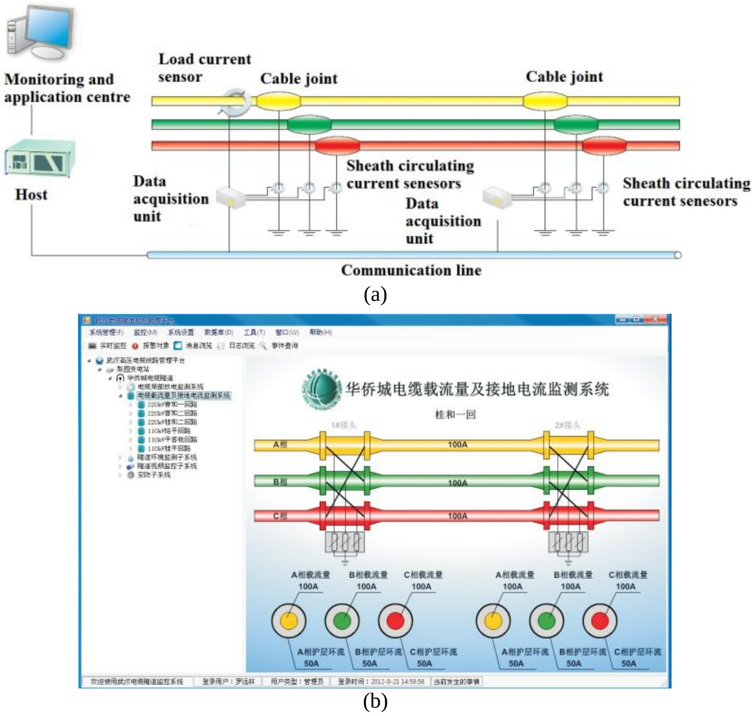


Fig. 5. On-line diagnosis of Sheath circulating current and load current: (a) Physical configuration of sheath circulating current monitoring and (b) Results display of measurement of sheath circulating current in two cable joints

2.2. Sheath circulating current and load current monitoring subsystem

On-line sheath circulating current monitoring is an efficient diagnostic method to detect failures in sheath and cable accessories, especially in cross-bonded three-phase cable systems. Statistics indicates that faults in XLPE cables usually appear in the metal sheath or its accessories whilst relative low failure rates have originated from the main insulation of power cables [3]. During normal operations of the HV cable system, at least one point of the metal sheath must be earthed. However, the external insulation of the metal sheath may have a risk of being damaged by external mechanic forces in the tubing process or corrosion after a long period of service. These may cause earthing faults due to metal sheath or oversheath damage and consequently lead to drastic increase in circulating currents. Excessive sheath circulating current results in overheat which may in turn cause damages to the cable insulation, shorten cable service life and reduce the cable transmission capacity. Therefore, on-line monitoring of sheath circulating current is crucial to detect cable faults at an early stage and can avoid unplanned outages. Fig. 5 shows the schematic diagram and results display for sheath circulating current monitoring. The figure indicates the sensors installed in the tunnel to measure three-phase sheath circulating currents. Due to the fact that load current has a significant impact on sheath circulating currents, monitoring of the load current and the sheath circulating current are combined in a comprehensive system.

2.3. Video monitoring subsystem

Video monitoring subsystem aims to monitor the visible environment and personnel activities in key areas of cable tunnel such as the entrance/exit, cable joint and intersection of tunnels. Based on the traditional video surveillance, remote intelligent monitor and localisation of personnel can be achieved through advanced computer processing techniques. When invasions happen, the system can identify and record the invader automatically meanwhile report to the control centre rapidly to allow maintenance respond timely. Figure 2 shows the images extracted from the on-line cable tunnel monitoring system.

2.4. Temperature detection subsystem

Temperature detection subsystem uses optical fibre as both detector and communicator. The optical fibres are fastened to the surface of power cables and the top of tunnel to ensure that distributed fibre temperature sensor (DTS) can measure the temperature timely. Once the measureable temperature is higher than the predefined values, the warning message can be reported to the control centre. Figure 6 shows the temperature detection subsystem with optical fibre lying on cables.

Fig. 6. Temperature detection subsystem using optical fibres

2.5. Environment monitoring subsystem

Environment monitoring subsystem focuses on conditions of invisible environment including: noxious gas (CO, HS and CH_4), oxygen density of air and other environment conditions such as the water level. Through intelligent monitoring of environment, the increased water level and combustible gas can be detected. Then, related ventilation and drainage system can operate automatically to improve environment conditions of the tunnel and to ensure the safety of power cables.

2.6. Security subsystem

Security system includes personnel location and access control system. In order to protect underground power cables, non-essential personnel are not allowed to enter the tunnel. The access control system can avoid the unauthorised entry while localisation system can send warning message when invasions happen.

2.7. Emergency contact subsystem

Emergency contact system can provide convenient communications during emergency or when distances among staff working in the tunnel are beyond the wireless signal coverage.

3. 3 Smart Monitoring

Smart monitoring aims to convert condition monitoring of data collected by sensors to visual diagnosis information automatically based on signal processing, signal classification and knowledge rule or expert based diagnostics systems. Take PD diagnosis for example. Accurate diagnosis of cable conditions, to date, relies on knowledge rules which are based on intensive analysis by human experts. This expert knowledge has, so far, been exclusively obtained from off-line PD tests. The data acquired, and the rules derived, are often not applicable to on-line PD monitoring because emphasis of off-line and on-line are substantially different [4]. As a result, using on-line smart monitoring for automatically accurate diagnosis can save labour cost and eliminates errors caused by human. However, to diagnose possible fault by PD, there are some main challenges [5] including:

- developing denoise techniques to identify PD signals accurately,

- developing pattern recognition techniques to classify fault signals,
- communicating and data mining to transmit large volumes of data from front-end processor to the control centre, and
- identifying and localising possible faults when PD activity occurs in cables

These techniques are essential techniques which help to enable smart monitoring by recognising PD and localising faults in an autonomous manner. Only by the identification of features, the condition monitoring can be applied as smart monitoring in smart grid. Figure 7 illustrates how the condition monitoring data are converted to diagnosis information.

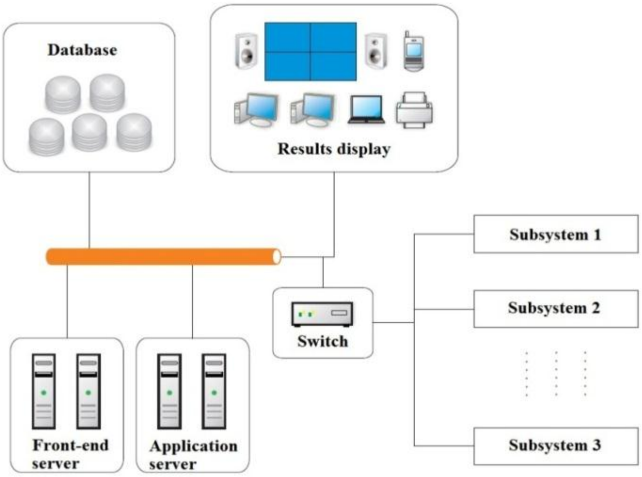


Fig.7. Conversion and management of condition monitoring data to diagnosis information

In light of the Smart Grid, on-line PD smart monitoring in the fault management area has become even more significant. The combination of intelligence methods for the analysis of insulation conditions of cables and on-line data mining methods, fit into the Smart Grid vision [6]. It would give utility asset managers effective support for accurate diagnosis of cable conditions and enables them to effectively convert potentially overwhelming amount of on-line monitoring data into useful information. Smart condition monitoring will allow continuous, efficient and economical asset assessment through more relevant fault diagnosis than that of off-line tests. The success in such a practical application will be of major benefit to the power supply industry in the UK and abroad.

4. 4 Conclusions

Smart grid was proposed to establish an efficient and reliable power network. Therefore, applications such as asset management and condition monitoring are developed in order to optimise asset service life and to improve system reliability. Asset management, which focuses on the integrated view of network, can magnify the weakness in the grid and therefore maximise the value of power asset.

The paper introduced seven subsystems for monitoring of cable systems in details. The subsystems can protect the cable system comprehensively from human to technical damage. However, it still needs expert knowledge and numerous labour costs. To overcome these imperfections, smart monitoring, which is able to convert monitoring data to diagnosis information, is developed to monitor cable conditions and to diagnose cable fault automatically. In PD based smart monitoring, four key techniques including denoise technique, pattern recognition technique, data mining technique and localising technique are seen as the key improvements. So far, PD based smart monitoring has been used in the condition monitoring system and investigations are carried out to diagnose cable faults accurately through sheath circulating current and dielectric loss monitoring.

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