A remote condition monitoring system for wind-turbine based DG systems

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Abstract. In this paper, a remote condition monitoring system is proposed, which fundamentally consists of real-time monitoring modules on the plant side, a remote support centre and the communications between them. The paper addresses some of the key issues related on the monitoring system, including i) the implementation and configuration of a VPN connection, ii) an effective database system to be able to handle huge amount of monitoring data, and iii) efficient data mining techniques to convert raw data into useful information for plant assessment. The preliminary results have demonstrated that the proposed system is practically feasible and can be deployed to monitor the emerging new energy generation systems.

1. Introduction
E-condition monitoring in this context is taken to mean the use of electronic monitoring devices and associated technologies in order to determine the condition of equipment and to predict potential problems remotely. In the health care system, e-monitoring utilises home monitoring devices that are connected to the internet to monitor patient data and allow management of patients. It could also enable an early detection of device malfunction, hence increasing reliability of the home monitoring system [1]. Similarly, e-monitoring was proposed for a milling cutting process, where microcontrollers were utilised as smart sensor systems, together with a robust industrial (CAN bus) network, to provide summative management information with regards to the action of the machine process being monitored [2].

Condition monitoring systems have been used for long time in power plants and, indeed, these systems have been remotely operated and maintained also for long time [3]. A conventional condition monitoring system usually consists of sensors, data acquisition modules, a data processing unit for analysis and diagnosis, and a computer for visualisation and data storage. In a remote monitoring, measurements are taken in the conventional manner; however, the data are automatically transmitted through the internet to either the power plants or to a remote monitoring centre. This will greatly enhance monitoring and management capabilities.

In light of this, remote condition monitoring has attracted significant interests over the past decades. For example, Siemens used Web-based condition telemonitoring and diagnosis in power plants to provide a global source of specialist support by integrating the diagnostic systems into user’s IT infrastructure [3]. A web-based aging monitoring system was also proposed to monitor, manage
and evaluate the aging conditions of the major mechanical components in a nuclear power plant under concurrent working environment using internet [4]. As can be imagined, transmitting the data over the internet would play a significant role in a remote monitoring. For this purpose, Virtual Private Network (VPN) has been recently present in remote monitoring, as VPN can avoid a need for leased lines whilst being able to transmit the monitoring data in a private internal network to offer secure internet connectivity [5-6].

In this paper, a VPN-based condition monitoring system is proposed for health monitoring and performance evaluation of distributed power generation systems. This monitoring system includes a database capable of handling huge amount of monitoring data. It is also anticipated that the proposed system can be used for a more efficient monitoring of the major components related specifically to an energy generation device.

2. System structure

Distributed generation (DG) is a growing area in generating and supplying electricity due to the use and deployment of renewable energy generation technologies such as wind farms, wave farms and hydro electric power. It is also known as embedded or dispersed generation due to its nature of generating electricity. In a DG system, electricity generating plants are connected to a distribution network rather than the transmission network. It has been widely recognised that this type of power generation technology can provide electric power with higher energy efficiencies by utilising a wide range of renewable energy sources at a site close to end users. One of the critical challenges for the deployment of distributed generation systems relates specifically to availability and reliability. The development of remote e-condition monitoring techniques has a particular significance in this context, in order to sustain energy generation and maximise a long service life of the energy systems unattended.

In condition monitoring, one of the key issues is to transmit the monitoring data and operational data of the plant to a remote support centre for further analysis. This analysis can be done to support an existing problem, to assess the current performance of a device or the overall performance of the system, to assist maintenance and planning, and to apply intelligent techniques to mitigate failure risks.

![Figure 1. Schematic diagram of a distributed condition monitoring system.](image)

Figure 1 shows a schematic diagram of a distributed condition monitoring system. At plant sides, condition monitoring modules (CMM) are connected to the onsite server via a local area network (LAN). The onsite server is primarily used to communicate regularly with the hardware monitoring
modules, collect and store the data from the devices being monitored. Monitoring data together with relevant operational data collected by other in-situ systems like a SCADA (system control and data acquisition) system need to be transmitted back to a remote support centre. Take a wind farm as an example. Based on published statistics, the failure rate per turbine and per year is as high as 3.5 for larger units (>1 MW) and around 1.0 for smaller units (<500 kW) in most European countries [7]. We suppose that each wind turbine is equipped with a CMM module, aiming to monitor most subsystems of the turbine, including blades, rotor, gearboxes, bearings, pitch control, yaw drive, generator, power electronics and their effects on electrical output. Apparently, the monitoring techniques involve dealing with mechanical, electromagnetic, electrical, thermal, acoustic, optical and meteorological phenomena to yield data for collection and desirable instruments for interpretation.

Communications between monitoring instruments in the power plants and the remote support centre can be made via a VPN. The VPN uses a public internet to provide support centre with secure access to the plants’ network. In addition, use of a VPN can provide the power plants with the same capabilities to their owned lines but with a much lower cost.

With a VPN, not only can live data be viewed but also hardware monitoring modules can be configured, operated and maintained from the support centre remotely. A VPN works by using the internet while maintaining privacy through security procedures and tunnelling protocols. In effect, the data are encrypted at the transmitting side and decrypted at the receiving side. In this way, the protocols send the data through a tunnel that cannot be entered by data that are not properly encrypted. The protocols can also involve encrypting not only the data, but also the transmitting and receiving network addresses [8]. This would further increase level of security of the system.

3. Implementation and monitoring data
The condition monitoring system can be implemented as described in figure 2. Essentially, the CMM module is a set of data acquisition modules that can be used to accommodate monitoring of different subsystems of an energy generation device. Take a wind farm as an example again. One of the CMM hardware modules can be designed to have multiple input channels suitable for wind turbine blade load measurement whereas other modules can be assigned for bearing temperature inspection, shaft vibration monitoring, stator winding temperature monitoring, rotor flux monitoring of the generator, monitoring of voltages and currents at the point of common coupling (PCC), etc. Moreover, the affiliation of different monitoring techniques of a wind turbine into one hardware unit would require fewer hardware systems with reduced costs and communication problems due to electromagnetic interference. A NI CompactRIO system is used to build our own embedded systems and test algorithms.

![Figure 2. Implementation based on a configurable control and data acquisition system.](image-url)
The PC 1 connected to the CMM module represents the plant server, by which plant operators can view both the live and the stored historic data. The PC 2 in figure 2 represents the client monitoring server at the support centre. Standard Dell laptops with 2.27 GHz processor and 2GB RAM were used in the tests.

3.1. VPN configuration
As mentioned earlier, a VPN uses a special protocol to establish a virtual channel between two networks or two machines. In order to achieve a convenient and secure VPN connection, the network at both sides must be configured i) to be compatible with VPN standards, ii) to use the same identification and authentication mechanism, and iii) to use the same code encryption methods [5].

A remote VPN access can be used in our condition monitoring system. As can be seen from figure 1, firewalls are located between LAN and external network. Data encryption is used to provide data confidentiality for the data that are transmitted between plant server and the support centre server. A connection without encrypting the data is not allowed. If more computers in the support centre need to be connected to operate and maintain the CMM module remotely, they must be an authorised user of the centre. Relative authentication technology must be applied to these extra connections.

The VPN connection, as shown in figure 2, works in a one-way relationship to simplify the problem, where the destination network has the VPN setup and there is no agreement with another network to share. In this case, the PC 2 needing to make the connection with the network must have VPN client software and the request can only be made from the client (PC 2) to the network (PC 1).

3.2. Data file and database
Handling huge amount of data in condition monitoring requires a suitable data file format and an effective database system. XML (Extensible Markup Language) documents can be used to achieve this, as they are designed to store and transfer data between programs and over the internet that are fully platform-independent.

Basically, XML documents uses tags to define objects and their attributes. The document format is similar as a HTML document but XML allows the user to define own tags and own document structure. An XML document is divided into two parts, a document header with processing instructions when configured for data collection and a content part with the intrinsic data. In the content part, tags are defined to distinguish data. For each tag, the data samples are recorded with a number of attributes defined such as time stamp when the data are collected, value of the data, type of data, and the unit of data related to a physical signal, etc. Different type of tags can be recorded in the same XML document to contain all necessary signals appropriate for analysis and diagnosis of a target system being monitored.

With regards to database structure, SQL database has been designed effectively to manage data in a relational database management system. Such database allows for data insert, query, update and access control. The data stored in SQL database can be retrieved into XML documents that can be in turn transmitted over the internet.

3.3. Monitoring data
As an example, figure 3 shows a plot of winding temperature of an induction machine. It can be found that there are changes in winding temperature that may be caused by the power output or other operational parameters of the machine. In reality, monitoring of data trends would compare values against normal bounds numerically determined from historic data. The sampling rate is 5 minutes; 288 samples are displayed in figure 3, representing the measurements collected over a day, i.e., 24 hours. The XML data file was initially placed on PC 1 and then received by PC 2 after communication, as shown in figure 2.
There are several tools that can be used to deal with XML data in the programs like LabView. Measurement data can be converted to XML format for transfer while the XML data once received can be retrieved and saved to a text file. These data may be subsequently passed to other programs for off-line investigations.

Figure 4 shows an example about the dynamics of an induction machine when directly connected to the electrical grid by a combination of events due to environmental changes and fault conditions. It is evident that the operational data of the system change with the mechanical and electrical events of the turbine and induction machine, which can be traced back further to the effects of incoming winds and external disturbances. Clearly, there is correlation between these monitoring data, revealing nature of the disturbances.

3.4. Information extraction

In condition monitoring, large volumes of data need to be transmitted and processed for further analysis and diagnosis, especially for the online monitoring cases. For example, it is assumed that around 250 points are required for a typical 2 MW wind turbine to monitor most subsystems of the turbine. This gives rise to about 12,500 monitoring points for a 100 MW wind farm. If a sampling rate is set to 5 minutes, around 72 K data per 2 M turbine are acquired, giving rise to 3.6 M data every day for a 100 MW wave farm.

A natural consideration is to achieve a high data compression using a suitable compression technique such as wavelet-based methods through storing the effective wavelet coefficients rather than the original data [9]. This can greatly reduce the storage memory requirements of on-line measurement and also expand the content part of XML documents through storing these transformed coefficients. Consequently, this may potentially solve the problems related to the bottle-neck of data communication between the distributed generation plants and the remote monitoring centre.

As can be seen from figure 4, mechanical and electrical performances of the turbine are instantly affected by the environmental changes (e.g., wind gust, wind ramp) and fault conditions (e.g., single phase grounded, 3-phase grounded fault occurring at the connected electrical grid side). These signal changes are in essence determined by the location, duration and severity of the disturbances. With an appropriate pattern recognition approach or a statistical method based on the extracted features, health conditions of the system can be quantified and categorised [10].
4. Conclusions
A distributed condition monitoring system is proposed in this paper. It is aimed that the condition monitoring modules are designed on a configurable and modular basis for both hardware and software. Preliminary tests have shown that creation of XML data files from measurement data and communication between two networks via VPN protocol connections is practically feasible and effective. The received data can also be easily retrieved for further analysis and diagnosis.

The research has also showed that development of efficient data mining techniques to convert raw data into useful information are necessary for plant assessment. This can be done by extracting such as wavelet coefficients from raw data and then integrating the features into the XML documents, hence reducing data file size. Moreover, the operational performance of the system can be further quantified and categorised based on the extracted features.

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