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Development of Auxiliary SCADA System for Wind Farm Operation Based on Open Platform Communication

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Keywords： wind energy, wind turbine, O&M, SCADA, OPC.

ABSTRACT

The remote supervisory control and data acquisition (SCADA) system is necessary for the wind turbine (WT) operation and the management of a wind farm. Technicians can resolve minor WT failures remotely and prepare equipment and spare parts for an on-site maintenance in advance with the aid of the SCADA system. This work is a case study, malfunction of the SCADA system for a wind farm in middle-Taiwan was encountered but the maintenance of WT manufacturer was no longer available due to the company bankruptcy. Since the emerged SCADA system failure is mainly caused by the storage and access of database, an auxiliary SCADA system based on the open platform communication (OPC) was designed to recover the SCADA system function. The OPC-based SCADA system is capable of retrieving data and reconstructing data structure from the WT controller directly. The rebuilt database has been employed in a front-tier web-based interface to regenerate the monitoring function for this wind farm.

INTRODUCTION

The installed capacity of the onshore wind power in Taiwan is about 690 MW. These wind turbines (WTs) distributed in 30 wind farms are designed by five manufacturers, the details are listed in Table 1. The operational maintenance of wind farm is usually conducted by the WT manufacturer in the first 2-5 years. After the warranty period, a new wind farm O&M (operation & maintenance) contract with the WT manufacturer can be signed up or the wind farm operator performs the O&M by itself. No matter which O&M mode is adopted, a remote supervisory control and data acquisition (SCADA) system is indispensable for the wind farm management.

Table 1. Wind turbine models installed in Taiwan.

WT Manufacturer	Country	WT Model Type
Vestas	Denmark	V80 (mostly)
Enercon	Germany	E70
GE	USA	1.5s
Gamesa	Spain	G80
Zephyros	Netherlands	Z72

Supervisory Control and Data Acquisition (SCADA) System

SCADA is a remote monitoring and control system architecture comprising computers, networked data communications and graphical user interface for high-level process supervisory management and real-time data acquisition, while also comprising other peripheral devices to interface with process plant. The SCADA system resides on a server in the form of a database, and the raw data is collected from the hard-driver of the microprocessor/sensor system deployed on the WT (Wang et al., 2014). The main function of SCADA system is to provide early warnings of possible failures and to optimize the maintenance schedules to reduce the downtime and the maintenance cost, and to enhance the WT reliability and safety (Mntezami et al., 2014). The recorded data by SCADA system can be categorized into following types: wind conditions, WT performance indexes, WT vibration behavior, temperature states, and any occurred errors (Verma et al., 2012). A large set of high dimensions and many types of data are collected from massive WTs to predict their conditions and life (Liang et al., 2015; Tchaloua et al., 2014; Tao et al., 2019). Various methods of using SCADA data for WT condition monitoring have been developed, which can be classified as (1) trending, (2) clustering, (3)

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normal behaviour modelling, (4) damage modelling and (5) assessment of alarms and expert systems (Tautz-Weinert et al., 2017). Trending approaches refer to monitoring the changes of SCADA parameters over time to reveal early signs of faults, e.g., the trend of WT gearbox oil temperature against gearbox efficiency (Feng et al., 2013) or rated power (Astolfi et al., 2014). Clustering means to diagnose the WT condition to be normal or not, e.g., a modified k-means clustering algorithm was used to analyze the WT vibration (Zhang et al., 2012), and the Catmull's method was employed to diagnose the gearbox failure (Wilkinson et al., 2014). The normal behaviour modelling is a model-based monitoring method. The utilized model is built and trained by various algorithms, e.g., the linear and polynomial model for drive train temperature (Wilkinson et al., 2014) and generator bearing temperature (Schlechtingen et al., 2010), the artificial neural network-based monitoring system for WT component temperatures and power output (Li et al., 2014), the fuzzy inference system for WT controller malfunction and hydraulic oil leakage (Schlechtingen et al., 2014). The damage modelling is a physics of failure approach for damage calculation and failure probability estimation. This approach can better represent damage development and give more accurate results, e.g., to develop a damage model based on a physical understanding for the WT yaw failure (Gray et al., 2010) and the gear tooth damage of gearbox (Qiu et al., 2016). The last method, assessment of alarms and expert systems, is to interpret outputs from SCADA alarms by evaluating the status codes (Chen et al., 2015) or diagnosing the SCADA errors with an expert system (Gray et al., 2015).

Open platform communication (OPC)

Enormous effort is necessary for the integration of large-scale systems, these facilities are complex, vase networked systems that comprise a vast number of devices and applications with different communication protocols. Therefore, data acquisition, exchange and processing are accomplished in a distributed way between heterogeneous data sources and consumers (Gonzalez et al., 2019). Open platform communication (OPC) is the interoperability standard for the secure and reliable exchange of real-time plant data between control devices from different manufacturers. The OPC standard is a series of specifications for industrial telecommunication. These specifications define the interface between clients and servers, as well as servers and servers, including access to real-time data, monitoring of alarms and events, access to historical data and other applications. The OPC standard was first released in 1996 under the name OLE (object linking and embedding) for process control, its purpose was to abstract PLC specific protocols (such as Modbus, Profibus, etc.) into a standardized interface allowing HMI (human and machine interface)/SCADA systems to interface with a middleware which would convert generic read/write requests into device-specific requests and vice-versa. As a result, an entire cottage industry of products emerged allowing end-users to implement systems using best-of-breed products all seamlessly interacting via OLE for process control.

As OLE for process control has been adopted beyond the field of process control, a new name, open platform communications, was given in 2011. The new name reflects the applications of OPC technology for applications in discrete manufacturing, process control, build automation and many others. The last standard version called OPC UA (unified architecture) was developed to address these needs and at the same time provided a feature-rich technology open-platform architecture that was future-proof, scalable and extensible. The OPC technique was adopted for the integration of the WT motor control system and electric control system (Lu et al., 2008). The interconnection problem of multiple control systems, the network security strategies and measures were discussed. A real-time online monitoring and control solution for large-scale wind farms was proposed (Bai et al., 2010). The OPC technique was utilized to integrate the communication management terminal. The wind farm data can be acquired through this power dispatch data network, and the bus voltage of step-up substation can be regulated. An integrated OPC-based test system for large-scale WT permanent magnet synchronous generator was designed and realized (Dong et al., 2009). The Profibus-DP and OPC interface are devoted to the development of the communication network and the software communication interface. For a large wind farm or for the power company, several SCADA systems may be engaged at the same time. Since different SCADA system is not compatible, a research about the data share between various SCADA systems was introduced (Wang et al., 2011). The OPC technique was used to realize the unified management of data for multi-wind farms, performance calculation and analysis.

Research Object and Motivation --- Wind Farm in Middle-Taiwan

The research object is a special O&M case. The basic information of the wind farm is listed in Table 2. This wind farm consists of twenty-two WTs when constructed. However, eight WTs were collapsed or broken severely over the past years because of typhoons. The WT manufacturer, Zephyros, suffered a financial problem and finally closed down. As a result, the O&M of this wind farm was taken by the operator after that. After years of operation, malfunctions of SCADA system in data storage and analysis function were encountered. The data storage function and access to the SCADA database was no longer available. Accordingly, wind farm technicians have to go onsite frequently to check WT status owing to the lack of real-time information remotely. The operator turned to find an alternative solution from local service. This work is focused on the improvement of the ineffective SCADA system. An OPC-based auxiliary SCADA system is proposed to regain the SCADA function belongs to the mentioned wind farm and carry out the communication between this wind farm and the remote power dispatching center.

Table 2. Specifications of Z72 wind turbine.

Item	Description
Wind farm name	Taichung harbor (in middle-Taiwan)
Wind farm size	14 WTs (now) / 22WTs (initially)
Turbine manufacturer	Zephyros/Harakosan
Turbine model	Z72
Rotor diameter	70.65 m
Rotor speed	Variable, nominal 22.5 rpm
Transmission	Direct drive generator
Rated wind speed	13 m/s
Cut-in / cut-out wind speed	3-25 m/s
Survival wind speed	70 m/s
Rotor speed control	Blade pitch
Wind class	2 and S according to IEC 61400-1
Generator mass	49 tons
Rotor mass	36 tons
Nacelle mass	12 tons

PRIMAL SCADA ARCHITECTURE OF Z72 WIND FARM

The SCADA system deployed in this Z72 wind farm is introduced in Figure 1 (Garrad Hassan, 2010). The SCADA site server (the database), WTs, meteorological station and grid station are all connected through the site communications network with the aid of the remote interface unit (RIU). The SCADA system allows the access to historical data retrieval, but without real-time interface and control functionality. For the purpose to schedule the power generation and dispatch, a remote power dispatching system was developed by the operator. As shown in Figure 2, path #1 is the Z72 SCADA system by the manufacturer (the original SCADA system). The current state for the monitoring of this Z72 wind farm is path #2, due to the limits of access authority of the primal SCADA system. In path #2, PC #C is for the wind farm data decoding (data acquired from the SCADA database), PC #D is to reconstruct the decoded data with the OPC tag, and PC #E plays the role of OPC server and data server. The condition information of Z72 wind farm is finally integrated with messages of other wind farms in the synthesized remote monitoring interface (#F2). For other wind farms, if the access authority of SCADA system is adequate, the wind farm information can be acquired by the remote power dispatching server (path #3 / PC #E) directly. Figure 3 is the illustration of the synthesized remote monitoring interface, there are more than 16 wind farms monitored by this remote power dispatching system.

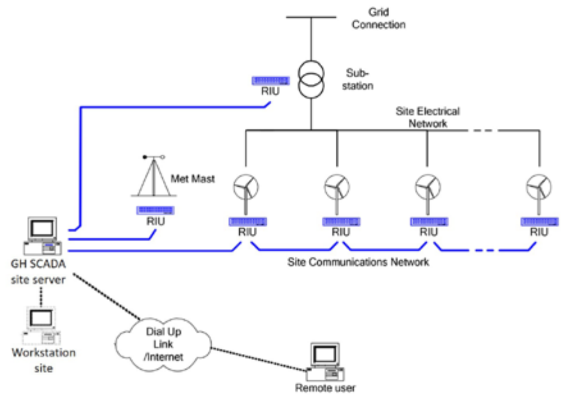

Fig. 1. Original SCADA architecture of Z72 wind farm (Garrad Hassan, 2010).

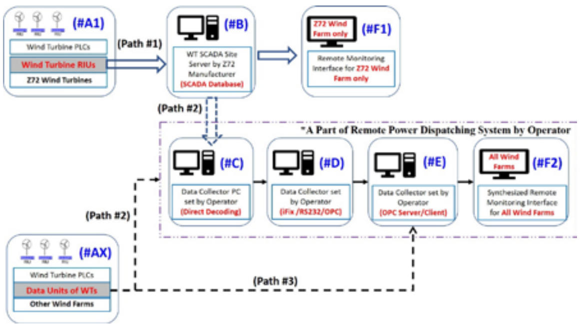

Fig. 2. SCADA architecture of Z72 wind farm by WT manufacturer and operator.

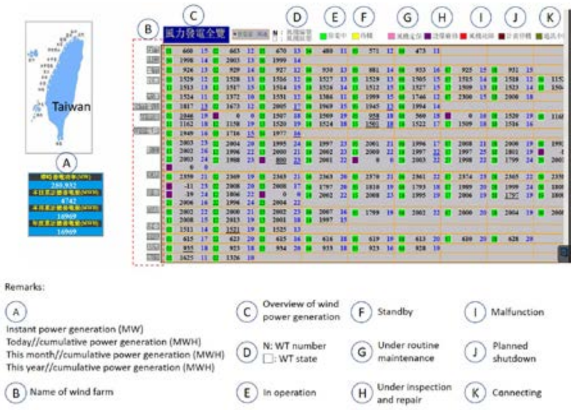

Fig. 3. Interface of the synthesized remote power dispatching system by operator.

OPC-BASED AUXILIARY SCADA SYSTEM DESIGN

The maintenance server by WT manufacturer was not available due to the company bankruptcy. After years of operation, a crash of SCADA database (PC #B in Fig. 2) was encountered. The functions of access and storage of the SCADA database was no longer available. As a result, the data processing path #1 and path #2 in Fig. 2 (for the Z72 wind farm) are out of service. The purpose of this work is to design a substitute SCADA system to cooperate with Z72 WTs. There are two key issues have to be addressed: (i) to redesign the communication architecture to build a new database (the SCADA site server, the role of PC #B in Fig. 2) for the WT data collection, (ii) to further simplify the current remote monitoring system by the operator (inside the dotted frame in Fig. 2 / PC #C to #F2) to improve the system reliability. For the first issue, the new database (SCADA site server) must have the following three functions:

1. Two-way communication with PLC controllers of WTs. The real-time data of WTs can be acquired by the new server, and operational commands can be sent to PLC controllers. The primal SCADA database by manufacturer is read only and limited to the historical data (real-time information is not available). In addition, the communication between WTs and the original SCADA site server is by means of the RIUs. Since the software inside the PLC controller is usually the core technology of the WT manufacturer, the OPC technique is employed to deal with the communication between WTs and external devices.
2. Storage of the WT data for the maintenance and analysis. Large amounts of data from 14 WTs will be transferred from PLCs to the new SCADA server. A well schemed, constructed and organized database server is necessary for WT data retrieval remotely.
3. The human machine interface (HMI) for the user login, query, WT monitoring, and WT control via web-server.

The second issue is to simplify the communication network of the remote power dispatching system (the dotted frame in Fig. 2 / PC #C to #F2). There are too many nodes from #A1 to #F2. A fault occurred in any node will terminate the data transfer and leads to a low system reliability. The redesigned communication network is shown in Figure 4. The structures of the new network (Fig. 4) and the original web (Fig. 2) are similar. But the WT data is acquired from the PLC instead of the RIU. In addition, the OPC database server and the web server are newly designed and installed in a single PC (PC #N). Users are allowed to connect to the SCADA web site by means of a desktop PC, a notebook, a panel PC or even a smart phone with a common web browser. The new communication network makes the monitoring and maintenance of wind farms more easily and efficient. The role of PC #E is to construct a data tags table for the integrated monitoring platform (#F2 in Fig. 4), and provide the full regulation function for WTs .

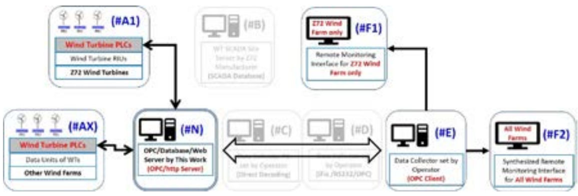

Fig. 4. Architecture of proposed auxiliary SCADA system.

One of the main tasks of this work is to accomplish the communication between WT PLCs (programmable logic controllers) and the OPC server, as shown in Figure 5. The equipped PLC in the Z72 WT is Bachmann MX220. The data exchange is complied with the standard of IEC 61400-25. OPC defines a number of manufacturer-neutral software interface for automation. Real-time system states and parameters values can be exchanged between controllers and applications. The data transmission from PLCs to the OPC server (PC #N) is by means of the DCOM (distributed component object model) protocol. DCOM is a proprietary Microsoft technology for communication between software components on networked computers. For the WT regulation, the control command is also transferred under the DCOM protocol from OPC client (PC #E).

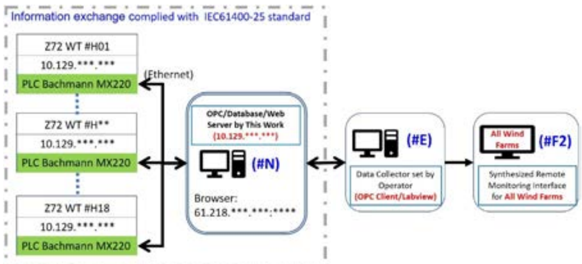

Fig. 5. Communication between WT PLCs and OPC server.

RESULTS AND DISCUSSION

The developed auxiliary SCADA System for Z72 wind farm is illustrated in Figure 6. In the main window, statuses of individual WTs are marked by different colors, for example, red means the WT malfunction occurred, green is referred to the normal operation of a WT, and grey indicates the specified WT is temporarily unavailable (e.g., under maintenance or planned shutdown). A detailed interface of the WT condition can be revealed by selecting a WT in the main window. Figure 7 is an individual WT condition interface (WT #H09 of the Z72 wind farm). The real-time WT state, the statistical data of WT operation, and the historical data retrieval of WT operation are all available in this interface. An extra web page of advanced information of individual component can be obtained by directly selecting the WT sub-component inside the WT picture in Fig. 7. Figure 8 is an illustration of information inside and outside the WT nacelle. The statuses of environmental parameters outside the WT nacelle include the instant wind speed, the average wind speed per minute, the wind direction, the atmospheric pressure and the surrounding temperature. The conditions inside the WT nacelle include the nacelle temperature, the control cabinet temperature, the temperature of cooling fan and the degree of vibration along different direction. Except for the historical data retrieval of WT operation, the post-processing and analysis of WT operation data is also available. Figure 9 is a sample of WT power output against wind speed. The connection of SCADA web site by a smart phone is allowed, as shown in Figure 10. The information of the mobile mode SCADA interface is less than that of PC mode (e.g., Fig. 6-Fig.9) owing to the panel size. However, alarms for any malfunction can be noticed by a technician immediately via a mobile device, the efficiency of WT O&M can be greatly improved.

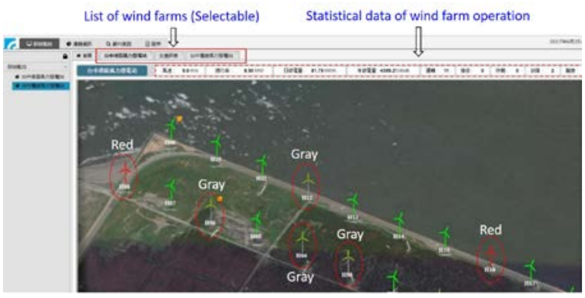

Fig. 6. Home page of the proposed SCADA web site.

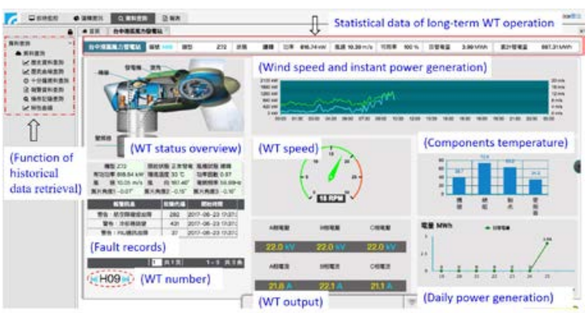

Fig. 7. Condition interface of single WT.

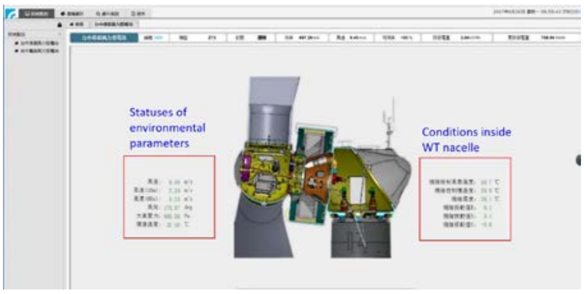

Fig. 8. Component screenshot (generator status).

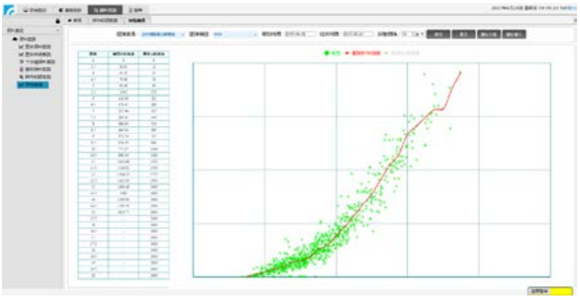

Fig. 9. Characteristic curve of WT power output against wind speed.

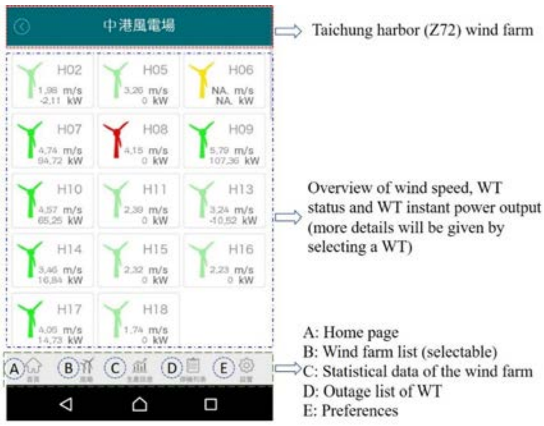

Fig. 10. Mobile interface of the proposed SCADA web site.

CONCLUSIONS

Due to the lack of maintenance service by WT manufacturer, an auxiliary SCADA system design was proposed and developed to deal with the malfunction of primal SCADA system. The OPC technique was employed to build the communication network between WTs and external devices. The architecture of the substitute SCADA system is two-ways communication, which means the monitoring and control of WTs are both available. In addition, for improving the system reliability of the remote power dispatching system, the system framework by the operator was rearranged and synthesized with the aid of OPC technique as well. The proposed auxiliary SCADA system allows technicians to monitor and regulate the WT operation through their PC or smartphone (the control function is partially limited under mobile mode). The newly designed SCADA web page function facilitates the wind farm O&M more easily and efficiently. The proposed OPC-based SCADA architecture is also adequate to various wind farms of different communication protocols.

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以 OPC 架構開發風場輔助 SCADA 系統

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摘 要

此研究探討消失性商源對風場運作造成之影響，SCADA 系統用於風機之遠距監控與數據收集，對於風場之運作調控與風機維護相當重要。本文研究對象為台灣中部之風場，由於風機母廠倒閉使得風場 SCADA 系統無法進行維護與升級，間接導致風機的可利用率大幅降低，有鑑於風機原廠軟體並非開源架構，本研究採用 OPC 開放平台架構進行輔助軟體開發，藉由直接與風機硬體通訊方式達成數據雙向傳輸之目的，除了重建監控與基本調控功能外，亦開發手機監控介面提高輔助 SCADA 對於風場監控的實用性與即時性。