The Scheme Design of Smart Offshore Wind Farm

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***Abstract*—Based on the characteristics of offshore wind farm and marine meteorology, combined with the design-build-operate life cycle process, this paper studied the definition and framework of smart offshore wind farm. The overall monitoring of offshore wind turbines, offshore substation and onshore control center is realized, with surveillance, operation control, comprehensive information analysis, intelligent alarm, management and other functions. In this way, the real-time monitoring of offshore substation, onshore control center, marine environment, vessels and offshore personnel is achieved to optimize the dispatch resources and construction maintenance plan. Finally, the smart offshore wind farm solution in this paper realized the life cycle management of offshore wind farms, which reduces construction and operation costs, increases generating capacity, extends equipment life and ensures personnel safety.**

Keywords- smart offshore wind farm; wind turbine monitoring; intelligent construction operation management.

I. INTRODUCTION

Since the offshore substation and wind turbine are unattended, the wind turbine monitoring system for offshore wind farm need to be fully monitored and controlled to ensure the healthy operation and fault diagnosis. The offshore wind farm monitoring system needs to integrate the monitoring of offshore wind turbines, offshore substation and onshore control center to ensure system integrity [1,2].

Due to the tightness of offshore wind power construction vessels equipment, the short window period of offshore operations, and the limited production capacity of offshore wind turbines and submarine cables, the construction period of offshore wind farms is long, and construction schedule and quality cannot be effectively controlled [3].

The complete equipment operational monitoring data is lacked in the wind farm. At the same time, there is a lack of operational management programs considering the marine environment, wind turbine unit status, vessel and personnel dispatching resources comprehensively [4,5].

The cost ratio of offshore wind farms is 35% for wind turbine, 14% for electrical infrastructure, 13% for wind turbine foundation and structure, 11% for construction and installation, 8% for site planning and other, and the remaining 19% for operation and maintenance [6]. It is quite important to ensure the safety, stability and economic operation of offshore wind farms and reduce the costs of wind turbines, construction, installation, operation and maintenance. Therefore, this paper studies a scheme design of smart offshore wind farm to improve the overall income of offshore wind farms by excavating the construction and operation rules and equipment status, maximizing the use of wind resources, optimizing maintenance cycles, and realizing early warning and diagnosis of accidents and equipment failures.

II. THE SMART OFFSHORE WIND FARM DEFINITION

Referring to the definition of smart substation and considering the particularity of offshore wind farms, the definition of smart offshore wind farm is the application of intelligent equipment, which realizes digitalization of offshore wind farm information, network of communication platform and standardization of information sharing. It has perfect monitoring function of offshore wind farms and monitoring of equipment status. At the same time, based on the characteristics of offshore wind farms and marine meteorology, it has the optimal scheduling of vessel resources and the safety monitoring of personnel, and guides the construction, operation and maintenance of maintenance through construction of production information management. Finally, it can support advanced functions such as real-time automatic control of the grid, intelligent adjustment, online analysis and decision-

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making, and collaborative interaction. It achieves the goal of reducing construction and operation costs, increasing on-grid power generation, extending equipment life and ensuring personnel safety [7,8,9,10].

The smart offshore wind farm should have the following main features.

1) For the characteristics of offshore wind farm and marine meteorology, smart offshore wind farm should include wind turbines, offshore substation, onshore control center and corresponding connecting submarine cables in space, and "design-build-operate" life cycle process.

2) It has the perfect monitoring functions of offshore wind farm, perfect equipment condition monitoring and application of online diagnostic equipment. It increases the power generation amount of wind turbines and extends the life of equipment to ensure reliable operation of wind farm.

3) Combining the characteristics of offshore engineering, it can optimize the dispatching of vessel resources and personnel safety monitoring, and form an intelligent operation management system. It reduces the cost during construction and operation and ensures the safety of personnel and vessels.

4) It has also the feature of intelligent application of main equipment, hardware platform sharing and information sharing of monitoring equipment. The signal output and control inputs of the intelligent primary equipment use digital technology. And the smart offshore wind farm adopts a standardized network communication platform, with a new mode of information sharing, hardware platform integration application, software function plug-in multiplexing, and logic function intelligent strategy. It realizes intelligent monitoring and inspection of offshore wind farm.

III. THE SCHEME DESIGN OF SMART OFFSHORE WIND FARM

The smart offshore wind farm has unified planning and design of the monitoring system of wind turbines, offshore substation and onshore control center. Through the IEC4100 communication protocol, the information data of onsite production automation and dispatch management is fully integrated to realize remote monitoring and controlling of the entire wind farm.

The functional structure of the smart offshore wind farm application is divided into three levels as shown in Figure 1, with the data acquisition and unified storage, unified access interface, and five types of application functions.

The five types of application functions include the operational monitoring, operation and control, comprehensive information analysis and intelligent alarm, operation management, and auxiliary applications [7,11,12].

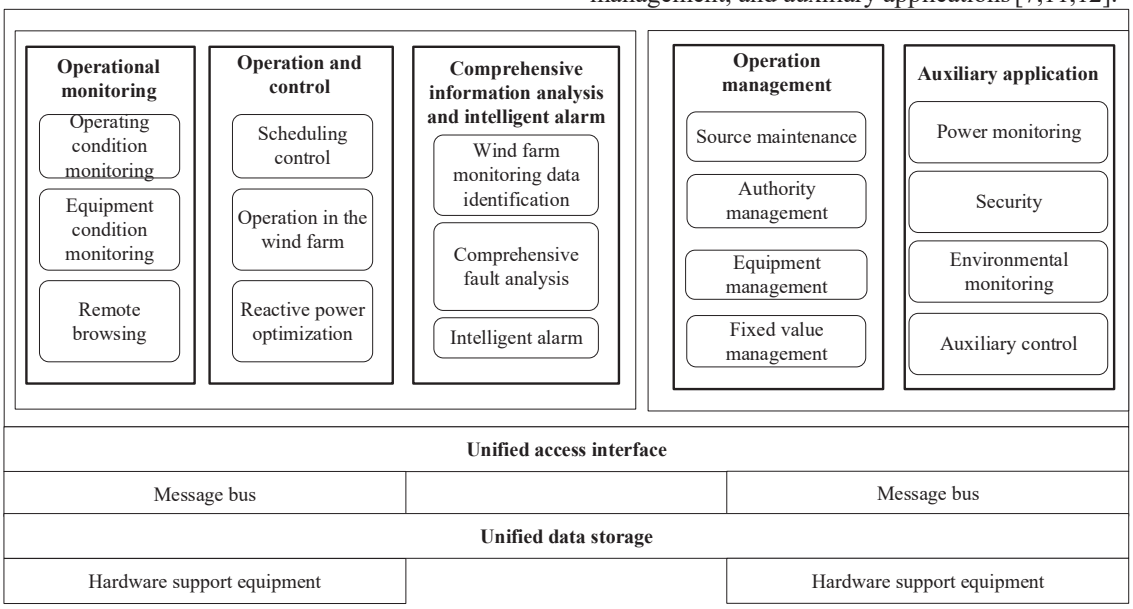

Figure 1. The application function structure diagram of offshore wind farm integration monitoring system

1) *Operational monitoring*. It realizes the operation monitoring and comprehensive display of the corresponding equipment such as wind turbines, offshore substation and onshore control center of offshore wind farms. At the same time, the enterprise group remote center can view its operational data from a distance.

2) *Operation and control*. It realizes the operation control of the equipment in the offshore wind farm on site and in the distance, including the electrical main equipment of the offshore wind farm, wind turbines, reactors, SVG and other corresponding equipment.

3) *Comprehensive analysis of information and intelligent alarms*. Through the comprehensive analysis of the operation data of the entire wind farm, the results of intelligent alarm and fault analysis are realized.

a) Wind fault diagnosis based on electrical and mechanical characteristics. As a wind turbine with a strong electromechanical coupling system, any mechanical and electrical faults are reflected in the electrical and mechanical characteristics. For example, when the bearing of the gearbox gear is damaged, and the fault between the generator stator and the rotor is short-circuited, the mechanical characteristic of the

generator shaft vibration is caused. At the same time, the electrical characteristics of the stator and rotor are also changed due to changes in the air gap distribution. Therefore, a full comprehensive analysis of the wind turbine can be carried out by fully exploiting the correlation between the electrical and mechanical characteristics between the various state monitoring.

b) Fault diagnosis of key components based on multi-parameter information fusion. At present, the single parameter information content is limited, it is difficult to accurately reflect the abnormal state of key components, especially the early potential failure. It can make full use of multi-type parameter information (such as spectrum, time domain and other signals) to obtain more accurate key component status monitoring and fault diagnosis results

4) *Operation management*. It can manage the rights of the wind turbines, offshore substation, and onshore control center, such as authority differentiation and protection setting.

5) *Auxiliary application*. It realizes the monitoring and linkage control of AC and DC offshore wind farms, automatic fire alarm and fire control, ventilation and air conditioning control, environmental monitoring, video surveillance, lighting, intelligent dispatching system and other systems.

A. Operation Monitoring

(1) Operational condition monitoring

1) Unified storage and centralized display of panoramic data of offshore wind farm can be realized.

a) It can provide the comprehensive real-time, historical production curve, including thewind power curve, wind speed curve, daily, monthly, and annual curves of power generation.

b) It can compare and analyze the output power of wind turbines of different manufacturers under the same condition, and analyze the cost performance of wind turbine products from different manufacturers.

c) It can provide the wind rose map, master the wind resource law of the wind farm, and provide data reference for the wind farm production plan.

d) It can count the number of accident trips of the switch and gives an alarm when the set number is exceeded automatically.

2) The unified information display interface and report service, and comprehensively display the grid operation status, equipment monitoring status, auxiliary application information, event information, and fault information can be provided.

a) The year, month, and daily electricity report can be provided. The system has the summary analysis of power generation in any time span of the year, month and day.

b) The multi-parameter comparison analysis can be provided. The system is equipped with multi-parameter comparison analysis functions, such as multiple analysis dimensions (such as power generation, integrated plant power consumption, and power limit).

(2) Equipment condition monitoring

1) On-line monitoring and comprehensive display of the operating status of the primary equipment can be realized.

2) To realize on-line condition monitoring of the secondary equipment, it is necessary to realize secondary equipment operating conditions, network status of the station and virtual terminal connection status monitoring by means of visualization.

3) A comprehensive display of the operating status of the wind turbines and auxiliary equipment can be achieved.

The system has the detailed view of a single wind turbine, showing the real-time data of the wind turbine unit in detail, such as the nacelle, tower, wind turbine system (electric pitch), doubly-fed generator, inverter, transformer, grid access, wind turbine control , wind turbine vibration, transmission chain, yaw system, etc.

(3) Remote browsing

The dispatching (regulation) center can remotely view the operational data of the offshore wind farm through the data communication gateway machine, including various original information and analysis processing information such as grid power flow, equipment status, historical events, operation record, and fault comprehensive analysis result.

B. Operation and control

The local control and remote control of the offshore wind farm equipment can be realized, including sequential control, reactive power optimization control, switch/knife operation under normal or emergency conditions, anti-disoperation locking operation, etc. The scheduling (regulation) center realizes these functions such as scheduling control, remote browsing through the data communication gateway machines.

(1) Operation in the wind farm

1) It has the function of control and parameter setting for all circuit breakers, electric switches, main transformer on-load tap changers, reactive power compensation equipment and intelligent equipment related to control operation of offshore wind farm.

2) It has the emergency control function of the accidents, and realizes rapid isolation of fault areas through emergency control of the switches.

3) It has the function of soft strap operation, fixed value area switching and fixed value modification.

(2) Scheduling Control

1) The dispatch (regulation) center to control and adjust the equipment in the station can be supported.

2) The dispatching (regulation) center to remotely adjust the protection equipment and soften the board can be supported.

(3) Automatic control

1) Reactive power optimization control

Based on the actual load level of the power grid, the capacitors, reactors and transformer gears in the station are automatically adjusted according to certain strategies. And the

dispatching and control adjustment commands of the dispatching (control) center can be received.

2) Load optimization control

It can realize the dispatching of active power and reactive power commands to each wind turbine to meet the requirements of wind farm active power and reactive voltage to automatically adjust remote control. Wind turbine control mode uses two-stage control is wind turbine SCADA system control and local control.

3) Sequence control

Under the premise of satisfying the operating conditions, a series of control functions are automatically completed according to the predetermined operation sequence, and should be coordinated with the intelligent operation ticket.

(4) Anti-misplacing

According to the network topology structure of the electrical equipment of the offshore wind farm, the topological calculation of the electrical equipment with three states of power, power failure and grounding is carried out, and the logic of preventing electrical disoperation is automatically realized.

(5) Intelligent operation ticket

Under the premise of meeting the requirements of anti-disclosure and operation mode, the operation ticket conforming to the operation specification is automatically generated. This includes mobile App job features.

1) *Two votes management*. All two ticket processing and signing tasks can be completed on the mobile terminal, such as work ticket invoicing, work ticket issuance, work permit, work termination and work ticket termination.

2) *Production indicators*. In addition to providing the statistical analysis query function of the running data on the PC side, it also provides real-time statistical data query function on the mobile terminal. For example, the unit load, production daily report, monthly report and other statistical data can be browsed at anytime and anywhere, so that the management personnel can grasp the important production index data in time.

C. Information Comprehensive Analysis and Intelligent Alarm

The result information can be provided, including classified alarms, fault briefings, and fault analysis reports by comprehensive analysis and processing of various operational data of offshore wind farms (real-time/non-real-time operational data of wind farms and wind turbines, auxiliary application information, various alarms and accident signals, etc.).

(1) Data Identification

1) Data check

It can detect suspicious data, identify bad data, and verify data accuracy in real time.

2) Data screening

It has the screening, sorting, and uploading alarm information for offshore wind farms.

(2) Failure Analysis Decision

1) Failure analysis

In the case of grid accidents, protection actions, device failures, abnormal alarms, etc., the fault type identification and fault cause analysis are realized through the sequence analysis of events, protection events, fault recording, and synchronized phasor measurement.

2) Analytical decision

The treatment measures are given based on the failure analysis result. It is advisable to establish intelligent knowledge decision functions such as single event reasoning, associated multi-event reasoning and fault intelligent reasoning by setting up an expert knowledge base.

3) Human-computer interaction

Based on the analysis decision results, the operational treatment suggestions are offered, and the results of the accident analysis are visualized.

After integrating various state monitoring, the fault diagnosis of the wind turbine based on electrical and mechanical characteristics and the fault diagnosis of key components based on multi-parameter information fusion are realized.

Table 1. Wind turbine fault diagnosis analysis of offshore wind farm auxiliary monitoring system

No.	Monitoring part	Fault type
I	main bearing	spindle bearing damage
II	gearbox	bearing failure, gear wear, broken teeth
III	generator	bearing failure, shaft misalignment, rotor imbalance, generator electrical fault, structural resonance
IV	blade	structural imbalance (bulging, cracking, deformation, fracture), aerodynamic imbalance, ice coating
V	tower	structure resonance, excessive tilt, loose bolts
VI	structure	structure resonance, uneven settlement, structural corrosion

(3) Intelligent Alarm

The logic and reasoning model for fault information of offshore wind farms is established to perform online real-time analysis and reasoning, implement classification and filtering of alarm information, and provide classified alarm briefings for dispatching (control) centers.

It can show the health status of the wind turbine in operation, such as the number of wind turbines alarming from different parts, the histogram of the number of wind turbines alarming from different parts, the alarm time of different units and the health status of the wind turbine in the wind farm.

D. Construction and operation management

(1) Source Maintenance

Using the graphical model integrated modeling tool to generate a standard configuration file containing the main wiring diagram, network topology, primary and secondary equipment parameters and data model of the offshore wind

farm, and provide it to the offshore wind farm and dispatching (control) center.

(2) Authority Management

The operation authority can be set. According to the security rules or security policies set by the system, the operator can only access the authorized resources. And the function of automatically record detailed information such as user name, modification time, and modification content can be established.

(3) Equipment Management

1) Equipment account information is established by reading the offshore wind farm configuration description file, interacting with the production management information system and manual entry.

2) Equipment defect information is established by means of self-checking information, status monitoring information and manual entry information.

(4) Construction Production Information Management

1) Wind farm construction and operation information

Relevant construction and operation data of the wind turbine and its foundation, offshore substation and its foundation, onshore switchyard and submarine cable are displayed in real-time. The wind turbine status (including faults) are classified into five categories is construction, operation, standby, maintenance, and fault, and the communication interruption is separately identified.

2) Wind tower information display

The real-time display data of the representative height of each layer (10m, 30m, 50m, 70m, 100m) collected by the wind tower, including atmospheric temperature, pressure, humidity, wind speed, wind direction and other information are displays in real-time on the system.

3) Construction and operation management functions of wind farms

It has the function of offshore wind farm material management (spare parts, tools, etc.), wind information resource management, safety monitoring, fault-assisted retrieval, machine equipment file management, group operations (including inspection, inspection, faults, defects, etc.), auxiliary report system, operation and analysis.

(5) Inspection Management

Based on the planning management terminal, the management of the maintenance work ticket generation and execution process is realized, including the unit power curve check, the reason for the loss of power generation loss, and the frequent fault location analysis.

E. Auxiliary Application

Monitoring and controlling of auxiliary equipment such as power supply, security, fire protection, video, environmental monitoring, vessels and personnel are realized by standardizing interfaces and information interaction. It includes the following five aspects.

(1) Power Monitoring

The power monitoring collects the operating status data of power supply equipment such as AC, DC, uninterruptible power supply, and communication power supply to realize management of power supply equipment.

(2) Security protection

The security protection receives the security, fire, access control equipment operation and alarm information to achieve centralized monitoring of equipment.

(3) Environmental Monitoring

The environmental monitoring realizes the real-time collection, processing and uploading of environmental information such as temperature, humidity, wind power and flooding of offshore wind farms.

(4) Auxiliary Control

The auxiliary control realizes the linkage with video and lighting.

(5) Intelligent dispatching

The intelligent dispatching realizes the safety management of vessels and personnel. The intelligent dispatching system consists of four parts is the human-vessel communication intercom platform, the refined marine weather forecast, the real-time monitoring of the ocean environment, and the personnel safety management.

1) Person vessel communication intercom platform

The person-vehicle communication intercom platform can be established, covering the land switch station and the wind farm area to realize the intercommunication between the land command center and the person and vessel communication.

a) The real-time position tracking function for vessels in the safe range of wind farms and 220kV submarine cables can be realized.

b) The classification and group management function for the vessels to be tracked can be realized. And the vessels with different logical groups are displayed with different icons.

c) The real-time position and navigation trajectory of the designated vessel in the wind farm can be displayed.

d) It can realize the operation time and operation content management of the operation and maintenance vessel, and provide suggestions for operation and maintenance.

2) Refined marine weather forecast

a) The forecast of marine meteorological refinement in the next 7 days, has includce these elements by temperature, pressure, current humidity, wind direction, wind speed, precipitation, effective wind wave height, average wave direction, average wave period, effective wave height.

b) The short-term forward forecasting function of strong convective weather (typhoon, heavy rain, short-term wind, hail,

low visibility) can be It realized, which has a major impact on the production and operation of wind farms.

3) Real-time monitoring of marine environment

a) A far-infrared thermal imaging camera with fog-passing function is installed on land to observe the situation of ocean vessels inside the offshore wind farm.

b) The wind farm's ocean area by installing corresponding cameras at the wind tower and offshore substation can be monitored. At the same time, it installed meteorological acquisition equipment to monitor surges and wind speeds.

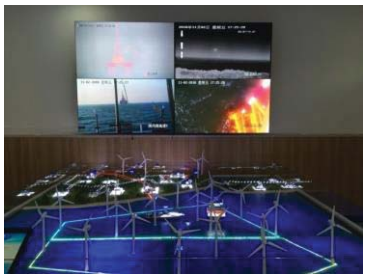

Figure 2. The real-time monitoring of ocean condition

Combined with the vessel's real-time position tracking and personnel landing ocean emergency indicator, video linkage is used to monitor the ocean state and personnel information of the offshore wind farm in real-time.

4) Personnel safety management

a) Personnel tracking management. An effective tracking management mechanism is established to realize wind farm personnel information and tracking card management based on the boarding card boxes of vessels, offshore booster stations and wind turbines.

b) Personnel rescue system. Based on the wind farm AIS equipment and personnel falling ocean emergency indicator equipment, the personnel rescue system can be formed. Once the person fall into the ocean, the personnel can be positioned and the corresponding search and rescue can be started by turning on the emergency indicator equipment. The corresponding search and rescue personnel can accept the specific help message of the ocean dropper, including the corresponding latitude and longitude coordinates and the specific contact information of the personnel.

IV. OUTLOOK

This paper clarifies the concept and characteristics of smart offshore wind farm. It can realize the life cycle management of offshore wind farms to reduce construction and operation costs, improve on-grid electricity, extend equipment life and ensure personnel safety. The smart offshore wind farm can achieve the following extended functions.

1) It can research on intelligent dispatching strategy of offshore wind power operation and maintenance based on big data analysis. It analyzes the conditions of operation and maintenance of vessel resources, terminal resources, marine meteorological conditions, optimizes the allocation of operation and maintenance of vessel plan.

2) It has the construction of marine biological environment monitoring, online collection of ocean environment, underwater noise, marine ecology, fishery resources and other data. It analyzes the inherent ecological characteristics of the temporal and spatial dynamics of the ecological environment of offshore wind farms and their response to wind power operation changes.

3) According to the combination and application of offshore wind power inspection and safety monitoring, it implements the construction and implementation of data-driven on-site unmanned aerial vehicles, submarine unmanned robots and other equipment inspection systems. For example, the offshore substation can be equipped with intelligent inspection robots to realize intelligent sensing, live detection, environmental monitoring, information sharing and comprehensive linkage of equipment conditions.

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