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INTELLIGENT CONTROL ON WIND FARM

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***Abstract*-- Since the renewable energy is popularly applied in power industry, especially the smart grid is fast developing all over the world during these years, the reliable connection between a wind farm and the main grid has been focused on. Due to the difficult control on the wind energy, the connection with the wind farm makes the grid more vulnerable. The communication technologies have been considered as a solution to solve the problems according to the IEC 61400-25 series protocols. This paper presents the significance of communication technologies in wind farm system by the simulations on some practical scenarios. By delivering the signals among WTs (wind turbines) and control centers, they both are able to recognize another side's operation situation and to adjust its own state to realize the optimization. A scenario is designed in this paper, in which a fault occurs in wind farm; then the protection performance are compared between with communication techniques and without communication technology. The characteristics of the communication network corresponding with the wind farm are previously illustrated by OPNET, and then the power system with wind farm is studied by EMTDC /PSCAD. The simulation results are analyzed to draw a conclusion.**

***Index Terms*— ISO reference model, LAN (Local Area Network), IEC 61400-25, IED, OPNET, EMTDC/PSCAD.**

I. INTRODUCTION

DUE to the energy challenge all over the world, renewable energy is experiencing dramatic changes and continuous developments, which makes modern power system enter a new generation with more and more distributed, deregulated, and highly interconnected integration in the grid. In addition, the wind farm electrical systems present some unique challenges for protection, monitoring and control. Communications among the Intelligent Electronics Devices (IEDs) in wind farms has been considered as an irreplaceable and valuable solution.

To get a green grid, not only the renewable energies are necessary, but also a smart grid. As the major target of power grid development mandated by the European Council for 2020 and 2050, Smart Grid, it is defined as an electricity network that can intelligently integrate the actions of all users connected to it in order to efficiently deliver sustainable, economic and secure electricity supplies. In other words, smart grid employs innovative products and services together with intelligent monitoring, control, communication [1]. Consequently, communication infrastructure allows potentially millions of parties to operate and trade in electricity markets.

The application of information and communication technology is a pre-requisite for data exchange between the different market players in the electricity supply chain and for the secure, economic and environmentally operation of Smart Grids. The benefits and impacts of information communication technology deployment for smart grid includes smart metering, online collection of customer data and support to customers' participation in the market, aggregation of distributed generation into virtual power plants, distribution automation (e.g. to enable self healing as the capability of the electricity grid to autonomously identify, localize, manage and repair an unforeseen disturbance or interruption), consistent data management within and between the enterprises, and the deployment is a necessary pre-condition for deployments of .other aspects of smart grid [1].

The trends of communication technology in smart grid are not only on 'plug and play' and interoperability, but also the communication moves down to the customers for decentralized energy management, smart metering and distribution automation [1].

This paper reviews the significance of communication technology applied in wind farms according to the IEC 61400-25 [2], which defines the communications between wind power plant components (e.g. turbines) and actors (e.g. SCADA Systems). Some simulations are carried out under some specific scenarios to demonstrate the impact of communication technology in wind power system. The contents of the paper are presented respectively as follows.

Section II introduces the wind farm communications, the relative communication models according to the IEC61400-25, and the corresponding communication requirements in wind power system. In Section Ⅲ, the possible communication technologies, in Data Link Layer according to the ISO reference model, are proposed and compared respectively and Ethernet is chosen in this paper as the Data Link Layer access technique. Then in Section Ⅳ the simulation scenarios and discussions of the Ethernet-based communication network employed in wind farm power system is conducted by OPNET and EMTDC/PSCAD. Finally in Section Ⅴ the conclusion is given.

II. WIND FARM COMMUNICATIONS

A. *Wind turbine monitoring and wind farm communication*

A wind farm is constituted with wind turbines in feeders, which contains wind turbines in different topologies, such as radial topology, bifurcated radial topology, feeder-subfeeder

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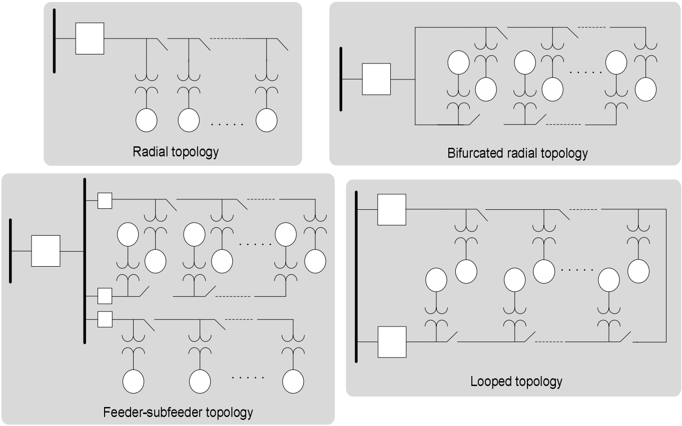
topology, looped topology, etc. [3], as shown in Fig 1. Each of them has specific applications according to practical circumstances.



☐: Circuit breaker; ○: Wind turbine

Fig.1 Wind farm topologies

A wind farm communication network is formed by plentiful wind turbine controllers, which are installed at the tower of each turbine. A wind turbine controller consists of a number of high speed processors (computers) which continuously monitor the condition of the wind turbine. The controllers on each wind turbines collect all necessary data from IEDs, who are connected with the devices of the wind turbine through a sensory system. Therefore the communication network is mapped as a hierarchical structure, as displayed in Fig. 2. The communication network covers wind turbines, meteorological system, wind power plant management system, and electrical system.

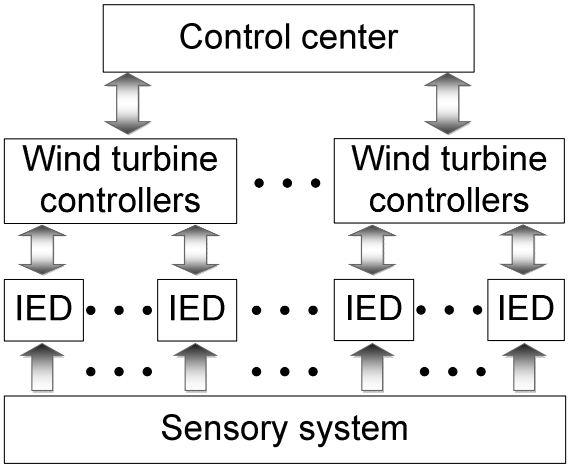


Fig. 2. Hierarchical structure of wind farm communication network

By the connections with IEDs, a wind turbine controller controls a large number of switches, hydraulic pumps, valves, and motors within a wind turbine. There are 100-500 related monitored parameters per wind turbine. They are as such:

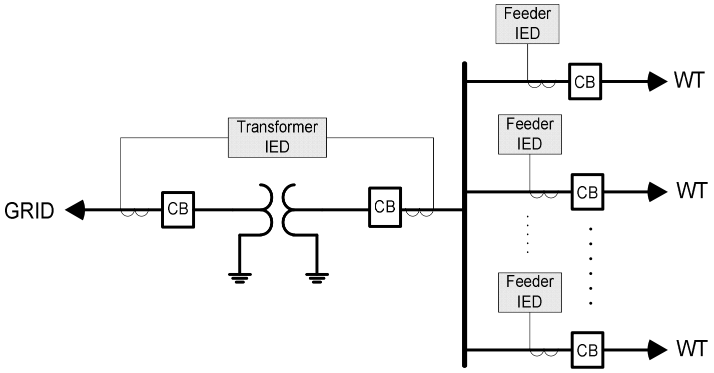
1) The speed of the rotor
2) The generator speed, voltage and current
3) Lightning strikes and their charge
4) Temperatures (*outside air, in the cabinets, oil in the gearbox, the generator windings, the gearbox bearings*)
5) Hydraulic pressure
6) The pitch angle of each rotor blade
7) The yaw angle and the number of power cable twists
8) Wind vane and wind speed
9) The vibrations in the nacelle and the rotor blades
10) The thickness of the brake linings
11) The alarm system

The controllers also transfer the data to the control center of the wind farm. Meanwhile they assign the commands from the control center to the devices to control the wind turbines.

Regarding the functions of the IEDs for wind farms, there are different IEDs connected with controllers, such like line IED, transformer IED, bus IED, and feeder IED, etc. They are located in different portions of the plants. Some IEDs monitor the operation conditions, including [3]:

1) Voltage unbalance
2) Overheating
3) Reverse phasing
4) Poor synchronizing
5) Voltage and frequency out of limits

Some of the IEDs are as demonstrated in Figure 3.



CB : Circuit breaker

Fig. 3 IED configuration of a single line wind farm

The communications between the controllers and the control center computer are conducted via a SCADA communications network. With the advance of power system communication technology and infrastructure, IP based Ethernet may be an alternative solution replacing the old high-voltage power line carrier systems.

B. IEC 61400-25

In terms of the communication in wind power system, IEC 61400-25 series is focused on the communications between wind power plant components such as wind turbines and actors such as SCADA Systems, as illustrated in Fig. 4. Logical nodes are used in wind farm communications as the information units to exchange information. They are the smallest entities decomposed from the application functions. Several logical nodes build a logical device. [4]. Fig. 5 depicts an example of a real wind turbine that uses several instances of logical nodes [2].

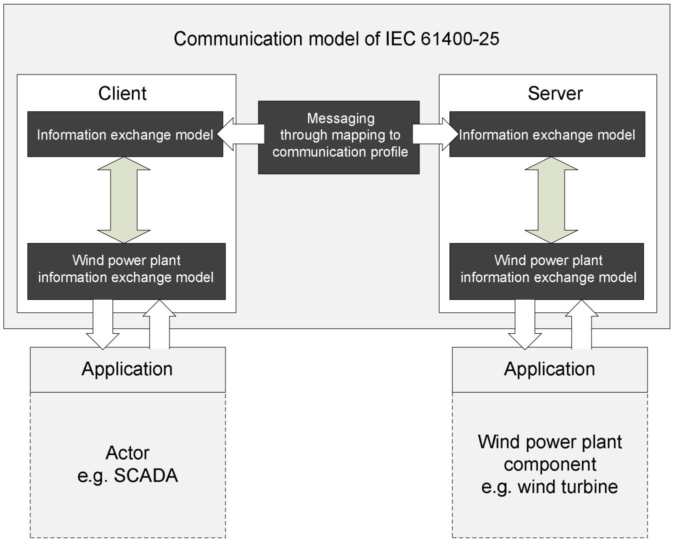


Fig.4. Conceptual communication model of IEC 61400-25 series

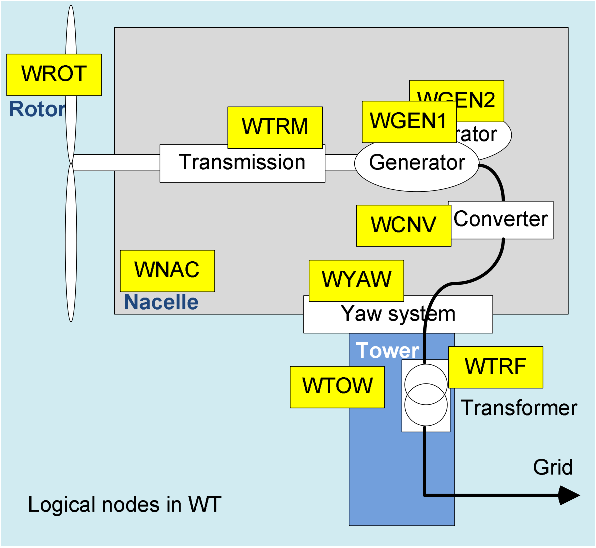


Fig.5. Use of instances of logical nodes in WT

IEC 61400-25 defines wind power plant logical node classes, which contains system specific logical nodes and wind power plant specific logical nodes. The yellow squares in Fig. 5 represent the distinct logical nodes in wind power plant specific logical nodes. Their definitions are listed in Table Ⅰ. Each LN (logical nodes) is defined as a class, which includes several to tens of attributes. For example, the specific attributes data of logical node WROT is explained in Table Ⅱ. [2]

TABLE I
WIND POWER PLANT SPECIFIC LOGICAL NODES

Logical Node Names	Explanations
WROT	Wind turbine rotor information
WTRM	Wind turbine transmission information
WGEN	Wind turbine generation information
WCNV	Wind turbine converter information
WNAC	Wind turbine nacelle information
WYAW	Wind turbine yawing information
WTOW	Wind turbine tower information
WTRF	Wind turbine transformer information

TABLE Ⅱ
ATTRIBUTES OF WROT CLASS

Attribute Names		Explanations
Status information	RotSt	Status of rotor
	BlStBl	Status of blades
	PtCtlSt	Status of pitch control
Analogue information	RotSpd	Value of rotor speed at rotor side
	HubTmp	Temperature in the rotor hub
	PtHyPresBl	Pressure of hydraulic pitch system for blades
	PtAngValBl	Pitch angle for blades
Control information	BlkRot	Set rotor to blocked position
	PtEmgChk	Check emergency pitch system

The LN concept is deployed in this paper to configure the communication network for wind power systems.

III. COMMUNICATION TECHNOLOGY IN WIND POWER SYSTEM

Any communication technologies structure has to obey the ISO reference 7-layer model definition. Therefore the communications for wind power systems has no exception. In this paper the communication technology is focused on the Second Layer (Data Link Layer) from the Seven Layered ISO reference model view.

A. ISO reference model

The ISO reference model [5] provides a framework for the coordination of standards development and to allow existing and evolving standards activities to be set within a common framework. The logical structure of the ISO reference model is made up of seven protocol layers, as shown in Fig. 6. The function of each layer is specified formally as a protocol that defines the set of rules and conventions used by the layer to communicate with a similar peer layer in another system.

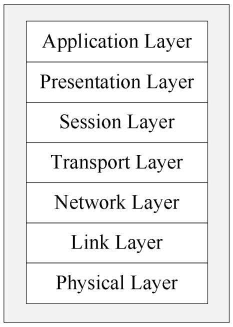


Fig. 6. ISO reference 7 layers model.

The upper layers are application oriented and are concerned with the associated protocols that allow two end user application processes to interact with each other, normally through a range of services offered by the local operating system.[5]

The three lowest layers are network dependant and are concerned with the protocols associated with the data communication network being used to link the two communicating nodes. Particularly, the link layer builds on the physical connection provided by the particular network to provide the network layer with a reliable information transfer facility. [5]

In this paper the second layer (Data Link Layer) is focused to investigate the effects of LANs protocols on the wind power system. Therefore the following Data Link Layer-based LAN access techniques: Ethernet is elaborated.

B. LANs access technologies: Ethernet

Ethernet defines a number of wiring and signaling standards for the Physical Layer of the ISO reference networking model, through the means of network access at the Media Access Control (MAC) /Data Link Layer, and a common addressing format. Ethernet is standardized as IEEE 802.3. The combination of the twisted pair versions of Ethernet for connecting end systems to the network, along with the fiber optic versions for site backbones, is the most widespread wired LAN technology. It supports all popular network and higher-level protocols. Traditional Ethernet supports data transfers at the rate of 10 Megabits per second (Mbps). As the needs of LANs performance have increased, the industry created additional Ethernet specifications, such as Fast Ethernet and Gigabit Ethernet. Fast Ethernet extends traditional Ethernet performance up to 100 Mbps and Gigabit Ethernet up to 1000 Mbps speeds. [5]

In this paper the Ethernet is selected as the communication technology applied for LAN. The switching techniques, decided as packet switching, and the network access methods decided as CSMA/CD (Carrier Sense, Multiple Access, Collision Detect) [5], are the two significant aspects, which are respectively illustrated in Fig. 7 and Fig. 8. By deploying the techniques, the LAN terminal devices share the limited bandwidth in high transmission speed without collisions.

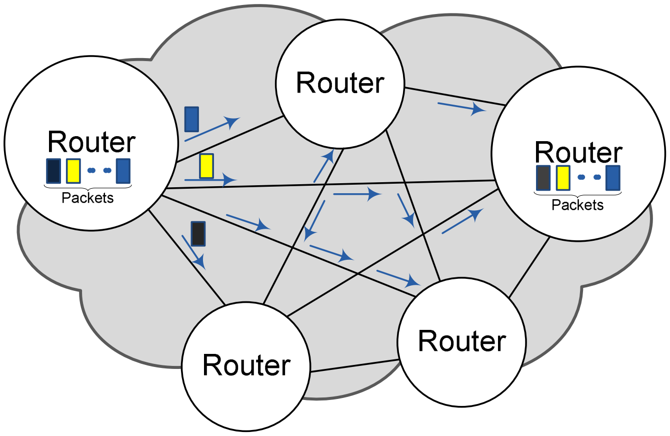


Fig. 7. Packet switching

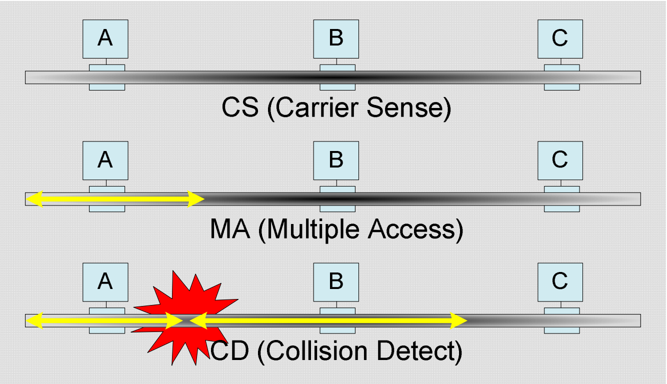


Fig. 8. CSMA/CD

IV. CASE STUDY

A. Wind farm Communication Scenario

The one line diagram of the studied wind power system is depicted in Fig. 9. The wind power system has three equivalent WTs. Each of the equivalent wind turbines is connected to the system through a wind plant feeder. The geographical layout of the wind farm is shown in Fig. 10. The WT2 and WT3 are electrically and geographically close to each other, and they are connected to the same bus bar. The WT1 is relatively further from WT2 and WT3. This study investigates the impacts of the employed communication technology on the control of the wind turbines.

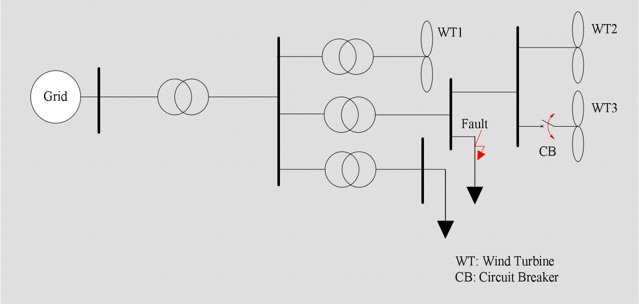


Fig. 9. The wind farm communication scenario

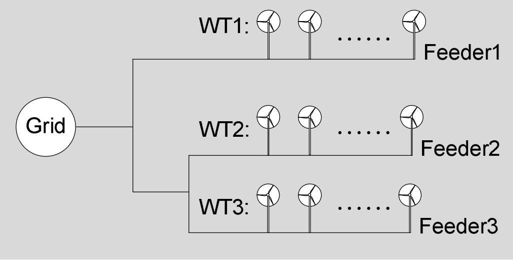


Fig. 10. The wind farm layout

In the study scenario, according to the layout of the wind farm shown in Fig. 10, assuming that the wind direction is from Feeder 3 to Feeder1, consequently, the wind velocity at Feeder 1 is delayed in comparison with the wind velocity at Feeder 3. When the wind velocity increases to 11.5 m/s the WT2 and the WT3 can be kept in stable operation. However, in high wind velocity situation, i.e. over the wind velocity limit, the wind turbines will be shut down for the protection.

Under a crucial situation, for example, a power system fault, some control strategies have been developed. In the scenario of a three-phase-to-ground fault happening as shown in Fig. 9, the WT2 and the WT3 lose stability, whereas WT1 keeps stable. However, with the assist of communication technology, the possibility of disconnection of WTs to the transmission grids could be minimized to decrease the wind plants generation loss.

B. Communication network development

In this paper, the communication network is configured as an Ethernet IED LAN, as displayed in Fig.10, whose main principles have been explained in Section III. The sampling frequency of the data transferring of each IED, for instance voltage and current data, is at lease 6400Hz for a 50 Hz power system, which means at least 128 data points are acquired in 20ms, and each sampling data is represented by 2 bytes. In this work the Ethernet network media transmission speed is 100Mbit/s.

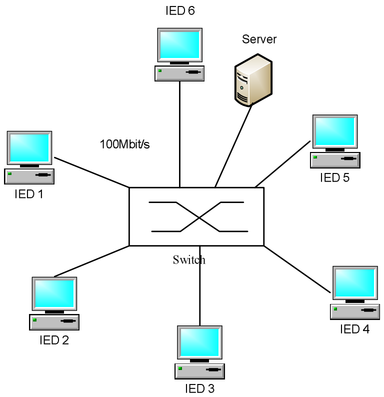


Fig. 10 An Ethernet IED LAN for the wind farm

The necessary data categories for wind farm communication are explained in section Ⅱ. Subsequently the data are analyzed and used in the related calculations at the local control center to make the devices operate correctly. In this scenario, based on the wind speed signal and the WTs mechanical speed, electrical torque and mechanical torque calculations, etc. the WT3 has to be disconnected from the grid at latest at 11.2 second, to secure sufficient voltage recovery of the adjacent WT, i.e. WT2, to keep it in operation.

As reported in our previous work on the communication network performance study for wind power system [7], the communication network transmission attributes have been demonstrated by OPNET [8] to satisfy the requirements on control signal transmission. In this scenario, when wind speed is 11.8 m/s, the disconnection time of WT3 at latest should be 11.2s, which is 1.2 seconds after the fault occurs. Referenc [7] explains that the control commands transferred by the Ethernet LAN are in ms order, even if the additional operation time on the CB (circuit breaker) of the WT3 is considered, the real operation time of disconnecting the WT3 is much less than 1.2 seconds. Consequently there is sufficient time to disconnect one WT to maximizing the generation during the fault, with the aid of communication technology.

C. Simulation results

The simulations on the wind farm system performance are conducted by EMTDC/PSCAD. If the discussed communication technology is not applied on the WTs, the WTs possibly lose stability in some fault situations and cause the generation loss of the grid. The higher wind speed, the greater hazard is. Fig.11 depicts the scenario when three-phase-to-ground fault happens at 10.0 seconds at the place shown in Fig. 9, if all the WTs try to stay in connection with the grid after the fault, WT2 and WT3 lose stability.

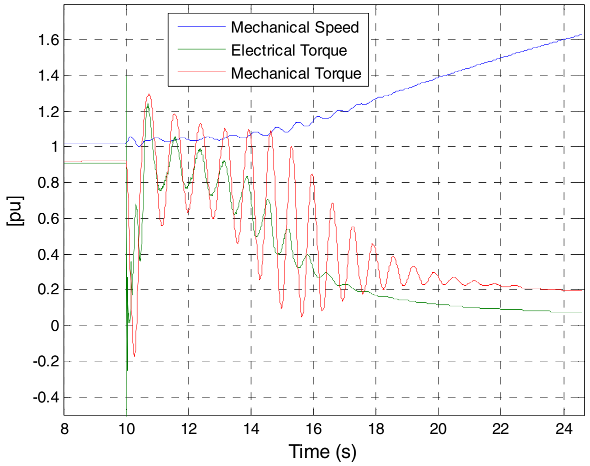


Fig. 11 WT2 performance without WT3 disconnecting with grid

On the contrary, if the control strategy based on Ethernet LAN technology is applied on the wind farm, the WTs can be controlled by the commands from the IEDs. Fig.12 illustrates that after the same three-phase-to-ground fault happens at 10.0 seconds under the 11.8m/s wind velocity, the smart control system can disconnect WT3 at 11.2 seconds (at latest), WT2 experiences approximately 13 second oscillation and ultimately recovered, which obviously minimizes the generation loss of the grid.

The simulation results also reveal that

1) When wind velocity is under 11.5m/s, assuming the three-phase-to-ground fault happens at 10.0 seconds, the WTs are able to recover by themselves. Therefore the follow analysis is focused on the scenario with wind speed higher than 11.5m/s.

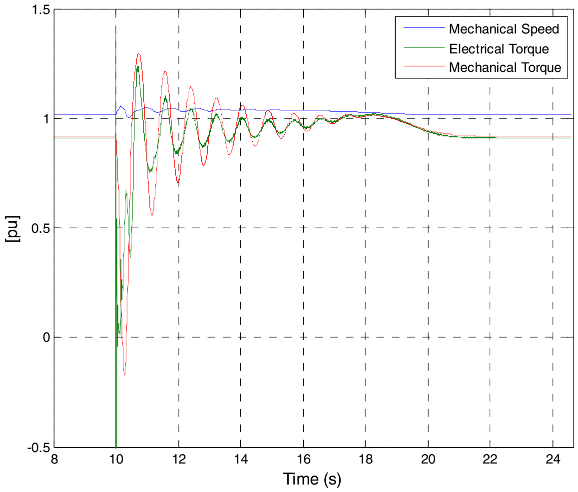


Fig. 12 WT2 performance with WT3 disconnecting with grid

2) Because of the 1), the WT1 experiences around 3 seconds' oscillation after the fault, ultimately it returns to normal operation, which is illustrated in Fig. 13.

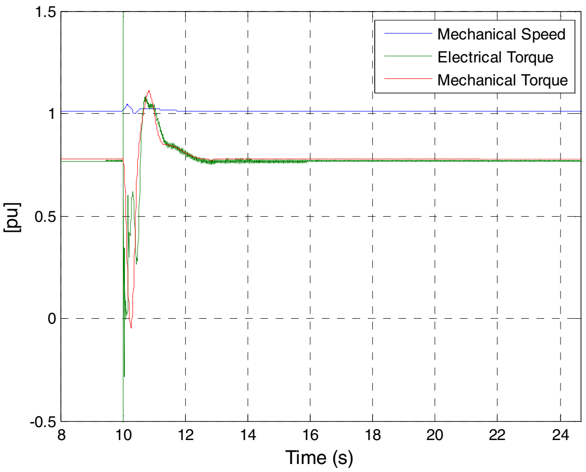


Fig. 13 WT1 performance during the fault

TABLE III
TIME REQUIREMENT OF DISCONNECTING THE WT3

Wind velocity (m/s)	WT3 latest disconnecting time (second)
11.5	14.0
11.6	12.4
11.7	11.7
11.8	11.2
11.9	10.9
12.0	10.8
12.1	10.6
12.2	10.2

3) When wind velocity is between 11.5 m/s and 12.2 m/s, assuming the three-phase-to-ground fault happens at the same time, the WT2 is able to recover by disconnecting the WT3 in time. The specific latest time of disconnecting the WT3 are listed in Table III. From this table, the latest disconnecting time of WT3 corresponding to the respective wind velocity are given, which states the higher wind speed, the earlier the required disconnecting time is, to ensure the stability of WT2.

4) When wind velocity is greater than 12.2 m/s, in the same conditions, the disconnection operation on WT3 may not help at all. It means in this situation, if a three-phase-to-ground fault happens, even if the presented communication techniques are deployed, the wind plant generation loss caused by disconnecting WTs' may not be avoided.

V. CONCLUSION

In this paper the communication network, i.e. an Ethernet IED LAN, involved wind power system is investigated. The performances of the WTs under some fault scenario are presented, and the phenomena are compared between without communication technology and with communication technology. The wind speed of 11.8m/s is taken as a case to illustrate the operations on the WTs to minimize the loss of generation to grid. The simulations in this paper demonstrate that the significant influence of the communication technology in wind power system, which is involved a case of smart grid technology, where communication technology plays a very important function.

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VII. BIOGRAPHIES

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