

Simulation Studies of Resilient Communication Network Architecture for Monitoring and Control Wind Power Farms

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Abstract— Real time monitoring and control of wind power farms (WPFs) require a high reliable communication network infrastructure. The WPFs monitoring and control can be guaranteed through the communication network by using redundant resources and quality of service (QoS) for different applications. In this paper, we study and simulate resilient network architecture for monitoring and control WPFs. The communication network architecture consists of three different levels: data generation level, data aggregation level and control center level. Each level is based on its function, physical location, type of communication channel and redundant resources. In accordance to IEC 61400-25 standard, the wind turbine monitoring traffic is classified into critical and non-critical data according to different QoS requirements. Due to lower cost, non-proprietary standard and guaranteed real-time services, the Ethernet technologies are currently used in various industrial applications. Several network failure scenarios based on Ethernet technology are used to simulate the network architecture through OPNET. The performance of the network architecture is evaluated in view of the amount of received data, end-to-end delay and data loss at control center. The simulation results show that the communication network architecture can guarantee the transmission of WPFs critical data.

Keywords—Communication Networks; IEC61400-25; Monitor and Control; Reliability and Resiliency; Wind Power Farms

I. INTRODUCTION

Wind is a natural and low cost resource that is never depleted which results in an environment friendly energy. This leads to a higher increase in wind power farms around the world. Mountains and offshore locations are the suitable choices for wind power because of stable and strong winds with space availability. Some European countries such as Germany, Denmark and UK are rapidly installing offshore WPFs with larger sized wind turbines (WTs) and higher power capacities. The offshore wind power generation is facing several issues: high construction cost, offshore installation, and maintenance cost. Construction and installation are considered to be initial and onetime cost. However, the maintenance and repair needs a special attention because it is a long term continuous task. The communication networks can play a significant role in reduction of maintenance and repair

cost by providing real time monitoring and control mechanism to these WPFs. Communication networks can enable the control center to measure the status of WTs through monitoring information.

The control center then controls the operation of WTs with control signals. Different monitoring techniques are in used, such as sensor based and IR-camera based monitoring [1,2]. Figure 1 shows a schematic diagram of WPFs communication network. The figure gives a detail description of one WT monitoring and control using communication network. An efficient monitoring and control operation strongly relies on the high availability of data with a minimum latency. In view of communication network the resiliency can be defined as: In case of any network failure (device/link) the communication network should be able to route the traffic to backup resources with ensuring the data transmission. The issues in communication network that can influence the WPFs system includes: plane maintenance, component failure, and accident/disaster [3]. In order to deal with these issues, the WPF communication network should be designed in view of fault tolerance. In the literature several communication architectures with redundancy were proposed which focused on the high availability of data. The author's in [4] proposed an Ethernet passive optical network (EPON) based communication network architecture.

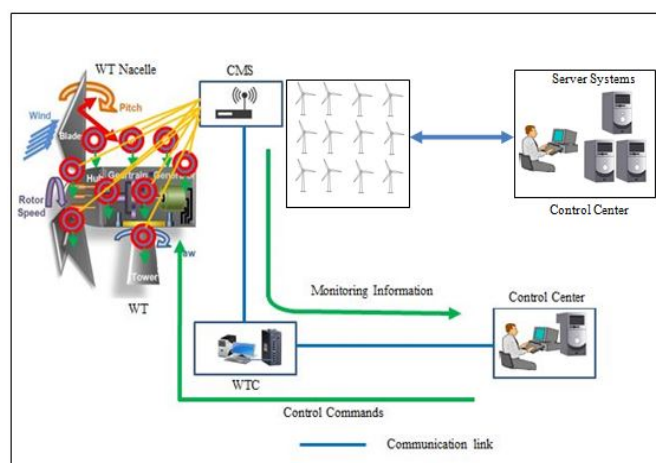


Fig. 1. Schematic diagram for WPF communication network

The paper modeled the system with numerical analysis by using redundant optical network unit (ONU) and optical line terminal (OLT). In [5] a resilient communication network for large-scale offshore wind farm was proposed with the focus on redundant devices (switches and routers) and links (SONET OC12 active and OC3 standby link). However the paper mainly considered WAN topology for monitoring and control WPFs. An open shortest path first (OSPF) protocols was considered for network convergence. Rapid spanning tree protocols (RSTP) was used to avoid loop in the network. Resilient wireless communication network architecture for smart grid in building area network (BAN) was proposed by the author's in [6]. To achieve high degree resiliency, the paper focused on wireless mesh network among the different communicating entities in BAN. To the best of our knowledge, simulation study towards the resilient communication network for local monitoring and control of WPFs has not been considered.

In this paper we studied resilient communication network architecture with three levels. To achieve higher degree network tolerance, the study considered redundant network resources at WPFs, offshore platform and control center level. Keeping the IEC 61400-25 standard optional and mandatory logical nodes into account the monitoring data are classified into critical and non-critical information to support different QoS. To analyze the performance of the communication network architecture with guaranteed data transmission for critical traffic, this study considered different network failure and recovery scenarios. The communication network is simulated through OPNET.

The rest of this paper is organized as: related work is discussed in Section II. Resilient communication network architecture for WPFs is presented in Section III. The WPFs communication network with data modeling and simulation set-up is given in Section IV, while the simulation results and discussion is presented in Section V. Finally Section VI summarizes the paper with concluding remarks and related future work.

II. RELATED WORK

A. The Horns Rev Communication Network

Elsam a Danish energy company installed first largest offshore WPF in the North Sea. The project consists of 80 Vestas V80-2.0 MW unit WT's with 160 MW power capacities. The 80 WT's are connected in 10 rings with a total of 8 WT's in each ring. The network architecture consist of a backup wireless communication channel to achieve resiliency in the network [7]. The network is equipped with redundant devices both at offshore (WPFs side) and onshore (control center) locations. All the communication is made through the active wired network of 1Gbps single mode fiber channel to support the 80 WT's traffic. In case of any failure in primary network the traffic routes to the backup network for data transmission. Keeping the IEC 16400-25 standard LNs into account one WT can generates approximately 1.8 Mbps of monitoring data [8]. However in the case of Horns Rev WPFs the backup wireless network has a limited capacity of 34 Mbps radio channel. In such case of limited channel resources there are chances for

data losses with an increased latency. Figure 2 shows the Horns Rev communication network diagram.

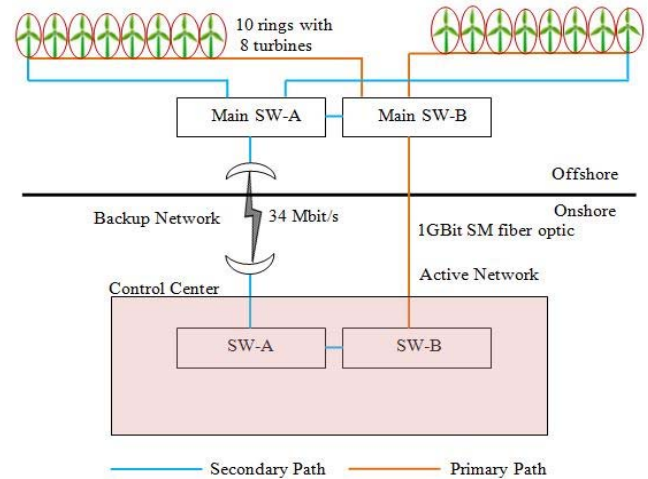


Fig. 2. Horns Rev Communication Network

B. The Greater Gabbard Project Communication Network

The Greater Gabbard project is developed by Scottish and Southern Energy (SSE) Company. The project consists of a total of 140 WT's with a power generation capacity of 3.5 MW per WT. The WT's are connected to two offshore platforms transformers via 33kv cable. The power is then exported to the onshore substation through 132kv submarine cable. The WPFs is connected to the onshore substation through three different set of Ethernet based communication networks. Each of the communication networks is designed to support different type of application. The detail of these dedicated networks is discussed as follows.

- ✧ **Balance of plant network:** This network can be called as "substation protection and control network" with the main function to connect all the protection and control IDE's at WT's, offshore and onshore substation.
- ✧ **Wind turbine generator network:** The WT's controllers are connected to central supervisory controlled and data acquisition (SCADA) control system through Ethernet communication channels.
- ✧ **Telephone and security network:** The video surveillance cameras and IP telephony services are provided by this network.

All these networks are connected to the onshore substation through gigabit Ethernet backbone with redundant switches and routers [9].

III. RESILIENT COMMUNICATION NETWORK ARCHITECTURE FOR WPFs

In this study we considered an Ethernet based resilient communication architecture for WPFs shown in Figure 3. In order to obtain higher system reliability the aforementioned architecture is divided into three levels: data generation level, data aggregation level and control center level. Each of the level is based on a specific function, location and has redundant

links and devices to maintain the network tolerance. The WPFs and offshore platform is located at offshore side while the control center located at onshore. The following section describes the function, topologies, technologies and redundant links and devices at each level. Rapid spanning tree protocols (RSTP) is used for network loop avoidance to manage multiple links and reconfigure the topology with traffic redirection to the secondary network in case of any failure.

Data generation level (DGL): Embedded sensors continuously monitor components of WTs at DGL. Each WT at this level has a wind turbine controller (WTC) which communicates with offshore platform through point-to-point link using Ethernet channel. The WTs are connected to the offshore platform primary and secondary switches through radial-loop topology. In case of any failure for primary and/or secondary connected link the data traffic route to the backup/alternate path in the network.

Data aggregation level (DAL): DAL is the middle level of the architecture between WPFs and control center. The function of this level is to aggregate the WPFs data to the control center. The offshore platform consists of primary and secondary redundant switches and links. Primary switch maintain a point-to-point active network while the secondary switch is reserved for passive network. To provide high reliability the primary and secondary switches also have a direct connection.

Control center level (CCL): The control center collects data through the offshore platform for processing. Control commands are then transmitted to WTs within WPF's for appropriate action using active and/or backup network. The control center consists of three switches and redundant point-to-point links to support the network reliability.

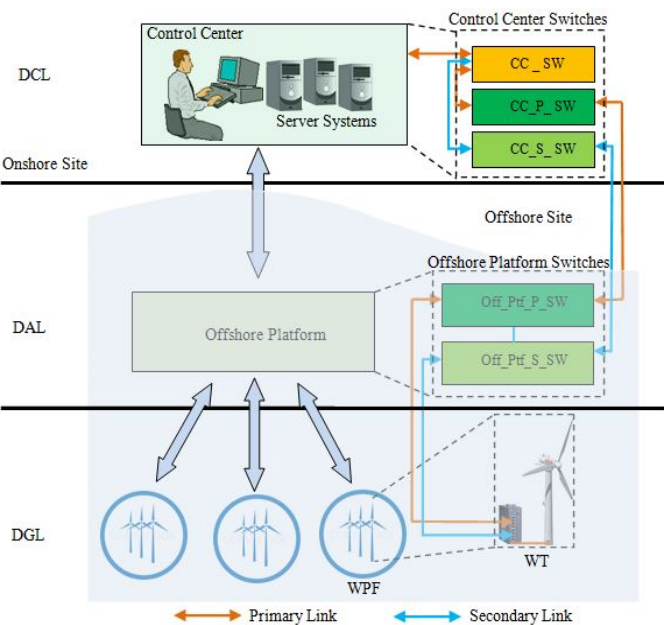


Fig. 3. Proposed WPFs communication network architecture

IV. WPF NETWORK MODELING

A. Traffic Modeling

WPFs integration into electricity grid explored new requirements in communication capabilities of WTs, and control centers. The standard information model and communication system can make it possible to integrate the WPFs into the electricity system. The IEC standard series 16400-25 define a standardized way for accessing wind power data [10]. The basic components of WT are modeled into several different data structures called logical nodes (LNs). Within a WT some LNs are optional (O) while the others are mandatory (M). We considered nine LNs including WROT, WTRM, WGEN, WCNV, WNAC, WYAW, WTOW, WTRF and WMET. In accordance to the mandatory and optional LNs the WT monitoring data are classified into critical and non-critical information to support different QoS requirements. Table 1 shows the critical and non-critical for a WT.

TABLE 1. CLASSIFICATION OF WT CRITICAL AND NON-CRITICAL DATA

LN Class	Description	M/O	Type
WROT	WT rotor information	M	Critical Information
WGEN	WT generator information	M	
WNAC	WT nacelle information	M	
WYAW	WT yawing information	M	
WTOW	WT tower information	O	Non-critical information
WMET	WPF meteorological information	O	
WTRF	WT transformer information	O	
WCNV	WT converter information	O	
WTRM	WT transmission information	O	

Each LNs is equipped with several different number of measurement devices [11]. In our previous work we proposed and simulate multilayer communication network architecture for WPFs. We considered 102 sensors that generates a total of 225,602 byte/s (approximately 1.8 Mbps) traffic for one WT [12]. Based on mandatory and optional information shown in Table 1 the WT critical and non-critical monitoring traffic can be calculated. Table 2 shows the critical and non-critical traffic information for stand-alone WT.

TABLE II. WT CRITICAL AND NON-CRITICAL TRAFFIC DATA

Traffic calculation for mandatory LNs		
LN Classes	No of sensors	Data transmission byte/s
WROT	14	642
WGEN	14	73764
WNAC	12	112
WYAW	7	220
Sub-total	47	74,738 byte/s $\approx$ 0.57Mbps
Traffic calculation for optional LNs		
LN Classes	No of sensors	Data transmission byte/s
WTOW	4	8
WMET	7	228
WTRF	12	73740
WCNV	14	74060
WTRM	18	2828
Sub-total	55	150,864 byte/s $\approx$ 1.15Mbps
Total	102	225,602 byte/s $\approx$ 1.8Mbps

Table 3 summarizes the overall traffic for each type of information for small scale WPF (12 WTs).

TABLE III. CRITICAL AND NON-CRITICAL TRAFFIC FOR SMALL SCALE WPF

Type of WPF	No of WTs	WT/WPF monitoring data in Mbps		
		Critical data	Non-critical data	Total
Stand alone	1	0.57	1.15	1.8
Small	12	6.84	13.81	20.64

B. Network Modeling

The communication network for WPFs can be defined on the basis of electric power system topology. The author's in [13] define different electric topologies for WPFs. To achieve high reliability this paper follows the radial-loop topology. Figure 4 shows the OPNET [14] topology of small scale WPF communication network architecture. It consists of 12 Ethernet work stations whereas each workstation represents one WT. Offshore platform consists of primary and secondary switches. WPF are connected to primary switch through primary link while the secondary link is used for secondary switch connection with WPF. The control center has three switches. The primary switch maintains an active connection with offshore primary switch. The secondary switch is used as backup/secondary connection. Both the primary and secondary switches are connected to the control room server system through main switch. To support the WPFs monitoring information the active network uses 100Mbps Ethernet channel. The standby backup network reserved a 10Mbps Ethernet channel. The Ethernet server at control center is the SCADA system which supports WPF's critical and non-critical data. Four different applications are configured which includes: 1) *WT_Application* that generates the WT monitoring traffic at application layer of OSI model by using FTP. FTP protocol is serviced by TCP protocol at transport layer. 2) *WT_Profile* supported by Ethernet work stations and server system to carries the WTs information across the network. 3) Different link failure and recovery scenarios are configured through *Failure_Recovery_Point* application configuration. 4) To support different quality of service for critical and non-critical data. The *QoS_Application* are configured to prioritize WT critical data.

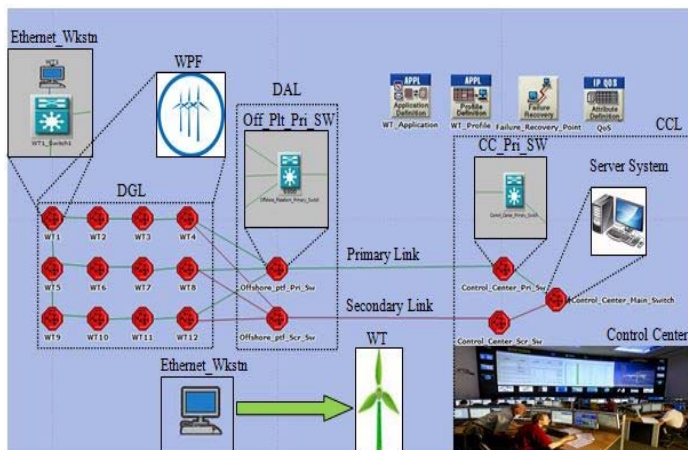


Fig. 4. OPNET Model for proposed architecture

V. RESULTS AND DISCUSSION

To analyze the performance of the resilient communication network architecture, several scenarios with and without

failure are simulated. The first scenario considered no failure in the network. The results in Figure 5 validate our simulation. It shows received data for critical and non-critical data at the control center and follows the numerical calculation in Table 3. Figure 6 shows the end-to-end delay for both application which are 6.5 ms and 9.5 ms for critical and non-critical information respectively. In the second scenario the primary link failed and recovered at different points. Figure 7 shows the transmitted and received traffic with different failure and recovery point. The results indicate that the failure in primary connection results in data drop for the received traffic. This is because the traffic diverts to the secondary link. The peak line in the figure is due to the retransmission of the data packets in the waiting queue. The third scenario was configured with QoS to priorities the critical information over the non-critical. Figure 8 shows received critical and non-critical data for WPF. These results clearly indicate the data dropped in non-critical information. However the transmission of critical information is guaranteed. Figure 9 shows the end-to-end delay of 69 ms and 353 ms for critical and non-critical information respectively. There are two main factors that can cause the increasement in delay. First the secondary link has a lower channel capacity and second is the retransmission of data packets in the queue. Thus a higher downtime for main communication network channel could result in higher end-to-end delay.

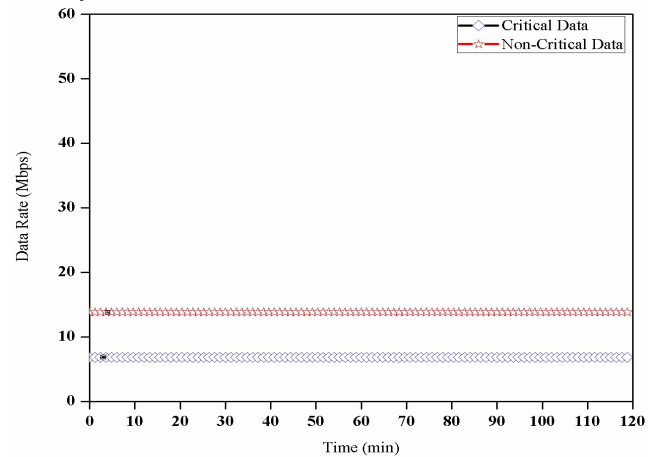


Fig. 5. Total amount of received data without failure

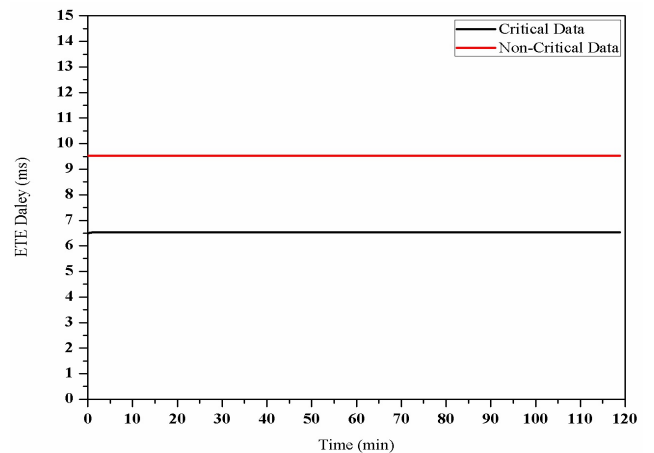


Fig. 6. ETE delay without failure

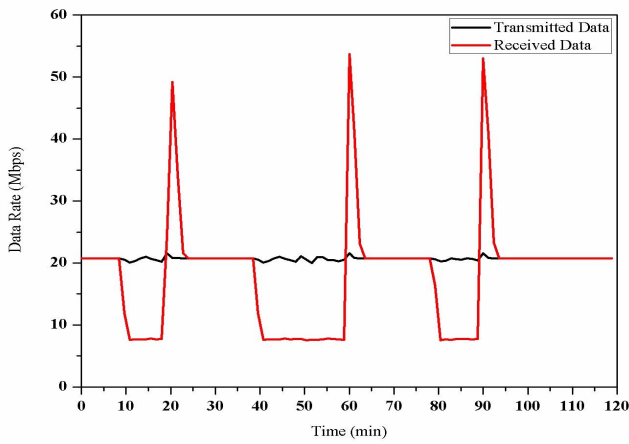


Fig. 7. The impact of primary link failure

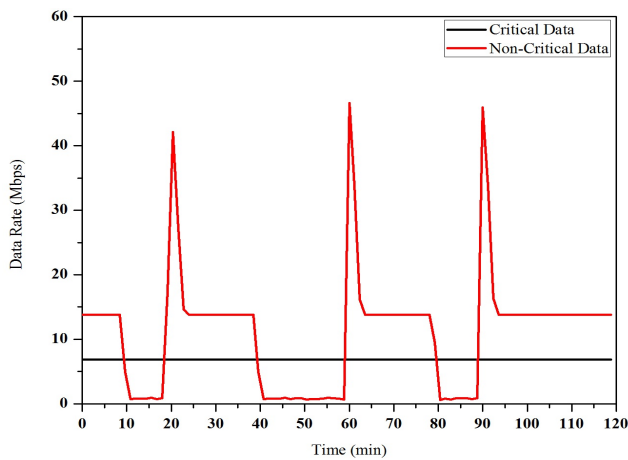


Fig. 8. Total amount of received data with primary link failure

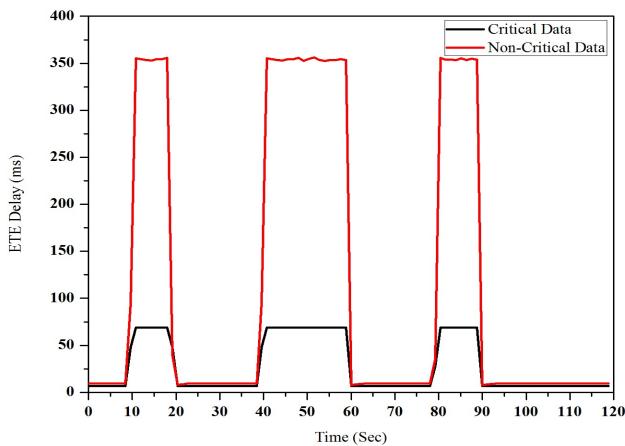


Fig. 9. ETE delay with primary link failure

VI. CONCLUSION

In this paper, we studied and simulated resilient communication network architecture for WPFs. The

communication network architecture has redundant resources consisting of three levels: DGL, DAL and CCL. We defined function, physical location, type of communication channel and redundant resources at each level. To achieve resiliency in the network, the architecture focused on redundant links with different channel capacities. It must be noted that keeping the same channel capacities for primary and secondary communication channels can provide a full resiliency in the network. But in this case, it cannot be a cost effective solution because the secondary link are not used for all the time. To have a cost effective solution, the network is modeled with two different link capacities of 100Mbps for active network while 10Mbps for passive network. The traffic of WT LNs is modeled into critical and non-critical information according to the IEC 14600-25 standard. The WPF's monitoring data are prioritized according to the different QoS requirements. Recovery scenarios for different link failures are simulated to measure the network performance in view of received data, data loss and end-to-end delay. The QoS application can be used to improve the performance for the communication network with lower secondary link capacity. Through the simulation results, it has been observed that the transmission of WPFs critical information can be guaranteed according to required QoS. This paper can contribute in designing a reliable communication network for WPFs.

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REFERENCES

- [1] S. Hussain and Y.-C. Kim, "Simulation Studies of Wind Power Farm Communication Network using SONET," in Korea Information and Communication Society(KICS)2014.
- [2] S. Hussain, M.A. Ahmed and Y.-C. Kim, "Communication Networks for Wind Turbine Monitoring based on Infrared Camera," in International Symposium on Information Technology Convergence(ISITC) 2014, vol. 3, no. 2, pp. 34–37.
- [3] T. Sakamoto, "Protection Schemes Beyond Currently Defined in FTTx," in Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference (OFC/NFOEC), 2013, pp. 1–3.
- [4] M. A. Ahmed and Y.-C. Kim, "Protection schemes of EPON-based communication network for offshore wind power farms," in International Conference on ICT Convergence, 2013, pp. 1135–1139.
- [5] K. Gajrani, K. Gopal Sharma, and A. Bhargava, "Resiliency in offshore wind farm communication networks," J. Renew. Sustain. Energy, vol. 5, p. 023139, 2013.
- [6] Y. Tsado, D. Lund and K. Gmager, "Resilient Wireless Communication Networking for Smart Grid BAN," in Energy Conference(ENERGYCON), IEEE International, 2014, pp. 846–851.
- [7] J. R. Kristoffersen and P. Christiansen, "Horns Rev offshore windfarm: its main controller and remote control system," Wind Eng., vol. 27, pp. 351–359, 2009.
- [8] M. A. Ahmed and Y.-C. Kim, "Hierarchical Communication Network Architectures for Offshore Wind Power Farms," Energies, vol. 7, pp. 3420–3437, 2014.
- [9] M. Goraj, Y. Epassa, R. Midence, and D. Meadows, "Designing and deploying ethernet networks for offshore wind power applications -

- a case study,” 10th IET International Conference on Developments in Power System Protection (DPSP). Managing the Change, 2010, pp. 84–84.
- [10] “Wind turbines – Part 25-2: Communications for monitoring and control of wind power plants – Information models,” Int. Stand. IEC 61400-25-2, 2006.
- [11] M. A. Ahmed and Y. Kim, “Hybrid Communication Network Architectures for Monitoring Large-Scale Wind Turbine,” J. Electr. Eng. Technol., vol. 8, pp. 724–752, 2013.
- [12] S. Hussain and Y.-C. Kim, “Multilayer Communication Network Architecture for Wind Power Farm,” IEEE 19th International Workshop on Computer Aided Modeling and Design of Communication Links and Network (CAMAD), 2014, pp. 105, 109.
- [13] H. J. Bahirat, B. a. Mork, and H. K. Hoidalén, “Comparison of wind farm topologies for offshore applications,” IEEE Power and Energy Society General Meeting, 2012, pp. 1–8.
- [14] “Opnet Technologies,” OPNET Modeler. [Online]. Available: <http://www.riverbed.com/>.



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