Wind Turbine Fault Detection System in Real Time Remote Monitoring

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ABSTRACT

In new energy development, wind power has boomed. It is due to the proliferation of wind parks and their operation in supplying the national electric grid with low cost and clean resources. Hence, there is an increased need to establish a proactive maintenance for wind turbine machines based on remote control and monitoring. That is necessary with a real-time wireless connection in offshore or inaccessible locations while the wired method has many flaws. The objective of this strategy is to prolong wind turbine lifetime and to increase productivity. The hardware of a remote control and monitoring system for wind turbine parks is designed. It takes advantage of GPRS or Wi-Max wireless module to collect data measurements from different wind machine sensors through IP based multi-hop communication. Computer simulations with Proteus ISIS and OPNET software tools have been conducted to evaluate the performance of the studied system. Study findings show that the designed device is suitable for application in a wind park.

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1. INTRODUCTION

In front of the huge increase demand in energy over the world, and in order to search a substitutional kind of energy against the prices rise of the energy fossil fuels resources and its exhaustion reserves in the long term. Furthermore, the commitment of the governments to reduce greenhouse gases emissions has favored the research of others energy sources. The recourse to renewable energy becomes a societal choice. The development of this alternative is encouraged because it offers natural, economic, clean and safe resources. Among the renewable energies, wind energy has been progressed in a remarkable way in these recent years. It provides a considerable electrical energy production with less expense a part from the construction and maintenance budget. Nowadays, wind energy investment has increased by the multiplication of the wind parks capacities. This contributes greatly to the expansion of terrestrial and offshore wind parks which are usually installed in far locations, difficult to access and subject to extreme environmental conditions [1]. Wind turbines contain a complex electromecanical system which is prone to defects. Therefore, their monitoring and diagnosis become essential to reduce maintenance costs and ensure continuity of production because stopping a wind installation for unexpected failures could lead to expensive repair and to lost production [2]. This operating stopping becomes critical and causes very significant losses. For these reasons, there is an increase need to implement a robust efficient remote maintenance strategy to guarantee uninterrupted power in the modern wind systems [3]. This online surveillance allows an early detection of mechanical and electrical faults. It must be able to prevent major component failures. That facilitates a proactive response, anticipates the final shutdown of wind generators, minimizes downtime and maximizes productivity by analyzing continuously the measured physical signals collected from different types of sensors [4], [5], [6]. This is why reliability of wind turbines becomes an important topic in scientific research and in industry. Most of the recent researches have been oriented toward electrical monitoring, as it would be the most practical technique and less costly. Another powerful tool used for diagnosis of an induction motor or generator is current stator analysis (CSA) [1], [4], [5], [6], [7]. It utilizes the result of the spectral analysis of the stator current to indicate an existing or incipient failure. Moreover, with recent digital signal processor (DSP) and wireless communication technology developments, it is possible to detect electric machine faults prior to possible catastrophic failure in real-time based on the stator line current allowing precise and low-cost [7]. The main objective of this paper is to study the design of a real time monitoring and controlling system for state supervision of wind generator machines which integrates intelligence and robustness functions.

2. RELATED WORK

In the literature review, few of research studies have been developed to analyze the theoretical aspects of the application part in condition monitoring of wind turbines operating [1], [8], [9], [16]. As known, these faults cause a modulation impact in the magnetic field of the wind generator, which is reflected by the appearance of a significant harmonics (peaks) in the stator current spectrum [3]. Some research works are applying enhanced signal processing techniques like Fast Fourier Transform method (FFT), Short Time Fourier Transform (STFT), periodogram, Discrete Wavelet Transform (DWT), Wigner-Ville representation, Concordia Transform (CT) and the Hilbert-Huang transform and other advanced tools based on wind generator stator current to diagnose prospective electromechanical faults under transient conditions [3], [6], [14], [15]. Besides, in [2] a statistical diagnosis approach is proposed based on residues analysis of the electrical machine state variables by the use of the Principal Components Analysis method (PCA) for faults detection in offshore wind turbine generator. The main drawback of this approach is that the detection efficiency requires a good choice of the principal components number. Some researchers are proposed failures diagnosis and monitoring of wind turbines generators using impedance spectroscopy (IS) [17-21]. Due mainly to their advantages, high resolution methods (HRM) such as MUSIC, ESPRIT and their zooming techniques having high accuracy can detect frequencies with low SNR [21], [22], [24], [30]. They have been recently introduced in the area of induction motors and wind generators faults diagnosis to improve the detection of a large number of frequencies in a given bandwidth. Other practical research techniques are used to solve online maintenance problems with the help of real time by integration of the Wireless Sensor Network and the industrial communication protocols in wind turbines diagnosis [10-13], [20], [23]. This paper presents an intelligent remote monitoring and fault diagnosis system for wind turbine using real time hardware based on a wireless communication module.

3. PROBLEM FORMULATION

The current maintenance planning based online monitoring systems used in wind parks is not optimized. It has several limitations both in terms of performance and installation cost. This is the result of various reasons:

- Cable structure monitoring with its problems (cuts, noise, and configuration), mainly through fiber optic, is not effective and not appropriate since wind parks are often deployed over a large geographic area having environmental obstacles such as offshore, desert, mountains, rivers, forests and plains that are located far away from the control center.
- Wind turbines monitoring need to implement a proactive maintenance system based on an early, fast and real time fault detection and diagnosis, allowing a secure and reliable communication for better maintenance management. This strategy avoids failures leading to serious damages, expensive repair and production loss.
- The storage of the monitored parameters in the control center database is a need, because it is an essential operation which helps to monitor accurately the lifetime of the wind turbine components. Therefore, it allows exploiting collected data for studying statistically the most occurring faults and their timing.

To overcome these imposed application constraints, an interactive embedded system has been designed to provide an efficient, reliable and economical link between various wind turbine sensors for an accurate remote controlling and monitoring scheme.

4. MONITORED PARAMETERS IN WIND TURBINE

Since the wind turbine machine is a complex system, it contains a large number of parameters to be monitored. Hence, to pursue and to control all functions of the wind turbine in order to ensure its optimum operation at any wind velocity, there is a strong need to install a set of sensors that collect performance data of the wind turbine continuously and then transmits it to an internal controller which is designed to allow local supervision and command in case the machine functions are required. In case of anomalies or errors, the data is stored in a database or log alarm, allowing error analysis of wind machine. The monitored parameters are acquired through ADC devices connected by means of the direct connection or by RS232 and USB interfaces of the computer or by a wireless connection. When a failure occurs inside the wind turbine, the controller reacts quickly to avoid the evolution of any type of defects. In this optic, a robust and reliable system must be developed leading to the possibility of real time and detecting faults accuracy in their incipient stages before they transform into more serious failures causing undesirable downtimes and damages. Table I encloses the list of sensors and the parameters monitored in wind turbine.

Table 1. Monitored parameters

Parameter	Sensor
Bearing, gearbox lubrication	SKF Windlub
Windvane	INV-40A
Anemometer	INA-46A
Temperature, gear bearing	PT100
Temperature, generator	PT100
External Air Temperature	PT100
Temperature Nacelle	PT100
Temperature gear oil	PT100
Rotor speed (gear tooth)	EI 30 10 PPos, PNP
Generator speed	DU 10, EP, PNP
Pitch position (linear actuator)	Vert-X 22
Atmospheric Pressure	NRG #BP20, WXT520
Humidity	P14 SMD
Vibration	WLNJ-S2-G, HS-100
Hydraulic oil level	Gems LS600-150-NO-10

Figure 1 gives a detailed description of the location of various sensors used in the monitoring of a wind machine. The current/voltage intelligent sensors, based on generator current stator spectral analysis (CSA), are used in cooperation with one bit vibration sensors for an early identifying of prospective occurring mechanical faults.

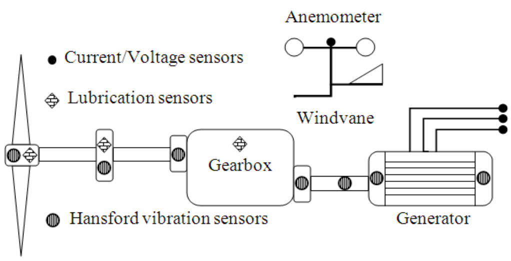

Figure 1. Sensors localization scheme

5. DESIGN OF SYSTEM STRUCTURE AND NETWORK

The proposed system is an Intelligent Embedded System for Control and Remote Monitoring (IESCRM) that has the capability of processing, monitoring and controlling [29], this system finds its application in many field areas especially remote electromechanical condition monitoring of wind turbines in a park. It comprises sensors, microcontroller, memories, etc. It typically has a specialized function with programs stored on ROM. An added feature in this embedded system is its ability to communicate. The communication can be via Wi-Fi, GPRS, Wi-Max or Ethernet cables. The TCP/IP protocol is a widely used standard for modern digital communication. It provides real time data traffic. The main goal of this hardware is to make internet/IP enabled for the developed embedded device which serves as advanced remote data logger to be accessed remotely via workstation. The mentioned device will be interfaced with various sensors as illustrated in table1. The measurements and control data are then communicated to the central server, which adopts client/server web and database frameworks, through an Ethernet or wireless connection. This server holds all the past data transmitted by the system using web pages. Figure2 illustrate the monitoring and control system architecture allowing online data transfer between the wind turbines and the control center. The designed interactive embedded hardware provides an efficient, reliable and economical link between various systems, sensors and actuators. The choice of the GPRS and Wi-Max protocols is justified by several reasons: first, wind parks are implemented on a large geographical area that can reach some kilometers. Thereafter, their remote monitoring requires a wide cover wireless communication protocol, and then the implementation of these communication technologies does not require any new infrastructure installation because it uses the mobile cellular telephony network 2.5G, 3G or 4G. Some differences existing between these two protocols are data rate and transmission time [25].

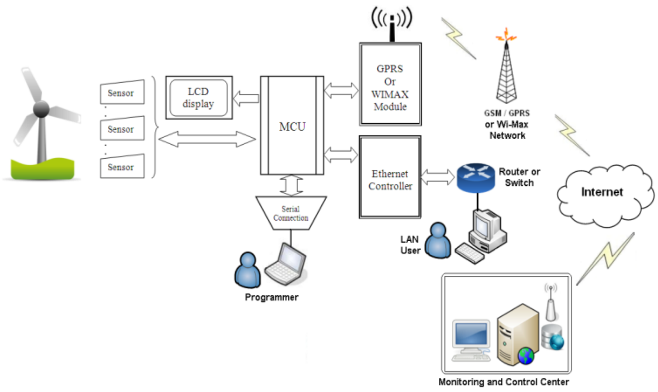

Figure 2. Block diagram of monitoring and control system Architecture

The sensors listed in table 1, are connected to the microcontroller which is used as a computer and the Ethernet chip ENC28J60 [28] is used to connect the microcontroller to LAN with Ethernet cable by an RJ45 port. Figure3 shows the interconnection of ENC28J60 with MCU. The electrical power supply of the IESCRM module does not pose a problem because it can be powered by a rechargeable battery connected to an AC/DC conversion circuit of the current received from wind turbine during operation.

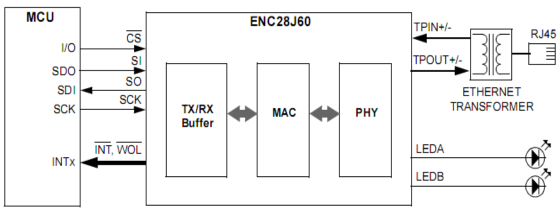

Figure 3. Ethernet Chip and MCU interconnection

Whereas, Wi-Max or GPRS module (like ZTE IX256-RJ45 Modem [26] for Wi-Max or SIM900A-RS232 Modem [27] for GPRS) are used to establish an online wireless internet connection with the base station server. The sensors are connected to the AN_{0-7} pins. The MCU is chosen from PIC24 family of microcontrollers because it has many advantages: large number of I/O pins, high memory space, built in ADC channels which make it easy for interfacing the sensors, developed using NanoWatt technology that reduces power consumption during operation. The LCD displays the current and any new IP address of the communication. The serial connection RS232 is used to configure the module (to change the IP address). It can also be used for debugging purposes. The IESCRM module is an automaton with integrated web server.

Once programmed, it contains software consisting of web pages for configuring, monitoring and visualization of data measurements of the different sensors connected to this module. Both GPRS and Wi-Max are two IP based service protocols which can be used to access a range of IP services by running TCP/IP protocol stack, such as FTP, Web Browsing, Machine-to-Machine M2M and Simple Mail Transfer E-mail SMTP. TCP/IP Stack is divided into multiple layers. The code implementing each layer resides in a separate source file, while the services and APIs (Application Programming Interfaces) are defined through header/include files. Another protocol used in IESCRM module is HTTP which simply involves an exchange of text messages followed by the transfer of Web data via a TCP connection. To fetch a Web page, the browser opens a TCP connection to server port 80, and then uses HTTP to send a request. The basic program which is localized in MCU EPROM runs as a server providing multi-user access to a number of databases. A MySQL/PHP Web/Database server based on APIs are used to implement adequate software through CGI protocol for interfacing external application software with an information web server. By this technique, the information regarding physical parameters is sensed from the sensors. This is received by microcontroller and is stored in CGI variables. These CGI variables can be accessed by CGI scripts running in web/database server. The data are stored in the MySQL database. Finally the required graphical representation of the data can be displayed interactively in the dynamic website as illustrated in figure 4. The developed module offers several features that require a SIM card:

- Access to web pages of the module via Ethernet connection, GPRS or Wi-Max
- Sending alarm messages by e-mail via GPRS or Wi-Max
- Sending alarm messages by SMS

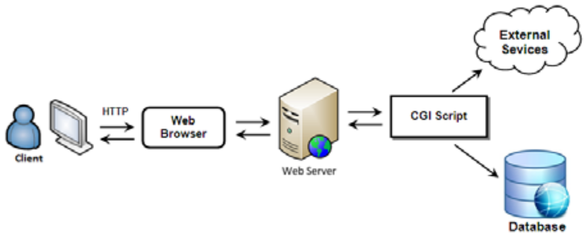

Figure 4. CGI and Web Server connection with Database

The IESCRM module provides an early damage detection procedure that enables remote, automatic maintenance and control of a wind turbine hard to access, eliminating the need for an on-site service engineer to perform extra manual intervention. Reacting to the problems detected by this system. A condition monitoring specialist can set the proper alarm settings to trigger appropriate decision. If failures are detected such as empty or blocked lubrication pumps or torn feed lines or oil/grease levels, operators are notified immediately. In this case, depending on the type of fault and its severity, it will be necessary that the wind turbine controller takes an operating strategy of around four operational states:

- On
- Pause
- Off
- Emergency

6. CIRCUIT DESIGN USING PROTEUS SOFTWARE

To evaluate the operation of the designed module, its computer simulation has been made with Proteus ISIS software version 7.7, figure 5 show electronic schematics circuits of IESCRM with a GPRS module. Furthermore, figure 6 present electronic schematic circuits of the IESCRM using Wi-Max modem whereas the architecture of the centralized network for supervision and remote maintenance of a wind park can be described as shown in figure 7.

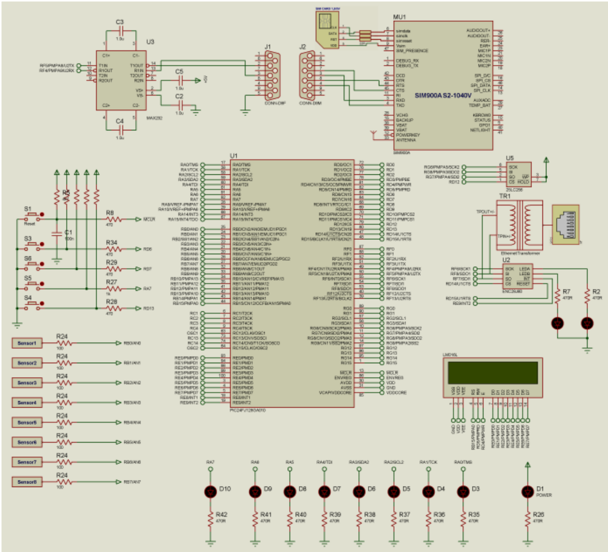

Figure 5. Electronic schematics of IESCRM with GPRS module

The web pages can be viewed by browsing directly to the specific IP address device from the base station or from any other computer on the network. To maximize program memory space (and be able to fit the code in a PIC24FJ128GA010) an external 25LC256 Serial EEPROM is added which uses the SPI interface that can be shared with the ENC28J60 and the device much faster than the I2C part.

The IESCRM physical interface model transmits and receives data packets to base station through GPRS or Wi-Max connection. Meanwhile, the PIC24 runs it own TCP/IP stack and software, comprising a simple web server. This software enables the microcontroller to behave as a communications server, providing a support for a web client/server.

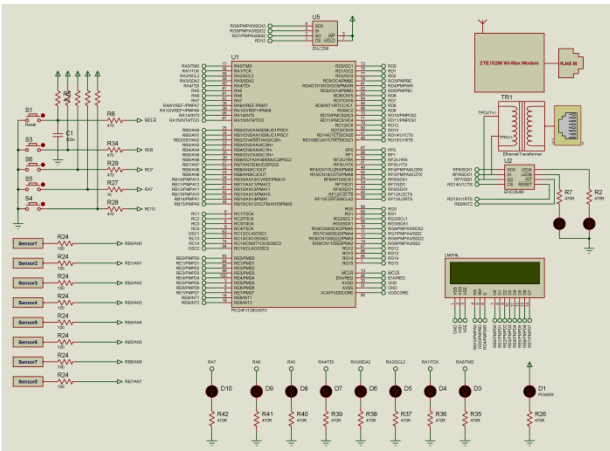

Figure 6. Electronic schematics of IESCRM with Wi-Max modem

When the simulation is started, the LCD display the IP address allocated to the wireless modem by the office network DHCP server. For demonstration purpose, the IP address of different IESCRM in wind park network are assigned to be 192.168.11.X, where X take it value between 2 and 255 and the IP of the central web/database server was assigned to be 192.168.1.1, both connected to the same network router.

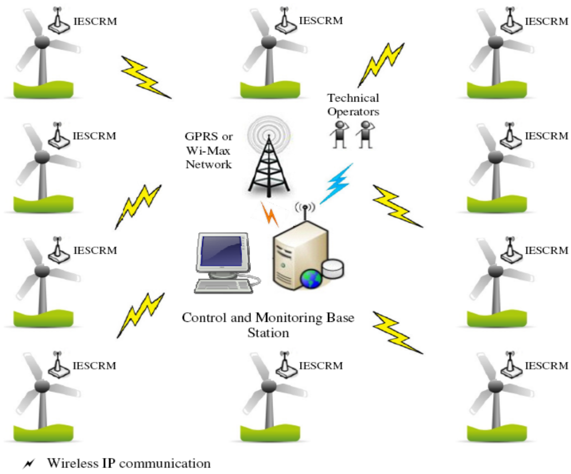

Figure 7. Structure of control and monitoring system of a wind park

In this architecture, each wind machine is equipped with an IESCRM module identified by its own IP address, this allows to collect and to store data received from different sensors installed on each wind turbine. The IESCRM takes care of the real time regular transmission of all measurements via GPRS or Wi-Max to the server of supervision and control station which has a specific IP address. This communication is established by means of a dynamic web page shown in figure8 indicating the time and date, the wind turbine ID and its IP address and the received data. On the other side, IESCRM collaborates with the central automaton regarding the operation mode of the wind machine.

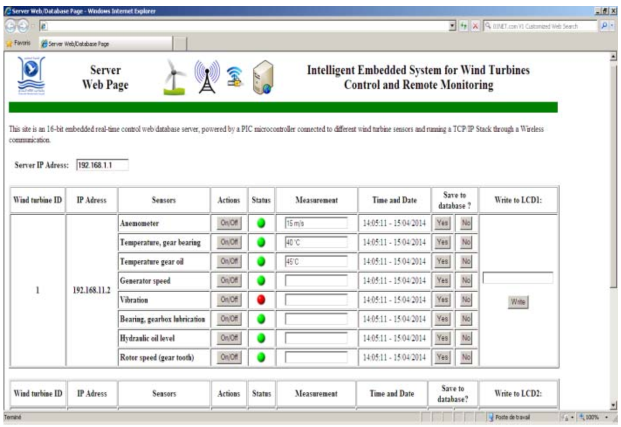

Figure 8. IESCRM Server Web/Database Page monitoring

The base station server allows management and processing of the database samples received from different wind turbines in order to make a decision or to apply a command using diagnostic algorithms.

7. SIMULATION RESULTS

The system described in the previous section for wind park controlling and monitoring has been implemented and simulated based on a realistic task by the OPNET Modeler 14.5 an Proteus ISIS via virtual serial connection ports under two scenarios and carried out the simulation to evaluate and to compare the performance of the IESCRM system in term of real time data traffic for two different network technologies. The scenarios developed in OPNET for Wi-Max and GPRS over UMTS are shown in figure 9 and 10 and the system parameters for both networks are detailed in table 2 and 3.

Table 2. Wi-MAX Simulation Environment Parameters

System Parameters	
Simulation time (sec)	3600
Data traffic rate	10 Mbps
Basic rate	1.5 Mbps
Service Class Name	Gold/UGS
Antenna Gain	15 dBi
PHY profile	Wireless OFDMA 20 MHz
Max. Transmit power	0.5 Watt
Path loss	Pedestrian
BS MAC address	Distance based

Table 3. UMTS Simulation Environment Parameters

System Parameters	
Simulation time (sec)	3600
UMTS MN cell state	CELL_DCH
UMTS RLC process time	0.015 sec
CPICH transmission Power	1Watt
Shadow fading Standard deviation	10
Processing time	0.02 sec
Path loss	Pedestrian
UMTS GMM Timer	15/30/10

Two different applications are used: HTTP and Database. The studied Wi-MAX and UMTS network models consists of two Base Stations and two cells; each cell has four fixed wind turbine machines which are equipped with an IESCRM to serve all applications types.

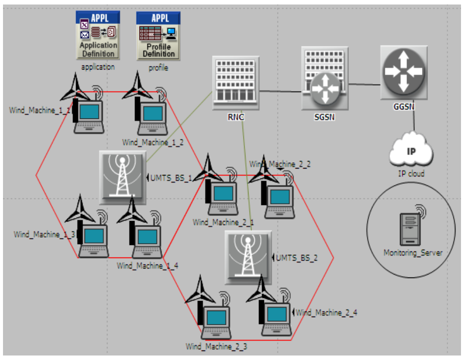

Figure 9. GPRS over UMTS wind park monitoring OPNET scenario

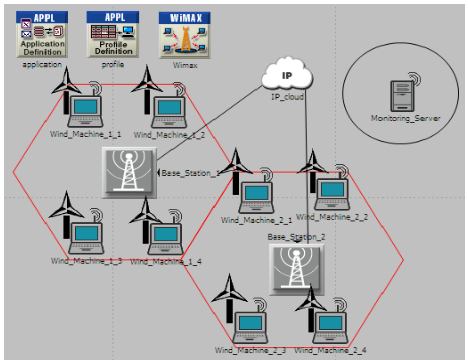

Figure 10. Wi-Max wind park monitoring OPNET scenario

The coverage of one cell is approximately 2km by 2km of area. UMTS model shown in figure 9 comprises user equipments, Radio Network Controller (RNC) which is connected to the packet switched network via GPRS Support Node (SGSN) and through GPRS Gateway Support Node (GGSN) which in turn is connected to the IP Network. Based on figure 11, the average response time in database query for GPRS has an unstable behavior. It is delayed with almost 127 times compared to the same time for Wi-Max network. In other side, it is clear from figure 12 that the average traffic received in database query increase significantly with time increasing and it takes a fixed maximum value for both GPRS and Wi-Max networks. The traffic received is much more important for the Wi-Max compared to GPRS and the difference between them is about 80%.

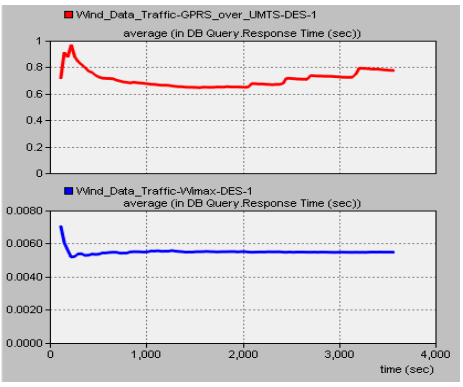

Figure 11. Average response time in Database Query

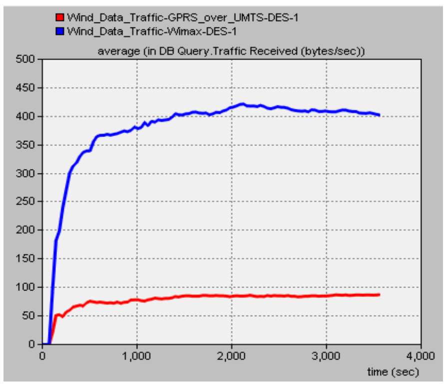

Figure 12. Average traffic received in Database Query

Whereas, referring to the simulation results illustrated in figure 13, Wi-Max is much faster to provide web page in HTTP service and it exceeds GPRS with about 187 times in average. This page response time has an unstable evolution. Concerning the average traffic received in HTTP service for GPRS and Wi-Max shown in figure 14, it can be observed that the value of this parameter is greater for Wi-Max than GPRS with about 94%. Indeed, as illustrated in figure15, average network activation delay for Wi-Max is multiplied 137 times than that of GPRS. The obtained results can be justified by the fact that GPRS network covers a wide area but it data transmission is only able to achieve a data rate between 35Kbit/s and 87Kbit/s in practice. This is much less than Wi-Max which can reach 75Mbit/s. Wi-Max is able to bring more bandwidth and provides more connection quality services to benefit from the wind park monitoring.

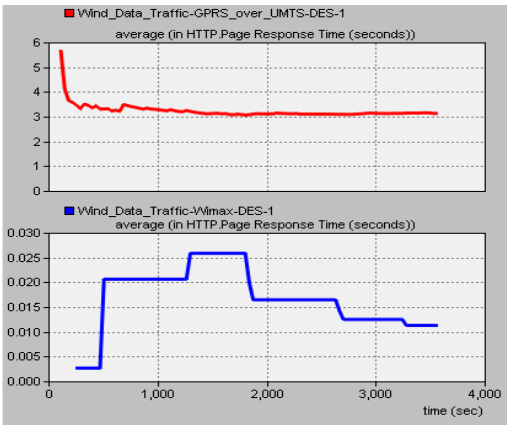

Figure 13. Average Page response time in HTTP service

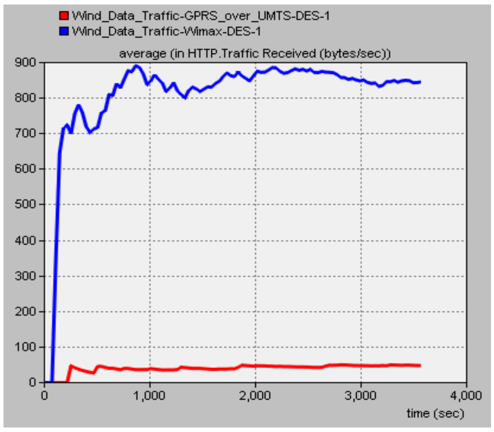

Figure 14. Average traffic received in HTTP service

Furthermore, GPRS has a huge fluctuation in speed whereas Wi-Max gives a constant bandwidth which results in a constant and a fastest Internet service. Wi-Max remains the most appropriate technology choice to satisfy the QoS requirements and real time data traffic for wind turbines control and monitoring application.

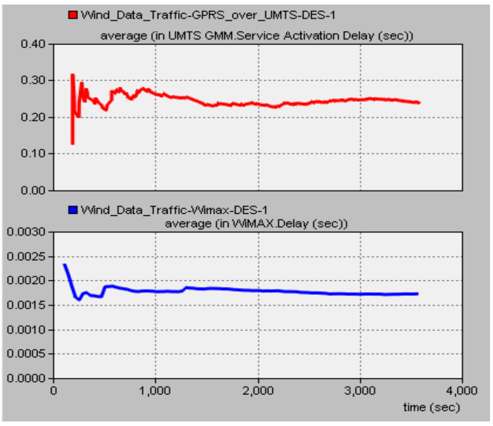

Figure 15. Average network activation delay

8. CONCLUSIONS

Wind turbine machines need periodical proactive maintenance to prolong their electromecanical components lifetime. The main contribution of this paper is to design, by study and analysis, an intelligent wireless remote monitoring and control system according to wind turbines features and requirements. Both hardware module and operating mode have been described in detail. This system based on IP communication combines Web and database client/server technology to copy data measurements received from the differents sensors installed in the wind turbine machines and therefore sends it to the base station through a wireless connection. The simulation comparison, with Proteus ISIS and OPNET simulators between GPRS and Wi-Max implementation with the studied module, favorites Wi-Max network due to their benefits over GPRS network. This intelligent device has low cost and it can be used in other application areas. Maintenance issues are now able to be resolved with this efficient communicator tool. The future work will be focused on the test and application of the whole monitoring system in the practice.

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