BUILDING A WIND MAINTENANCE SYSTEM WITH OPEN SOURCE SOFTWARE AND LOW COST HARDWARE

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SUMMARY

The use of open source software in many institutions and organizations is increasing. However, a balance should be considered between the software cost and the cost of its technical support and reliability. In this article it will be presented a maintenance system for wind farms. It is with an information system for maintenance, called SMIT (Terology Integrated Modular System), as a general base to manage the assets and as a strategic line of evolution of this system, which was introduced on-condition maintenance modules, and the corresponding research and development done around this theme. The SMIT system is based on a tcp/ip network, using a Linux server running a PostgreSQL database and Apache web server with PHP. Octave and R software are used for numerical analysis. Maintenance technicians, chiefs, economic and production management personnel can access SMIT database through SMIT clients for Windows. However, this maintenance system for wind systems uses also special low cost hardware for data acquisition on floor level. The hardware uses a distributed tcp/ip network to synchronize SMIT server master clock through Precision Time Protocol. Gnu gcc-4.3.3 toolchain for arm processors, newlib-1.17.0 and binutils-2.19.1 are used to program the ARM Cortex-M3 processor. Usually, the manufactures construct, deploy and give the means to the suppliers to perform the wind system's maintenance. In some cases, the owners of wind farms can choose the maintenance company. This is a very competitive area, where companies hide the development details and implementations. Another important factor is that it is the first time, in last ten years, that three countries with the largest installed power, together, have fallen to a minimum historic, below 40% of the market for wind power in the EU. Definitively, the other European countries encouraged the appearing of programs for installing wind power, with prominence for Italy, Portugal and Netherlands. Within this scenario, the development of maintenance management models for multiple wind equipments is important, and will allow countries to be more competitive in a growth market. For on-condition monitoring, the algorithms are based on Support Vector Machines and time series analysis running under Octave and R open source softwares.

Key Words: Wind maintenance management; predictive maintenance; sustainability; open source; SMIT.

1 INTRODUCTION

A wind turbine is a complex system with several components changing constantly and supporting strong forces. By consequence, it can experience many problems, such as vibrations, electrical failures and many other kinds of faults. Additionally, wind farms are usually far from cities and from companies that support their maintenance. Technical assistance is expensive and the combination of on-condition maintenance with the best practices of operational research to minimize distance costs is extremely important. Within this work, the main objective is to implement a maintenance plan using, namely, on-condition maintenance through on-line data instrumentation, acoustic techniques, vibration techniques [1], infrared images, stress measurement, zero crossing current analysis and artificial intelligence, in a coherent and synergetic way.

Another strategic objective of this work, is to build the entirely system with open source and low cost hardware. The reliability of actual microcontrollers and open source software is of great importance for market penetration. The increment on sustainable ecological energy is in the mind of all political persons in the planet. Nowadays, green energy is a very important subject and countries believe this it is the good direction to the ecological and oil savings. This is the case, not only for wind energy, but also for other kind of green energy like photovoltaic solar energy, sterling solar energy, and geothermal energy, only to name a few.

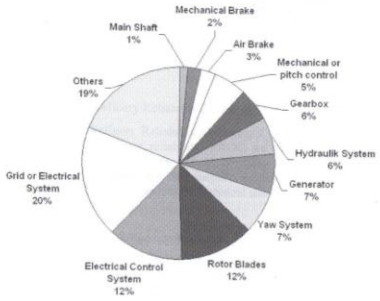
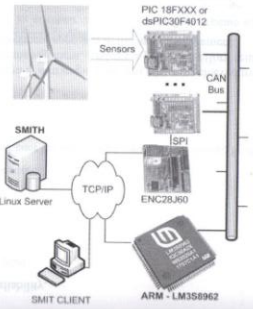


Figure 1. Share of components in the total failures in a Wind Turbine [3].

Around the wind energy, countries are now installing wind power capacity in Europe, United States, Asia, etc. In the last year, 2008, 27051 MW of new wind energy capacity was installed in the world, now being a total of 120798 MW [2]. This factor is not only important for green energy production, for companies, for less oil energy dependency but also for economical reasons, the financial money paid in the oil does not leave the country and, in alternative, can be applied in the construction of new wind farms, thereby leveraging an energy resource. Some authors have reported different types of failures in wind turbines, which presume the existence of an area of great economic importance, such as the financial costs about maintaining these facilities. Some of these reported failures can be seen on Fig. 1. In this scenario, maintenance problems will grow in future with the oldness of equipments and, in a reasonable way, it is important to study this problem to increase knowledge.

2 A WIND MAINTENANCE SYSTEM

The SMIT (Terology Integrated Modular System) [4], [1] is a general propose structure for a wind maintenance system including hardware and software components. The system includes the conventional modules of maintenance software, with some innovations like Maintenance Objects relations in matrix format, unlike the normal tree relation. Working Orders (WO) can be created by a non-periodic maintenance plan, by corrective purposes or by an on-condition triggered action based on data collected on plant level. Fig. 2 gives an overview of the global system and the components used on it.



2.1 Main components of maintenance program SMIT

The central system is based on a Linux server running a PostgreSQL database and an Apache Server with PHP language included. At the time the Linux distribution supporting SMIT was Slackware version 12.1 and also FreeBSD version 7.1 [5].

For remote access by browser technology an Apache server running PHP is used, versions 2.2.4 and 2.5.1, respectively. Some pieces of the maintenance software modules are available for maintenance intervention requests and information exchange with third parties using web services PHP technology. The core of the system uses the popular PostgreSQL database version 8.2.3 and, also 7.4.16. The entire application logic is based on PostgreSQL features, like stored procedures where data validation and integrations is performed.

stored procedures are written in PL/pgSQL, a native language similar to Oracle's stored procedure language. SMIT database includes 149 tables and 156 PL/pgSQL stored procedures. The SMIT users can interact with main system using windows interface modules programmed in Delphi 7. This is the single, no open-source programming tool used, however, especial design as been done to easily translate all source code with minor changes to be compiled by freepascal [6] and the RAD development with Lazarus project [6], as soon as its reliability on certain components is assured. Reports are also developed with a commercial program, Crystal Report (integrated in Delphi) and some others with PHP, both stored in special tables in SMIT database, and its portability to open source is also possible, and will be achieved by PHP reporting tools.

The window's system modules are able to perform automatic installations of new windows versions using CPAU program [7].This is an independent software command line tool for starting processes in an alternate security context, enabling software installation, without problems caused by SMIT third parties users, like "sabotage", and their windows Administrator password.

To protect this intellectual property around the development, particularly in the PHP and SQL postgreSQL scripts, two software tools for encryption had been created. For SQL scripts, only the PL / pgSQL functions are encrypted, as for the PHP, the entire contents of the program are encrypted. Obviously, to accomplish this task, there was a need to change the source of their distributions. Obviously, to carry through this task, there was the necessity to modify the source code of the respective distributions (PHP and PostgreSQL). With this solution, the administrator password of server SMIT can be provided to third parties if required. Another security feature, all the external connections to SMIT's database are made using SSL sockets implemented through OpenSSL.

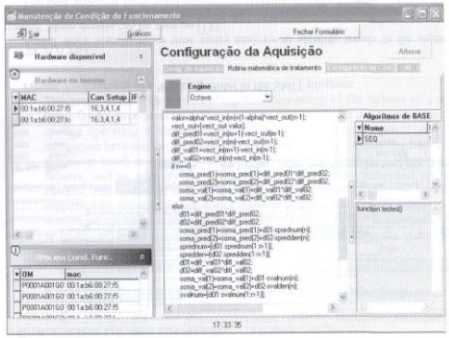


Figure 3. Octave script using time series algorithms, for numerical data analysis.

For numerical data processing, SMIT incorporates the Octave and R distributions version 3.0.3 and 2.8.0 [8]. The R and Octave scripts are stored in the database, enabling the users to modify/change them as needed, although not being specialized persons. By default, SMIT incorporates some algorithms; however it is necessary people skilled to do so, especially with knowledge of mathematics and programming, as can be seen on Fig. 3.

2.2 Low cost hardware developed

Many manufactures use industrial PLCs to control and acquire sensorial data in the wind turbine equipments. In Portugal many examples can be seen. It is also normal to have a higher failure rate in these components due to instability in the voltage. These aspects give another argument to use low cost hardware, also envisaging the possibility of supplying the hardware with photovoltaic panels or batteries avoiding the problems with instable voltage.

For low cost instrumentation, the prototype developed includes:

- A board based on the ENC 28J60 with tcp/ip communications at a 10Mbps half-duplex. The MCU is PIC18F2685 with CAN2.0B interface with 1Mbps maximum velocity and a SPI connection to the ENC 28J60 Ethernet controller. The programming is done in C using C18 Microchip compiler. This board will be a gateway between the traffic from the CAN network and the Ethernet network;
- An acquisition board based on PIC18F2685 with acquisition module of 10bits/sample at a velocity of 10ksamples/second and CAN 2.0B with 1Mbps maximum velocity. The programming is done in C using C18 Microchip compiler;
- An acquisition board for high speed powered by dsPIC30F4012, including the CAN 2.0B interface at a maximum of 1Mbps, and acquisition with a velocity of 1Msamples/second. Another important feature, this MCU is capable of perform synchronous acquisition in four channels simultaneously;

- A board using Microchip digital potentiometers to implement a Butterworth low pass filter of 8º order with cut off frequency between 100 Hz and 50 kHz and two cascade amplifiers with gain range between 0.1 and 10. The frequency and gain are programmed by software;
- A board base on the Luminary microcontroller LM3S8962, an ARM-Cortex-M3 architecture with support for Ethernet packet time stamping in hardware, with two interfaces Ethernet at a 10/100 Mbps full/half duplex and CAN 2.0B. All the programming tolls for this microcontroller as been constructed based on GNU GCC toolchain for ARM-Cortex-M3 version 4.3.3, Binutils 2.19.1 and newlib-1.17.0 under Gygwin. This is the most expensive component; however, it is priced by 12 Euros/unit, and with a few elements, an operational board is running. This board will be a gateway between the traffic from the CAN network to the Ethernet network.

3 ALL COMING TOGETHER

The acquisition timings are saved in SMIT's database, where the global acquisition network is designed and stored. At a first step, a SMIT user will configure the acquisition network, choosing the boards on the field. The gateway board will use DHCP protocol to acquire an IP number, and the setup for CAN network is also stored in the database. In this way it is very easy to change CAN network velocity by changing the parameters associated with the CAN network, Fig. 4.

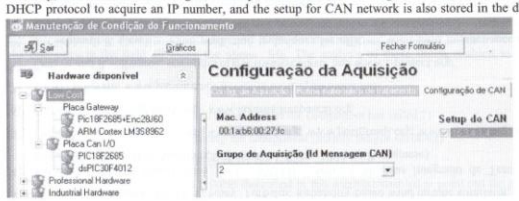


Figure 4. Choosing hardware: in low cost mode a gateway is always needed as also a I/O can board.

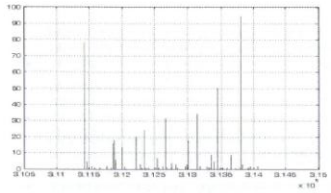
In the second step, the information related to frequency sampling is indicated, and also the temporal interval like the starting date and final date of the acquisition, Fig. 5.

These parameters are downloaded by the gateway board to control the sampling rate in the CAN bus, generating control signals for the I/O boards.

Another goal is to synchronize the acquisition boards through time propagation from the SMIT server to PIC micro-controllers in the CAN bus using SNTP or PTP running in a cooperative way in the Ethernet-CAN gateway. With this feature, it is possible to ensure that different devices placed in different wind turbines perform signal acquisition at the same time. This aspect makes possible the comparison of the same data in different wind turbines; it is guaranteed that the gap between the acquisition time is less then 3 micro seconds.

The CAN slaves, in setup mode, will auto-baud the communication velocity until a valid CAN message is received. After this stage they will start the normal cycle, waiting for a message asking for an acquisition and forwarding packets for measuring CAN propagation delay time, or receiving messages for firmware.

Figure 5. Programming the acquisition temporization for each low cost I/O board, in the SMIT's on-condition module.

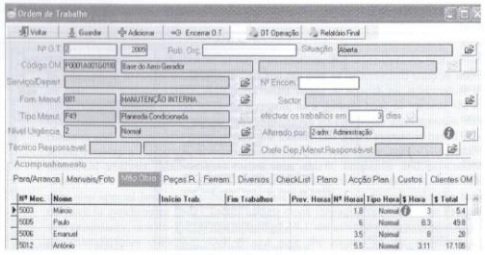


The CAN bus devices are restricted to the global acquisition rate. If the number of nodes together generate data with a flow rate higher than the CAN network speed, the nodes must be divided by two (or more) different CAN networks. For synchronizing the master gateway Real Time Clock, the system uses SNTP – Simple Network Time Protocol (PIC with CAN and ENC28J60 device) and the board based on the Luminary micro-controller uses PTP (Precision Time Protocol). The use of different protocols is justified by the Ethernet packet time stamping facility of the Luminary micro-controller that is full explored by the PTP. The SMIT server runs a SNTP and/or PTP daemons servers.

Figure. 6 – Sampling time measured (ns) in the Ethernet-CAN gateway after sending the CAN message with one byte. As calculated and measured, the CAN message should be sent 310 micro seconds earlier. In this example, the maximum error is about 2,5 micro seconds which gives an error of 0,8%.

4 ALGORITHMS FOR A WIND MAINTENANCE SYSTEM

In the literature many authors are working on this subject [9], [10], [11] and [12]. One important objective of this work is to perform the fault prediction, under the perspective of on-condition maintenance, through on-line data instrumentation. The techniques used to monitoring the condition of wind system are based on the following aspects:



- Vibration monitoring on generator and gearbox;
- Measure the wind speed, using an analogue anemometer (inexpensive) and a ultrasonic anemometer WMT50 from Vaisala Company;
- Active power measurement;
- Classification using artificial intelligence;
- Time series analysis using regression techniques.

Figure. 7 – Example of a Working Order in the SMIT program.

Actual work also includes time series analysis to identify trends in the signals and discover future illness in the wind turbine. More details can be seen on [13].

The data acquired from wind acquisition systems, usually presents irregular values. The system (on-condition classifiers) must be very accurate; otherwise a false error condition would be triggered. For example, when the wind break system is activated it is expected that the power curve differs from the relation published by the manufacturer; however, the inner axis rotation versus active power should maintain the relation, because the break will only change the rotation speed and not the relation between rotation speed and produced power. The same arguments are valid for the pitch system. The algorithm used for detecting an uncharacteristic operation will use Support Vector Machines (SVM) classifiers [14], [15], [16]. The goal is to decide if data measured in the sensors shall be detailed processed or just stored. If the SVM classifier indicates an anomalous situation, a detailed processing will be performed related to the sensors already installed (in the present work, vibration and current). The vector for classification uses in this case two measured values, active power and inner rotor velocity, as can be seen by equation 1 and results can be seen on Fig. 8.

$$\vec{x}_{wind\_turbine} = [Rotor\_shaft\_speed \quad Generator\_shaft\_speed \quad Active\_Power]^T \qquad (1)$$

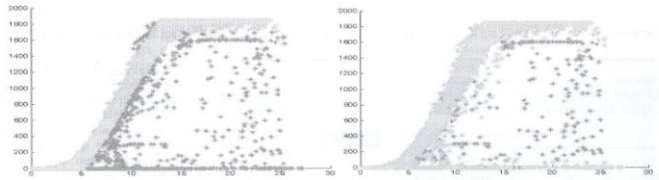


Figure. 8 – SVM classifier results. Left: using only active power and wind speed. Right: using equation 1.

5 CONCLUSIONS AND FUTURE WORK

This article describes briefly wind maintenance systems with all the components, from software to hardware, with main objective with the lowering prices; this through the use of open-source software and low cost hardware. An acquisition synchronization system is also presented using SNTP or PTP hardware with time stamping facility. Finally, a very briefly presentation for one algorithm used to perform on-condition monitoring.

Future work will be in the study of optimization of movement of technical personnel between different generators, taking into account cost functions, such as loss of production and probability of failure, and also using 3d models.

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