A Better Environment Through Better Terology

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Abstract: - A better environment can be achieved through the reduced emission of pollutants, the optimization of green energy production and the optimization of maintenance interventions, which is an important contribution in getting equipment functioning as efficiently and effectively as possible and, of no less importance, to minimize the downtime caused by faults. These are the key points presented in this paper, which also emphasizes the very recent contribution of 3D models in aiding fault diagnosis and terology in general. The way to achieve the above-mentioned objectives is through on-condition maintenance in two main fields, wind farms and Diesel engines. In wind farms, maintenance is done through the control of variables, such as vibration signals and the balance of electrical currents. As for Diesel engines, on-condition variables are the emissions of PM10, NO_x, CO, HC and CO_2. However, there are problems in both situations, namely, in the first case, the distance and accessibility of the generators and, in the second case, the problems associated with the fact that the equipment is not static. Another common problem in both situations is the measuring and transmission of the values of the on-condition variables, because, in the case of wind farms, the machine is placed on top of the tower and, in the case of Diesel engines, the vehicles are in operation most of the time and most of the measurements need be made while the vehicles are running. Also, although the two situations seem different, they have many issues in common, such as those above-mentioned, for which we will propose convergent solutions that have an Integrated Modular System for Terology (SMIT – Sistema Modular Integrado de Terologia) as a base platform. In addition, to collect, transmit and manage data, we also propose low-cost hardware devices and open-source software, with time series, Hidden Markov Models and genetic algorithms incorporated into them, to enable the prediction of new maintenance interventions. Another important development that is mentioned, with the objective of achieving a more effective terology system, is the implementation of 3D models to aid fault diagnosis and maintenance interventions in general. All these subjects are treated in this paper in a cohesive and synergistic way in order to achieve more effective terology management with an environmental perspective.

Key-Words: - Terology; Maintenance management; Predictive maintenance; Sustainability.

1. Introduction

Terology considers the overall life cycle of equipment with particular emphasis on the functioning period and maintenance of the equipment [1].

All aspects of a piece of equipment's life cycle are important but, when the environment has to be balanced with an organisation's objectives, this means that we have to accept important challenges and, as a consequence, respond with scientific methodologies and technological devices to meet those challenges

This is the reason why this paper presents the vision of terology from two perspectives or, in other words, with two objectives, namely to achieve the reduced emission of pollutants from Diesel engines and the optimization of energy production from wind farms through more efficient maintenance. The way to achieve this is through on-condition maintenance controlling variables such as, in the case of wind generators, vibration signals and the balance of electrical currents and, in the case of Diesel engines, PM10, NO_x, CO, HC and CO_2.

The measuring and transmission of the variables' values in both cases is not easy, because, in the case of wind farms, the machine is placed on the top of the tower and, in Diesel engines, the vehicles are in operation most of the time and most of the measurements need to be made while the vehicles are running. The two situations seem so different but they have many issues in common (for example, those above-mentioned) and for which this paper proposes convergent solutions that, at this moment, have as a base platform the Information Modular System for Terology (SMIT). Also, in the near future, this will include devices presented here, based on low-cost hardware devices and open-source software, with time series, Hidden Markov Models and genetic algorithms incorporated in order to enable the prediction of new maintenance interventions. Finally, the implementation of 3D models for both situations will aid fault diagnosis and maintenance interventions in general.

2. The new paradigm of Electricity Power Systems

The industrialised world has hitherto satisfied the demand for electrical energy by developing technologies to generate electricity, mainly using non-renewable energy supplies, such as coal or nuclear power. These environmentally hazardous generation technologies continue to be the backbone of the electricity generation system. The need to harness renewable energy supplies is apparent as the world population increases and as each individual presses for a higher standard of living in terms of material goods, especially in rural and developing regions [2].

Energy supply in Europe has been dominated by the large-scale centralized combustion of fossil fuels (coal, oil and gas), nuclear power and hydro power, with energy delivered over long distances to consumers. Concerning sustainable development in Europe, this traditional economy of scale presents some drawbacks.

Fig. 1 and Fig. 2 [3] show the old and new paradigms of the structure of modern power systems. Most projections indicate that fossil fuels will continue to dominate the world's energy mix for decades to come, with an overall rising demand for these fuels and, in result, with carbon emissions boosting accordingly.

International Energy Agency (IEA)[4] projections assume moderate growth in the use of renewable energy technologies. However, since non-hydro renewable energy accounted for only two percent of world electricity production in 2004, fossil-fuel consumption and global carbon emissions will continue to grow strongly until 2030. Indeed, current forecasts suggest that a continuation of business-as-usual trends will produce a roughly 55-percent increase in carbon dioxide emissions over the next two decades.

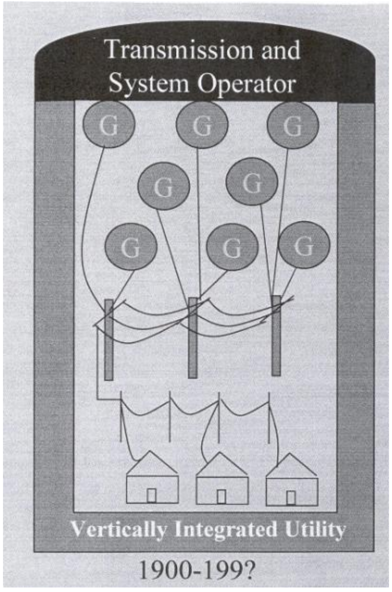

Fig 1 - The old paradigm of the structure of the modern power systems

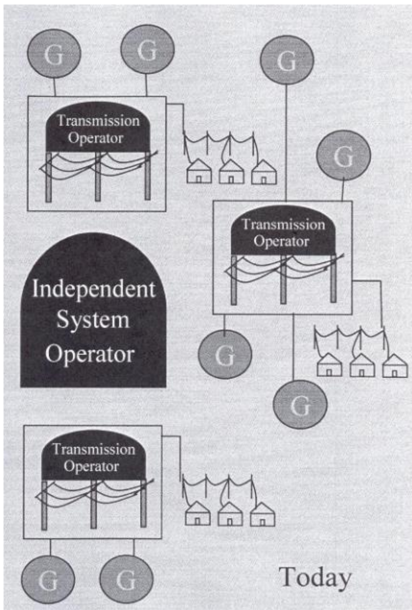

Fig 2 - The new paradigm of the structure of the modern power systems

The implications of these projections, from a climate perspective alone, are sobering. Limiting global warming to a change of 2–3 degrees Celsius will require stabilizing atmospheric concentrations of greenhouse gases somewhere in the range of 450-550 parts per million in carbon dioxide equivalent terms. Based on numerous scenarios developed by the IPCC (Intergovernmental Panel on Climate Change), achieving stabilization within this range could require absolute reductions in global emissions of as much as 30-85 percent compared to 2000 levels by mid-century. Today, we are conscious that we need to change the world's current energy trajectory through the accelerated deployment of more efficient technologies and sustainable, low-carbon energy sources.

However, the consequences of current trends are also troubling, from an energy security perspective, given the longer-term outlook for conventional oil supplies and given the energy expenditures and environmental impacts they imply, for countries struggling to meet basic social and economic-development needs. Recent forecasts suggest that a continuation of business-as-usual trends will produce a nearly 40-percent increase in world oil consumption by 2030, at a time when many experts predict that production of readily accessible, relatively cheap conventional oil will be rapidly approaching (or may have already reached) its peak. Moreover, although IEA reference case projections anticipate a substantial increase in energy consumption by developing countries, they assume only modest progress over the next several decades towards reducing the large energy inequalities that now characterise different parts of the world. This is perhaps not surprising insofar as the IEA projections are based on extrapolating past trends into the future; as such, they do not take into account the possibility that developing countries might follow a different trajectory from that followed by industrialised countries.

On the one hand, a significant proportion of Europe's generating installations, both coal and nuclear fuel, are reaching the end of their useful lives and the network infrastructure is also old, requiring ready now investments in the transmission and distribution systems.

Renewable energy replaces conventional fuels in four distinct sectors: power generation; hot water; space heating; transport fuels and rural (off-grid) energy. In power generation, renewable energy supplies about 3.4 percent of global electricity production (excluding large hydro-power projects).

On the other hand, the continuously increasing demand for energy, in particular for electricity, has highlighted a number of shortcomings:

- high level of dependency on imported fuels leading to potential rising prices and potential supply disruptions;
- large environmental impact through greenhouse gases and other pollutants;
- increased transmission losses;
- the continual upgrading of transmission and distribution systems.

These problems require an increase in efficiency, both of green energy production and, in its corresponding maintenance.

3. Wind farms – on-condition data technology

The efficient maintenance of wind generators is a huge step towards ensuring high levels of performance during the production of electricity. The methodology here adopted uses on-condition maintenance feeding on online data coming from the wind generators. The system developed to perform the data collection with high-performance and low-cost hardware is shown in Fig.3 [5].

The data acquisition uses a microprocessor and a communication interface with a CAN network. The benefit of CAN is that it enables the interconnection of more than two pieces of equipment on the same bus and is suitable for real-time operation; this network has shared bandwidth.

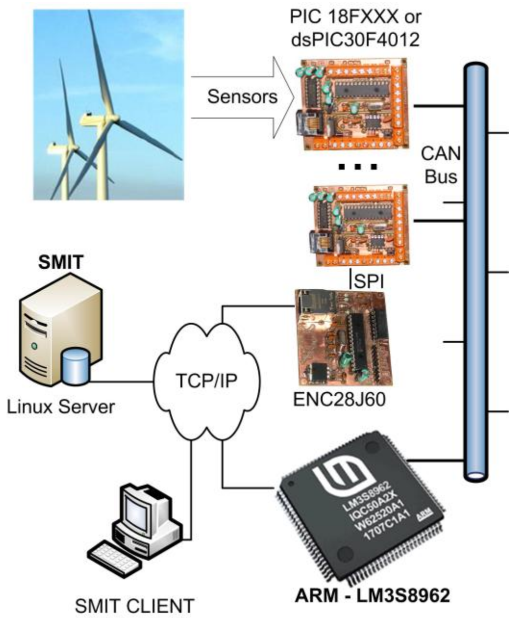

Fig. 3 - A low-cost wind hardware maintenance system

The monitored signals do not need a large bandwidth, as they are acquired at regular intervals with large amplitude, for example, one second, five seconds or more than five seconds. In a situation of higher demand, the system can be duplicated to ensure the bandwidth needs. In the present implementation, the CAN bus can run from 250 Kbits/s to a rate of 1Mbit/s.

For low-cost instrumentation, the prototype hardware developed includes:

- a board based on the ENC28J60 [6]. The ENC28J60 implements the physical interface to Ethernet allowing any micro-controller to use TCP/IP communications. The connection from MCU to ENC28J60 is performed by SPI. The Ethernet speed is 10 MHz half-duplex;
- an acquisition board based on the PIC 18F2685 [6]. This MCU allows the acquisition of 10bits/channel, at a speed of 100 kHz. It also includes a CAN 2.B controller with a maximum speed of 1 Mbps. The MCU frequency clock runs at 40 MHz. Programming is done in C using C18 from Microchip;
- an acquisition board for high speed has also been developed, being powered by the dsPIC30F4012 [6]. This MCU includes SPI, and CAN 2.B, with 10bits acquisition at a speed of 1Mbps, and the possibility of performing the synchronous acquisition of four channels. The CAN operates at a maximum speed of 1 Mbps. The MCU frequency clock runs at 40 MHz. The programming is done in MPLAB C30;
- a board using Microchip digital potentiometers [6], which implements a Butterworth low pass filter of 4th order with cut-off frequency set between 100Hz and 50 kHz. The board also incorporates two cascade amplifiers with gain ranges from 0.1 to 10. The frequency and gains are programmed by software using the SPI interface from digital potentiometers MCP42100, MCP608 and operational amplifier LM358;
- a board based on the micro-controller Luminary LM3S8962 [7], which implements an ARM Cortex-M3 with support for Ethernet packet time stamping. This processor includes two interfaces: Ethernet at 10/100 MHz full/half-duplex; and CAN 2.B with a maximum speed of 1Mbps (it will operate as a gateway Ethernet-CAN). The LM3S8962 frequency clock is 50 MHz. Programming is done in C using open source GNU GCC ToolChain for ARM Cortex-M3, with gcc-4.3.3, Binutils 2.19.1, and newlib-1.17.0 under Linux or Cygwin.

One of the biggest challenges of this apparatus is connected with the problem of synchronising the time of data acquisition between different pieces of equipment and, in the last-mentioned example, by different wind generators. Thus, it is important that the same type of sensor information is acquired simultaneously, with a very low deviation time.

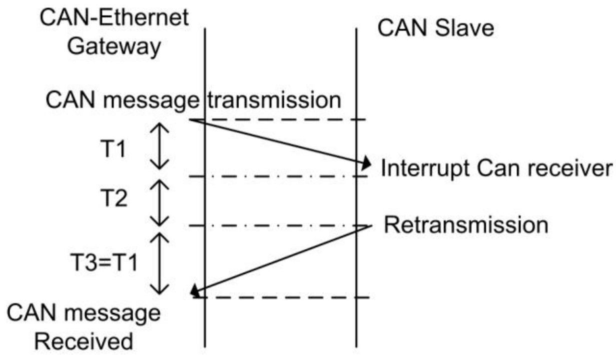

Fig. 4 - Measuring the delay in CAN bus transmission media

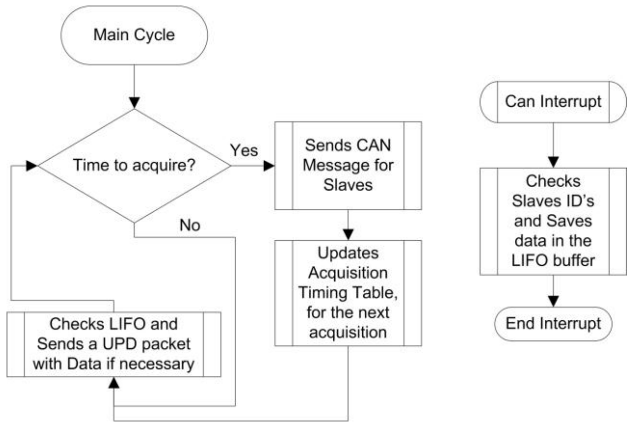

Fig. 5 – Ethernet Normal operation - CAN gateways

To solve this problem, a local clock is maintained and synchronised with the SMIT Linux Server master clock through SNTP [8] in the case of PICs, and through PTP [9] in the case of the ARM. The use of different protocols is justified by the Ethernet packet time stamping facility of the Luminary micro-controller, which is fully explored by the PTP.

For the acquisition through synchronisation in the CAN bus, the master board (PIC18F+ENC28J60 or LM3S8962) with Ethernet and CAN connectivity sends a special CAN message demanding a data acquisition cycle (the message ID pronounces which slave(s) should acquire data, Fig 5). Using this technique, a deviation of 10 microseconds is achieved in different boards.

In the set-up stage of this firmware, the gateway receives from the SMIT server the configuration: acquisition; timings/periods; and CAN set-up parameters. The CAN slaves, while in set-up mode, will try to communicate at 125 kHz, 250 kHz, 500kHz and 1MHz and will stay in this set-up mode until a valid CAN message is received. After this stage they will start the normal cycle, waiting for a message asking for an acquisition. While they rest for the acquisition, the packets can be forwarded for measuring CAN propagation delay time, or they can receive messages for firmware upload (just the slaves based on PIC micro-controllers). The method to measure the delay propagation in the CAN bus is similar to the one used in precision time protocol (see Fig. 4). A packet is sent by the LM3S8962/PIC gateway and retransmitted only by one slave. The transmission propagation delay is measured by dividing the time used by two slaves. Special care is taken in measuring this time while using CAN message with data from one to eight bytes and the results are saved in a table (different data-size CAN messages take different times to travel in the CAN bus). The CAN acquisition message sent by the gateway to ask slaves to acquire should be sent at (Fig. 4):

$$t = time_{requested} - \frac{T_1 + T_2 + T_3}{2} = T,$$

with $T_1 \approx T_3 = T$ and $T_2 \approx 0$.

For more details on SMIT architecture, see [10].

4. Diesel engines

Another problem related to the environment and for which a solution can be reached through low-cost hardware and open-source software is the pollution emitted by Diesel engines. The methodology adopted is also based on on-condition maintenance and is currently being validated on a bus fleet. The system state evaluation is done through the degradation evolution variables that provide data for on-condition maintenance planning [11].

Data on these vehicles' engines currently has to be sent to a service centre and/or a maintenance centre. Other alternatives exist for how this may be done. One option is to use an on-board CBM system in each bus. In this case, the vehicle is managed as a machine and the diagnosis analysis is performed on board; only refined information of the condition is taken from the vehicle. Another way is to collect real-time data in the vehicle and to let the diagnosis analysis be done in a maintenance centre. This means that a large amount of data must be transmitted to a central database. This transmission could use either the GSM technique through TCP/IP networks or other wireless protocols for short distances (Bluetooth, infrared, etc.), starting from the pollutant measure locations.

To predict interventions, reference values are used, such as the ones in table 1, which refer to vehicles equipped with compression ignition engines (Diesel). These correspond to extracts from tables from the MOBILE model with respect to model year classes between 1994 and the present date. The differences are shown as changes in the "zero mile" emissions.

Pollutant	Zero km Level (g/bkW.h)	Deterioration (g/bkW.h/10000 kms)
Hydrocarbons (HC)	0,30	0,00084483
Carbon Monoxide (CO)	1,45	0,003379321
Nitrogen Oxides (NOx) 1994-1997	6,27	0,002534491
Nitrogen Oxides (NOx) 1998-2003	5,00	0,002534491
Nitrogen Oxides (NOx) 2004 …	2,50	0,002534491
Particulate Matter (PM)	0,10	0,003379321

Table 1 - Adapted from Bus Diesel Engine Emissions Rates Used in Mobile 6

According to Directive number 72/306/CEE and later regulation, relative to subsequent approvals dated by October 2000, for Euro III, the concentration level should not exceed the absorption coefficient limit value of 0,8 m^{-1} [11].

The model to control and to predict planned interventions, with the objective of respecting the above referred limits or even lower, takes information coming from the monitored components, sub-systems or systems and from emission-measuring equipment. To process these data it is necessary to have software capable of handling complex (non-linear) relations and to detect operation-deviating trends. This is possible through a technique supported by Artificial Intelligence (AI), which has been developed over a few decades. Hidden Markov Model (HMM), Neural Networks [12], Watchdog Agent [13], Fuzzy Logics, Case-Based Reasoning and Expert Systems, to mention a few, are methods able to contribute to this type of application.

In the case under consideration, the model implemented to predict the next on-condition intervention uses HMM, and has proven to be adequate.

5. 3D models

The development of 3D models may give rise to a new and more flexible way to view the facilities and equipments (Maintenance Objects – MOs) in advance and, when used in the maintenance field, it will offer new opportunities for fault diagnosis, maintenance planning, upgrading and also training.

The downside of this is related to the complexity of virtual models of complex MOs and the time required for their development, unless it is possible to have many people simultaneously developing the MO under the same platform.

This is what is being implemented to aid the projects described below and when the development model has been fully implemented, it will be adaptable for all types of MO.

The difficulty in implementing the development model is guaranteeing connectivity through the web for a large number of users, because it is still not possible, in terms of space or in terms of costs, to have that many users/developers working simultaneously online.

The solution is to implement an online system that runs through communities that are working towards the same goal. Online collaboration allows the participation of any individual in a development platform for virtual machines, regardless of their geographical location. The implementation of a platform for 3D interaction in which various professionals can contribute to the virtual construction of this equipment is a key enabler of the construction of these environments [14].

The main objective of this model is to aid terology, it is not only an exercise in informatics itself. In addition, with the appearance of GoogleWave, it is anticipated that this step in model development may be bypassed, because this tool as the potential to allow for a very large number of users to contribute online to the final MO 3D model. But GoogleWave is not a 3D program, and this is where Blender Foundation makes an entrance.

Blender is an open-source software, in accordance with the approach adopted in the other projects.

This approach also raises other issues, such as the aspect of moderation in collaborative interaction and technological issues of virtual environments. The Internet is the key to achieve this end, as it is a way to get the collaborative development to the public, based on rules of collaborative participation.

3D models developed with this software will be indexed to the database SQL (Structured Query Language) of SMIT which currently operates on a Linux server with the following features:

- a PostgreSQL Database;
- a server pages, fax and email;
- a server TCP / IP for receiving data acquired by different data acquisition systems;
- an NTP (Network Time Protocol) Server;
- an SNMP (Simple Network Management Protocol) Server.

6. Integrating technology around Terology

Figure 6 shows a real configuration for integrating several terology pieces. The main characteristics of this design are its simplicity, its user-friendliness, and the low cost of the whole system, as it can be observed. The central system is based on a Linux Server running an apache web server and a PostgreSQL database [15]. The entire system is available through IPv4 connectivity from the acquisition system level to the Linux Server and SMIT clients. Data acquisition can be done not only by using special low-cost hardware, but also by high performance acquisition systems like National acquisition hardware using LabView (connections to SMIT server are also obtainable by IPv4 connectivity), and Ethernet PLCs. Also available on the SMIT Server are a Fax server (Hylafax), and a TCP/IP server for reception of data acquired from different acquisition hardware, using UDP packets with acknowledgement [1], Fig. 6.

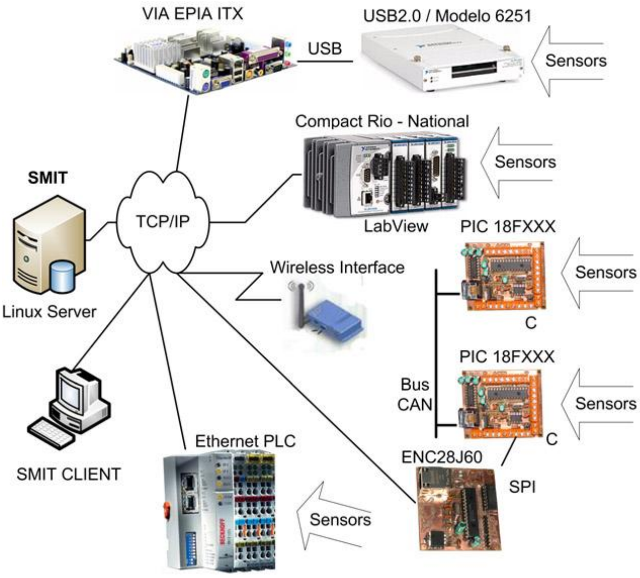

Fig. 6 - An integrated system for terology with online data reading

Today, SMIT has, or is beginning to have, new additions, such as:

- wireless communication with IP devices to receive measurements from any MO, like Wind Generators, Diesel engines, or any others;
- on-condition modules to predict planned interventions based on variables that are regularly measured remotely, by physical connection or manually.

7. Conclusion

The main objectives of all the developments in this paper are related to terology, with the objective to preview an environmentally sustainable planet.

All the developments are supported by the information system named SMIT. The new hardware and software solutions require complex integration and communication among the several pieces of these complex technological devices.

All the developments presented in the paper were performed taking into account two validation fields, wind farms and Diesel engines. The combination of low-cost hardware, open-source software and time series and genetic algorithms gives a complete approach not only in these fields but also in many others. In any situation where distance or the requirement of online and on-condition maintenance of an equipment can engender difficulties in establishing connections to a fixed installation, the developments presented can be used to solve these types of problems trough TCP/IP protocol. Again, these solutions are based on low-cost hardware and open-source software.

Also, 3D collaborative manipulation can be supported by these tools and may open a new door for the future of fault diagnosis, maintenance planning and also for training, with lower direct and indirect costs.

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