Predictive Maintenance System for Thermal Generator Units

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Abstract

The operating condition of generator affects the reliability of the power supply and system stability. For this reason, maintenance processes are increasingly employed in order to prevent faults. One of the technologies that can be employed within that purpose to predict failures is electrical signature analysis, which consists of a set of methods and techniques that monitor the condition of electrical machines through the identification of patterns and deviations detected by processing and analysis of voltage and current signals. This paper presents a system for monitoring of these faults in turbo-generators. This system is currently installed in a 404 MW TermoNorte Power Plant, in Brazil.

Keywords

Predictive maintenance, Failure detection, Digital Signal Processing, Turbo-generators, Measurements, Electric signature analysis

I. Introduction

The generating capacity of electric power systems represents a crucial point in the operation of the system. The economic implications of this operation are enormous and to guarantee that the component responsible for such an operation, the turbo-generator, operate correctly must be sought at any cost. What typically occurs is that the time of continuous work of the generators feeding electrical loads, submits this equipment the stresses that can cause failures and loss of their generating capacity, resulting in uncertainty about its real nominal capacity. Therefore, a careful and rigorous assessment of this operational capacity reduction produces, of course, a substantial increase in the reliability of the equipment, a visible reduction of costs with regard to the correct treatment involving preventive properly executed and the possibility to avoid unscheduled stops such equipment [1].

In order to avoid these unscheduled stops in the operation of the turbo-generators due to unscheduled contingencies, a series of maintenance procedures was developed over the last forty years. Initially, only the procedures involving a corrective maintenance were used. That is, if the equipment had failed, began a repair procedure involving, of course, interruption in the availability of the equipment in question. With the passage of time and the accumulation of knowledge involving the operation of the generating equipment, were developed preventive maintenance procedures that trigger the process of maintenance before the crash happen, based on the history of each equipment. Although this procedure produces a satisfactory outcome with regard to the reduction of the unscheduled stops, he implies, sometimes in unnecessary pre-programmed maintenance, because equipment which suffered the intervention is in perfect working order, even though it has been running for a number of hours that the average for the same type of equipment would be indicating the proximity of a failure. Recently with the advancement of digital acquisition systems and signal processing, another maintenance strategy was developed [2].

This technique, called predictive maintenance, aims to develop a diagnostic process of equipment under supervision, so that the indication for a maintenance intervention only occurs when the operating state of the equipment comes to present an important deterioration condition. At this time, the system must report to the level of deterioration of the equipment and to have a prediction of how long it can continue to function without widespread interruption happen. This strategy of maintenance, although much more rational, implies sophisticated management systems of the variables involved in the operation of the equipment in question, which was done in this project.

This paper presents the development and supervision equipment predictive diagnosis of degradation of TermoNorte's turbo-generators. TermoNorte power plant is located in the State of Rondonia, in the north of Brazil, closed to Amazon jungle.

II. Basic Concept of the Electrical Signature Analysis

Electrical Signature Analysis (ESA) is the nomenclature to define a set of techniques which produce evaluations about electrical machines based on current and voltage signals. The main idea behind the ESA techniques is each electrical machine has its own electrical signature which can be obtained by current and voltage signals. This electrical signature is the identity of the machine and represents its actual stage, i.e., its "health" conditions at this time.

There is another important believe in ESA techniques. When the machine health changes the values of the current and voltage signals also change consistently. And then, it is possible to infer the health of the machine by a correct interpretation of the electrical signals. In other words, the electrical signature of the machines changes each time its health condition changes.

There is different types of ESA techniques [3] available in the literature; however, in this project, we have used three of them, named: Current Signature Analysis (CSA), Voltage Signature Analysis (VSA), and Extended Park Vector Analysis (EPVA). Basically, the idea is to detect problems in the machines by the comparison of signals (signatures) obtained in different times.

The literature shows these techniques have been extensively used in industrial electrical motors [4] and they can detect electrical problems in the motors, but, also and mainly, mechanical problems in the motor, in the coupling between motor and load, and problems in the load. It occurs because the motor acts as a transducer for the problems. When a mechanical problem happens (in the motor, coupling or load), an electromagnetic imbalance also happens inside of the motor and it can be acquired in the electrical signals.

It is quite easy to explain; however to detect and interpret the problems into the electrical signals is a very hard mission; because many times the changes in the electrical signals have the same level (intensity) of instrumentation noises. In order to solve that, it is important two aspects. The first one is to have powerful digital signal processing techniques and the second one is to have practical experience to correlate signal and problem.

If this type of difficulties occur in industrial motors, where these techniques have been already used we can expected a major degree of difficulty to apply these techniques in power generators where the literature presents few references [5]. This is the case of this project presented in this paper.

In the following subsections, the theoretical basis to apply all three techniques used in the system implemented at TermoNorte Power Plant will be presented.

A. CSA and VSA Techniques

CSA and VSA techniques are presented together in this section because they receive the same mathematical treatment; nevertheless they seek different elements in their signals.

Current and voltage signals are collected and saved in the time domain. However, it is quite impossible to observe machine problems in these signals. For this reason, these signals are submitted to a Fast Fourier Transformer (FFT) in order to change from the time domain to the frequency domain, where it is better to observe changes into the signals [6]. Figure 1 shows how the shapes of the signals are changed.

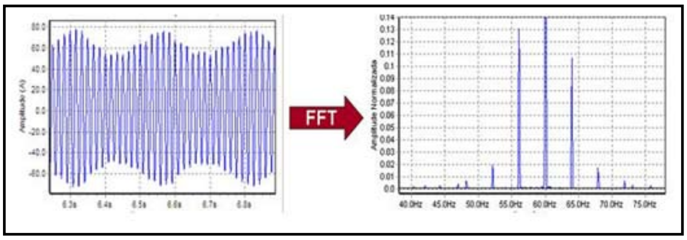

Fig. 1: Signal domain transformation from time to frequency

It is possible to verify by Figure 1 different frequencies, someone with the predominant aspects (in terms of amplitude) and others not so much. However, all frequencies are important because together they compose the electrical signature of the machine set (i.e., generator, coupling and turbine).

The main idea behind these techniques is in the first place to have a constant acquisition of signals from the machine set and produce a comparison between signals trying detecting changes in amplitude of the existing frequencies or appearance of new frequencies. After that, to produce a correlation between these amplitudes changes and/or new frequencies with a specific failure in the machine set. The produced system has also a set of alarms to produce alerts when some amplitude reaches a pre-set value or a new frequency appears.

B. EPVA Technique

EPVA technique has been used in industrial motors to detect imbalances in the motor stator. In this project, EPVA has been used to detect any type of imbalance produced in the machine set. EPVA technique checks imbalances by distortion of the Park's circle which is obtained by a transformation of the actual three-phase currents into two currents, named direct current (iD) and quadrature current (iQ), by the following transformation:

$$i_D = \left(\frac{\sqrt{2}}{\sqrt{3}}\right) i_A - \left(\frac{1}{\sqrt{6}}\right) i_B - \left(\frac{1}{\sqrt{6}}\right) i_C$$
$$i_Q = \left(\frac{1}{\sqrt{2}}\right) i_B - \left(\frac{1}{\sqrt{2}}\right) i_C \qquad (1)$$

Where i_A, i_B and i_C are the phase currents.

When there is no imbalance in the system the current are equilibrated and the Park's circle is a perfect circle. However, when any type of imbalance appears the phase currents also are not more equilibrated and the Park's circle becomes an imperfect circle, as shown in Figure 2.

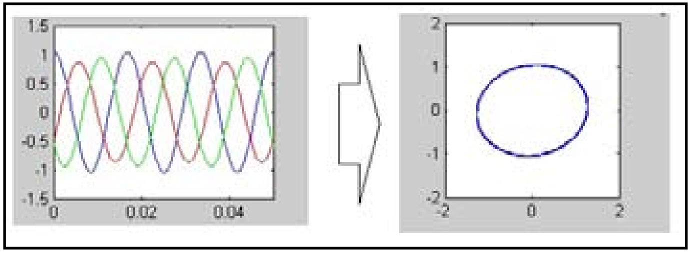

Fig. 2: Transformation of three-phase currents to a Park's circle

The imperfections in the Park's circle is clearly observed; however to analyse them is hard [7]. For this reason, EPVA technique proposes an addition in the Park technique. It is calculated the square of the Park's currents and then applied a FFT in this signal. In this case, it is possible to obtain a set of frequencies and the origin of the imbalance in the machine set. An example is shown below.

Let be the following currents for each phase of the generator, which represents the imbalanced currents shown in Figure 2:

$$i_A = i_d \cos(\omega t - \alpha_d) + i_i \cos(\omega t - \beta_i)$$
$$i_B = i_d \cos\left(\omega t - \alpha_d - \frac{2\pi}{3}\right) + i_i \cos\left(\omega t - \beta_i + \frac{2\pi}{3}\right) \qquad (2)$$
$$i_C = i_d \cos\left(\omega t - \alpha_d + \frac{2\pi}{3}\right) + i_i \cos\left(\omega t - \beta_i - \frac{2\pi}{3}\right)$$

Where: id is the maximum value of the direct sequence current; ii is the maximum value of the inverse sequence current; αd is the initial phase angle of the direct sequence current; and βi is the initial phase angle of the inverse sequence current in rad.

Computing the Park's current, the following currents are obtained:

$$i_D = \left(\frac{\sqrt{3}}{\sqrt{2}}\right)\left(i_d \cos(\omega t - \alpha_d) + i_i \cos(\omega t - \beta_i)\right)$$
$$i_Q = \left(\frac{\sqrt{3}}{\sqrt{2}}\right)\left(i_d sen(\omega t - \alpha_d) - i_i sen(\omega t - \beta_i)\right) \qquad (3)$$

Then the square of the Park's current is given by:

$$\left|i_D + j_Q\right|^2 = \left(\frac{3}{2}\right)\left(i_d^2 + i_i^2\right) + 3 i_d i_i \cos(2\omega t - \alpha_d - \beta_i) \qquad (4)$$

Now, simply apply the FFT in squared Park vector module and observe that it is composed of a DC level plus one additional term located at twice the frequency. It is exactly this additional term that indicates the emergence and aggravation of electrical stator asymmetries, as shown in Figure 3.

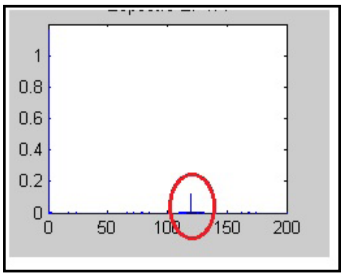

Fig. 3: Frequency due to the imbalance of the stator current shown in Fig. 2

The advantage of the EPVA technique lies in the fact the same combine the simplicity of the previous technique (analysis of the circle Park) with the potentiality of the spectral analysis. In addition, the fundamental component of the power generator is automatically subtracted from the spectrum by the transformation of Park, causing the components of fault features appear prominently. The most important point is the fact of considering the three phases of current (or voltage), generating a more significant spectrum by to encompass information from all three phases. This feature is extremely useful in cases where failure can only be detected if considered the three phases.

III. Patterns of failures

As told before, the main problem is detecting machine set failures observing the frequencies only. However, there is a set of typical patterns which can be searched in the spectrum of frequencies. These typical patterns are signals which are related to the fundamental frequency of failure. There are three main types of failure frequency to be analysed.

The first type of the failure frequency is named demodulated frequencies. If the main failure frequency is given by f_c , it is possible to appear in the spectrum integer multiples of this frequency, which can be represented by the frequencies obtained by the following equation:

$$f = k . f_c \quad (5)$$

Where f is the failure frequency in the spectrum and k is an integer positive number associated to the harmonic. Figure 4 shows this type of frequencies.

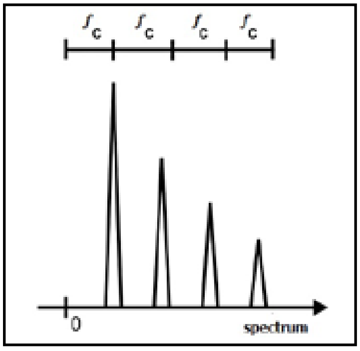

Fig. 4: Example of demodulated frequencies

The second type of the typical frequencies is named modulated frequencies. These frequencies are a composition of the previous demodulated frequency plus a modulation with the fundamental frequency of the generator *(f1)*. These frequencies are obtained by the following equation:

$$f = f1 \pm k . fc \quad (6)$$

Fig. 5 shows an example of modulated frequencies.

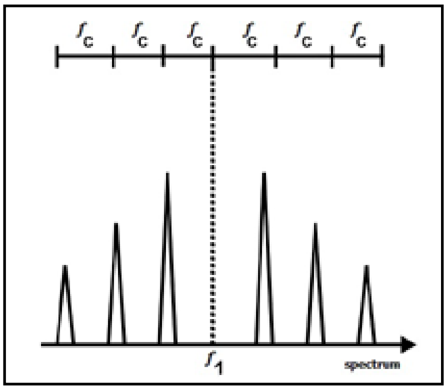

Fig. 5: Example of modulated frequencies

The third type of the typical frequencies is named modulated into the failure frequency. In this case, the modulation occurs under the failure frequency, as shown in Figure 6.

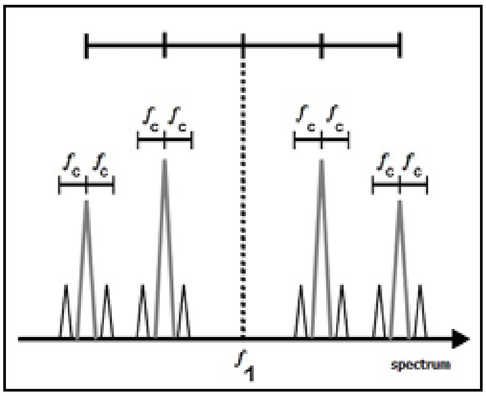

Fig. 6: Example of modulated frequencies into the failure frequency

IV. Overview of the System

This section presents some details of the predictive maintenance system installed at TermoNorte thermal power plant machine sets. This power plant contains two main units: (a) the TermoNorte I with a total capacity of 64 MW generation, held from 4 Wärtsilä Diesel motor-generators, of 16 MW each, and (b) the TermoNorte II with a capacity of 340 MW, has 3 GE gas turbines and 3 recovery boilers, without additional fuel burn.

A. Data Acquisition Modules

The system works with current and voltage signals acquired in the secondary of the Current Transformer (CT) and Potential Transformer (PT), respectively, using specific transducers developed for this system.

The system is also composed by a data acquisition centre, which the function is organize and save data, and a communication centre, responsible to produce the communication between the data acquisition system and the user console.

Fig. 7 shows the voltage transducers, the data acquisition centre, the communication centre, and the power supply of the system. The current transducers are located in the back of the closet. Figure 8 shows the data acquisition and communication centre in details.

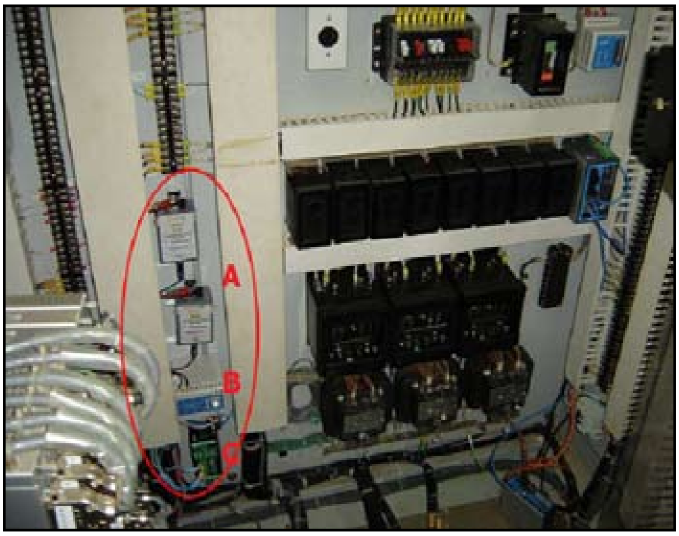

Fig. 7: Part of the system, installed in the control closet: A – potential transducers (2 units), B – data acquisition and communication centre, C – power supply

B. Computational Package

The developed computational package is composed by several routines which has among others:

a) A complete dataset of each machine set (data from the generators, as such speed, number of poles, nominal power, and nominal voltage; from the turbine, as such nominal speed, number of blades, and type of cycle; and information about the coupling and gear box);

Fig. 8: Detail of the data acquisition and communication centre

b) Data acquisition routes and control, where the user defines when the data acquisition process must be occurred in each machine set; and,

c) Analysis of data by CSA, VSA and EPVA proving a diagnostic and a tendency for each failure of the machine set.

Figure 9 shows an example of one of user screen can get the position of a data acquisition. In this case, the acquisition was made in TG1021 machine set made in February 23, 2011 (23/02/2011) at 17h 30 min 58sec (17:30:58). The next acquisition will be programmed to 30/03/2011 at 18:33:00. All inferences have been written in Portuguese (the Brazilian native language).

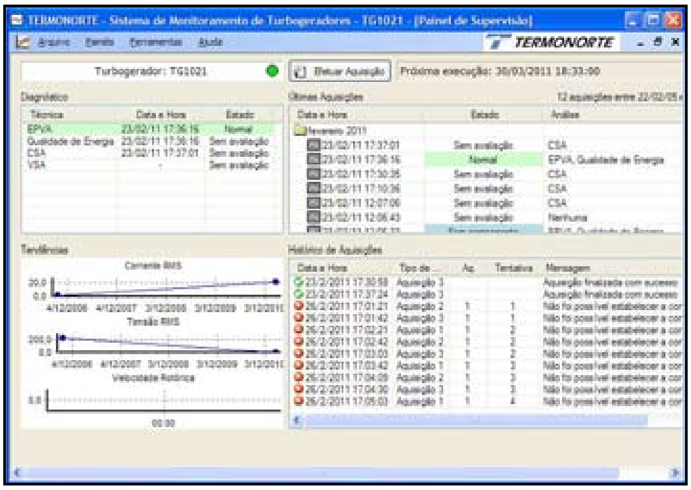

Fig. 9: User screen of data acquisition monitoring

In this case, a willful failure has been introduced in the turbo-generator. Figure 10 shows the current and voltage signals acquired by the same window the user can verify the signals without any treatment.

Figure 11 shows the one of the windows for analysis available to the user. In this case, the window made an harmonic analysis of the current.

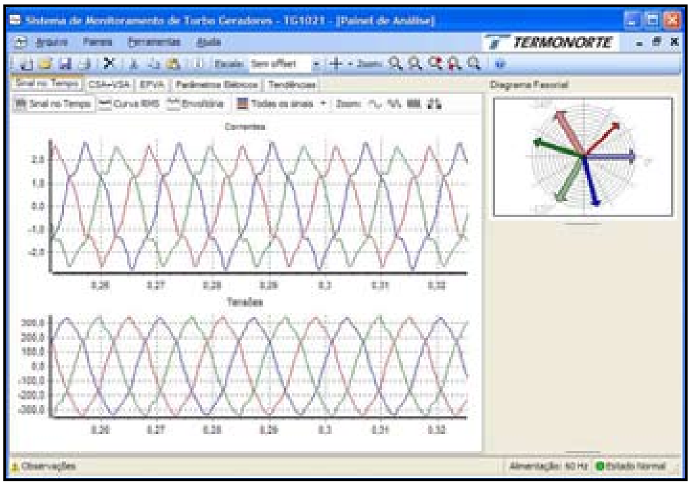

Fig. 10: Window with current and voltage signals without any treatment

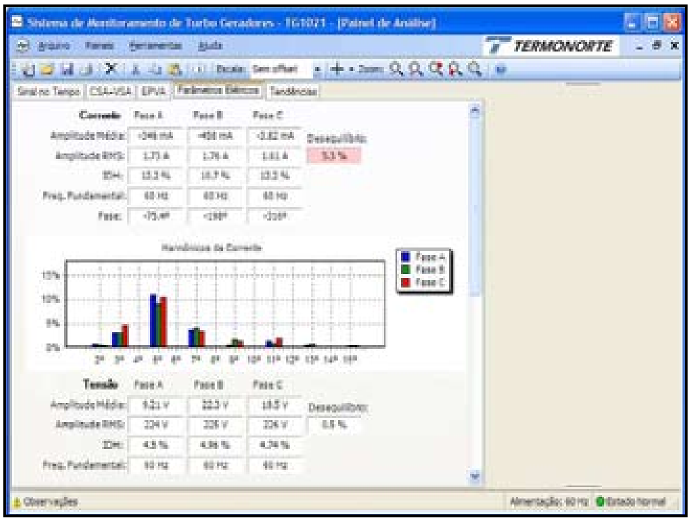

Fig. 11: Window with current harmonic analysis

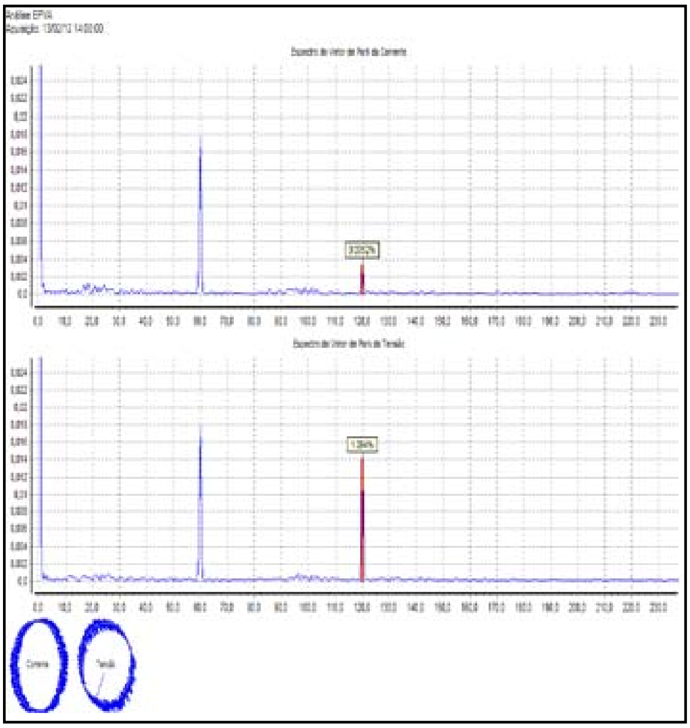

Fig. 12: Electrical imbalance by EPVA Signature

V. Practical results

This section shows an example of the practical results of the proposed system. In this example, short-circuit in a stator coil has been detected, causing an electrical imbalance. After an analysis of the EPVA technique in voltage signals shows the component of twice the fundamental frequency, as shown in Figure 12. Figure 13 shows the trend curve of electric voltage imbalance and was around 1.45% during this period of acquisition.

Fig. 13: Tendency of Electrical Imbalance by EPVA Signature

VI. Conclusions

This paper presents a system for predictive maintenance of turbo-generators. This system aims to detect early failures in the machine set. The analysis of the possible faults of turbo-generators is made via the magnitude of frequencies obtained from the voltage and current signals.

For this purpose, algorithms and structures of preprocessing, conditioning and processing of acquired signals acquisition system; formulas and calculations of extracting parameters of current and voltage signals were implemented. Then, the studies for the classification of possible failure of the turbo-generators and search algorithms and pattern identification on frequency spectrum have been developed, which serve as a basis for the analysis of patterns of equipment failure in analysis.

The system is installed and operating at the plant of TermoNorte, in Brazil.

VII. AcknowledgEment

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