An Experimental Laboratory System for Monitoring and Detection of Electrical Drives Systems with Induction Machines

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Abstract: This paper focuses on developing and testing a comprehensive monitoring and detection laboratory system, for use in electrical drives systems using Induction Machines. The article aims to provide further documentation for an advanced condition monitoring system including transducers, signal conditioning box and data acquisition device, in order to avoid undesirable operating conditions and to detect and diagnose incipient electrical faults. Also, this paper suggests the possibility of diagnosing different types of failures by means of spectral analysis of current and voltage.

Keywords: Condition monitoring, FFT, signal conditioning, signal processing.

1 Introduction

The reduction of operational and maintenance costs is continuously required of modern electrical drives systems. An important factor enabling this is to provide electrical drives with advanced condition monitoring systems and monitoring the machine during operation. This will help to avoid undesirable operating conditions and to detect incipient faults in the components, detect sensor and actuator faults [1–3].

Failure surveys have reported that percentage failure by components in induction machines is typically [3–7]: bearing related (40 %), stator related (38 %), rotor related (10 %), and others (12 %).

Many sources show that the majority of machine failures are caused by bearing faults and stator insulation breakdown. For small induction machines, the stator

winding insulation degradation is one of the major causes [2, 5, 8, 9]. Failure surveys have reported that percentage failure by components in induction machines is typically [5–7, 9]: bearing related (40 %), stator related (38 %), rotor related (10 %), and others (12 %.

During the past fifteen years there has been a substantial amount of research into the creation of new condition monitoring techniques for electrical machine drives. New methods have been developed which the operators are now using and research is continuing with the development of new and alternative on-line diagnostic techniques [3, 4, 6].

Modern measurement techniques in combination with advanced computerised data processing and acquisition [3, 6, 9] show new ways in the field of induction machines and drives monitoring by the use of spectral analysis of operational process parameters (e.g., temperature, pressure, steam flow, etc). Time-domain analysis using characteristic values to determine changes by trend setting, spectrum analysis to determine trends of frequencies, amplitude and phase relations, as well as cestrum analysis to detect periodical components of spectra are used as evaluation tools [1, 6, 8].

The objective of this paper is to develop and test a condition monitoring subsystem, for implementation in electrical drives systems using induction machines.

2   Description of the Experimental System

The electrical machine is a wound rotor induction machine (WRIM), with slip rings, rated at 11 kW. Two back-to-back PWM-VSI converters, with a DC-link including a DC - capacitor filter are used to control the rotor current, active and reactive power flow. The drive system is composed of a 15 kW squirrel cage induction motor and a 22 kVA-frequency converter, as can be seen in Figure 1. The most important com-
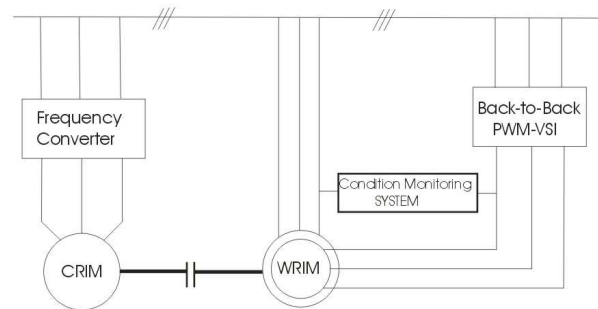

Fig. 1. Schematic diagram of the laboratory model of the electrical drives system using an induction machine.

ponent of the measurement system is a complete condition monitoring system, which comprises many subsystems like transducers, signal conditioning boxes and data acquisition devices, as can be seen in Figure 2.
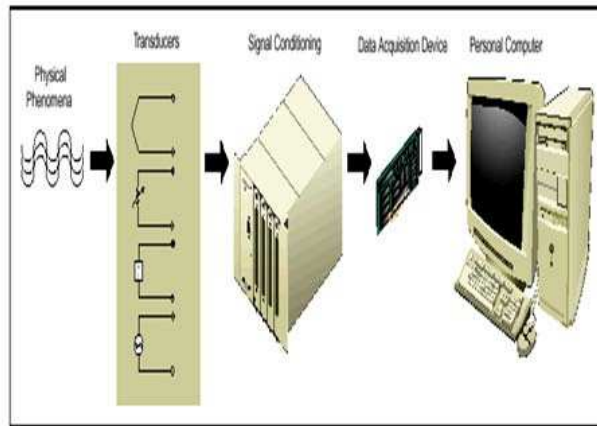
Fig. 2. Block diagram of the condition monitoring system.

2.1   The condition monitoring system

Most failures (incipient failure) give some warning of the fact that they are about to occur. This warning is called a potential failure, and is defined as an identifiable condition, which indicates that a functional failure is either about to occur, or is in the process of occurring.

The objective of condition monitoring is to provide maintenance personnel with reliable information regarding the current condition of the electrical drives system. This will enable maintenance activities to be planned on the basis of the real needs of the apparatus rather than based on an estimated safe time between services. This will keep the machinery operating in acceptable condition for the longest time for the least possible cost.

The principle of Condition Monitoring (CM) of machinery is straightforward: the goal is to identify changes in the condition of a machine that will indicate some potential failure and physical characteristics are identified that collectively indicate the current condition of the machine. Each of these characteristics is measured, analysed and recorded so that trends can be recognized.

CM is carried out for two main reasons: to detect sudden changes in condition that could lead to catastrophic failure and to identify the early onset of incipient failures so that a prediction can be made about their most likely progress and suitable actions can be planned.

A complete condition monitoring system could comprise many subsystems, each monitoring a particular part of the electrical drive system.Therefore will be a degree of overlap between the functions of the different subsystems.

This study includes the design and commissioning of a measuring system comprising the AD Card - ICS 645, signal conditioning boxes and transducers.

2.2 Transducers

Transducers are devices that convert physical phenomena, such as: temperature and speed into electrical properties, such as: voltage and current. Transducer characteristics define many of the signal conditioning requirements of a DAQ system.

The Rogowski Current Transducer-RGF 75 was selected to measure stator and rotor currents because of its merits compared to other transducers, such as: have a very wide bandwidth (10 Hz - 100 MHz), provide an isolated measurement at around ground potential, can measure large currents without saturating, accuracy typically 1 % and linearity 0.05 % full scale / 0.1 % actual reading. This type of transducers is also useful for harmonic analysis since they are linear.

The stator voltages were measured using a High Voltage Differential Probe-P5200. The P5200 provides a safe means of measuring circuits with floating potentials up to 1000 V (RMS value) from ground and up to 1300 V (DC + peak AC) differential. The P5200 probe allows clear and accurate measurements of high-speed transitions and provides an excellent common-mode rejection of noisy signals. Because of these features, the probe can safely measure the fast voltage transients in switching power devices such as testing high-voltage machine control circuits without damaging them. It is specifically designed to operate on Tektronix oscilloscopes with TEKPROBE interface.

Incremental Encoders are the most popular choice of transducers in applications where mechanical motion must be processed into digital information. Compared with alternate technologies (such as: resolvers, tachometers, etc.), optical encoders represent the best combination of accuracy, resolution, reliability, ruggedness, ease of use, value and variety of solutions in the industry. The rotor speed was measured using a shaft incremental encoder-Scancon 2R, which provides 9000 pulses/revolution. The SCANCON 2R is a shaft incremental encoder type with low current consumption, short circuit protection (thermal shut down at $155°C$) and wide supply range - min. 4.5 V to 30 V.

Thermocouples are a popular temperature sensor. Any two dissimilar metals may be used to make a thermocouple. Type K (Chromel-Alumel) is a general-purpose thermocouple with Fe as a positive material and Cu / Ni as a negative one. It is low cost and, owing to its popularity, it is available in a wide variety of probes. This type of thermocouple offers a $-200°C$ to $+1000°C$ ranges. Sensitivity is approx 41 μV/C The stator winding temperatures were measured by inserting 12 thermocouples-Types K in various winding slots, corresponding to each pole and phase of the wound-rotor induction machine.

2.3 The signal conditioning

Signal Conditioning (SC) provides the interface between the signals / sensors and the measurement system. It improves the performance and reliability of the measurement system with a variety of functions, including: signal amplification, attenuation, isolation, filtering, multiplexing, linearization, sensor conditioning, offsetting and noise reduction.

In our set up it was imperative to adapt the signals from transducers as the DAQ - ICS 645 accepts the input signals with peak amplitudes of 1.03 V with an input impedance of 500 Ohms. For example, thermocouples produce very low voltage signals, which required amplification, filtering and linearization. Voltage signals, acquired by high voltage differential probes, required attenuation of the signal while the voltage signals obtained from Rogowski coils required filtering and offsetting of the signal, as shown in Figure 3.
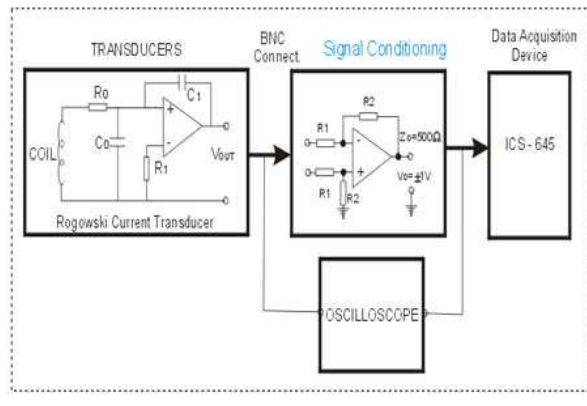

Fig. 3. Single channel block diagram of current transducers conditioning.

The output signals from incremental encoder must be converted, using a frequency to voltage converter, and then filtered and offsetted. All of these preparation technologies are forms of Signal Conditioning.

In Figure 4 is shown the current signal conditioning box test using Tektronix Oscilloscope - TDS 540.

The input of current signal conditioning box is configured on channel 1 and the output of current signal conditioning box is on channel 2. Sometimes, there is a small difference between input and output of the current signal-conditioning box, because the amplifier boosts the level of the input signal to better match of the range of the ADC, thus increasing the resolution and sensitivity of the measurement.

2.4   The data acquisition device

The DAQ ICS-645 is designed for high frequency, high precision, high-density data acquisition and high-speed test and measurement applications. It combines the ultimate in analog and digital technologies to provide up to 16 channels and sample rates of up to 5 MHz/channel.

The AD Card - ICS 645 is able to convert 16 channels simultaneously at up to 5 MHz sampling frequency, and with 16 bit conversion. Based on a new generation of ADC chip that combines Sigma-Delta and flash converter technologies, the ICS-645 offers an exceptional dynamic range over a wide bandwidth. Also, the over-sampling ratio can be selected depending on the input signal bandwidth. Over-sampling, digital
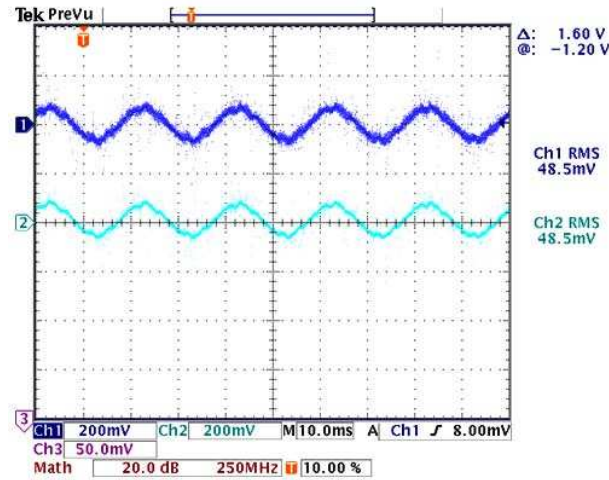
Fig. 4. IN and OUT of the current SC box acquired by Tektronix - TDS 540.
Scaling factor of the stator currents is 4 mV/A.

filtering and decimation inherent in the ADC device eliminate the need for a higher
order anti-aliasing filter.

2.5 Signal processing

It must be decided what to measure, and how to monitor these properties.

Measured results must be scaled, converted to digital form and stored, using data
acquisition module (AD card). It will be necessary to make many series of measure-
ments and record them for later analysis.

The data will firstly be processed to synthesis suitable indicators such as: current,
voltage, active power, reactive power, flux, impedance etc.

The next step would be to process the measurement results based on a model
of the monitored system, to construct a signal containing the required information.
The indicators could be resolved into spectra, showing the frequency content of the
indicators.

In order to detect the non-stationary components a signal processing techniques,
which can monitor a multi component signals, is required.

PC-based data acquisition (DAQ) systems are used in a very wide range of appli-
cations in the laboratory and on the manufacturing plant floor.

The ICS - 645 MATLAB Application Software is designed as a starting point
from which a user can build application - specific software.

All recorded data were processed using MATLAB to plot the currents and voltage
spectra and then to perform the FFT analysis. For each variable, 2^16 values were
recorded, with the sampling frequency of 2.5 MHz and with the amount of data points
of 65 536.

The monitoring system that has been developed consists of three main sub-systems. These include: signal conditioning, data acquisition and data analysis, as can be seen in Figure 5. Data acquisition and data analysis sections are accessed by MATLAB software package run from a PC. The controlling software allows the operator of the system to store the data in data files for future processing.
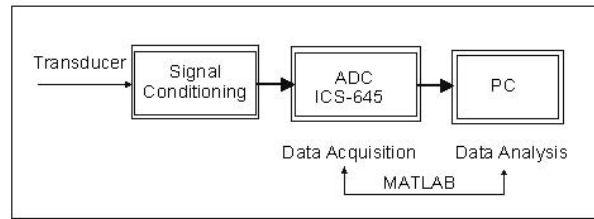
Fig. 5. Single channel acquisition system

Figure 5 shows a diagram of a single channel of hardware required to obtain the indicators for analysis purposes.

The data will first be processed to synthesise suitable indicators. The indicators will then be resolved into spectra, showing the frequency content of the parameters, such as: stator currents, rotor currents and stator voltages [1–3].

3   Experimental Results

The measurements were acquired by a Tektronix Oscilloscope-TDS 540 (Figure 6) and by the DAQ device - ICS 645 (Figure 7) via MATLAB software.

The WRIM was operating, during the measurements, at a rotor speed of 1475 rpm (sub-synchronous speed mode) corresponding to a stator active power of 2 kW (20 % of nominal power).

The pictures in Figures 6 and 7 show the stator current, stator voltage and power of the induction machine in steady-state corresponding to a load of 20 %.

Time-domain analysis using characteristic values to determine changes by trend setting and for extracting the amplitude information from current signals has been used in this section as first evaluation tool.

The acquisition of data by Oscilloscope was done to comparison with AD Card acquisition and to verify the accuracy and sensitivity of signal conditioning box.

4   Spectrum Analysis of the Indicators

The early detection of various fault mechanisms could prevent catastrophic failure from occurring and would also allow for carefully planned repair actions [1, 2, 4, 5, 9, 10]. To achieve this goal, on-line or off-line strategies that measure current and voltage may be utilized.

For Condition Monitoring, Fourier analysis (FFT) has been employed using the coefficients of the current spectrum or the power spectrum as an indication of how the
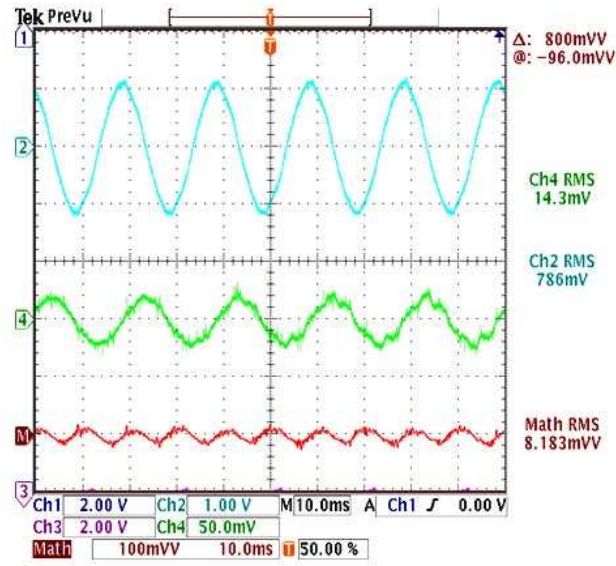
Fig. 6. The stator voltage, stator current and instantaneous power of WRIM in steady-state, acquired by an Oscilloscope. CH2: Stator Voltage (2mV/V), CH4- Stator Current (4 mV/A) and M: Stator power (6 mV/A).
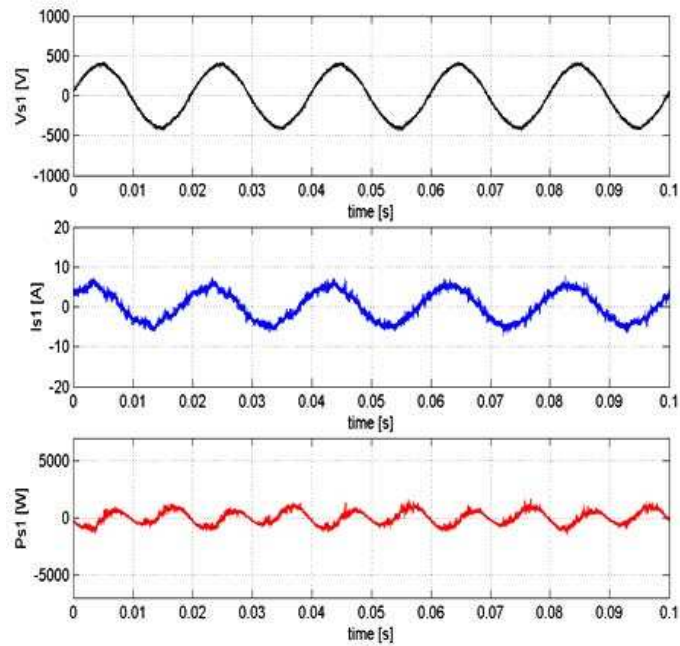

Fig. 7. The stator voltage, stator current and instantaneous power of IM in steady-state, acquired by the DAQ card ICS-645 via MATLAB.

harmonic content of a signal varies, as can be seen in Figure 8. If the variation of the harmonic content can be related to specific faults then it may be useful as an indicator.
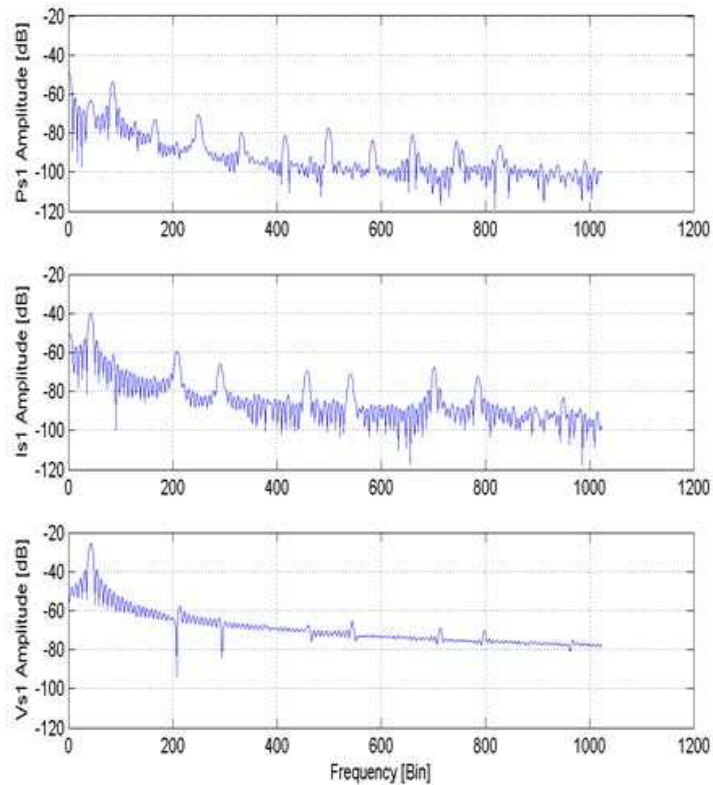

Fig. 8. Frequency spectrum of stator power, stator current and stator voltage of the WRIM. The data were recorded and processed by MATLAB software and acquired by DAQ card - ICS-645.

5   Conclusion

The objective of this paper was to develop and to test a condition monitoring system, for implementation in an electrical drives systems.

The software which controls both the acquisition and analysis of the signals is written in MATLAB and has been developed as a sub-part of the monitoring system.

The article has shown that Rogowski coils, voltage differential probe, incremental encoder and thermocouples can offer a useful contribution to building an art of measuring system for monitoring electrical parameters under transients and for normal situations, as well.

Modern measurement techniques in combination with advanced computerized data processing and acquisition enable new ways in the field of electrical drives systems monitoring by the use of spectral analysis of operational process parameters.

Most signals require some form of preparation before they can be digitized. Signal conditioners perform a variety of general-purpose conditioning functions to improve the quality, flexibility and reliability of the measurement system.

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