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# Using the AC Drive Motor as a Transducer for Detecting Electrical and Electromechanical Faults

# About the author:

Mark Lane has been working for Optima Control Solutions, Blackburn since 1999.
He is an automation expert Extensively using Siemens and Parker SSD control equipment. Winding, flying splice, printing and servo applications are among his specialities.

His academic background in control systems engineering is as impressive as his practical experience. He has completed two undergraduate courses in engineering – one at the University of Central Lancashire and one at Lancaster University.
He has two other qualifications including "Expert in Inspection and Testing of Electrical installations".
More recently, in 2011, he was awarded the degree of Master of Science by the University of Huddersfield.

This report is based on his research for the University of Huddersfield and concerns motor condition monitoring, preventative maintenance and their commercial implications.

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# Introduction

AC motors are responsible for approximately 70% of all electricity consumed on the grid network and are used in 90% of all industrial motor applications for manufacturing processes of various forms. Depending on the size of these units, from 1 kilowatt to megawatts they can be costly items to replace. Even on smaller motors, lost production resulting from motor failure often costs manufacturing more in downtime than the actual motor is worth.

Demand for monitoring the condition of AC motors is now high as the pressure on processes is toper form with less and less profit margin and with vastly reduced down-time available on plant equipment. This places a heavy emphasis on the components used to perform day after day, with the minimum of maintenance input and the maximum amount of up-time.

There are many methods that can be used to monitor the condition of a motor and those such as vibration analysis rely on a person to manually perform the measurement task. Often, this is not possible due to the hazardous or inaccessible location of these motors, particularly when processes are running. It would be of great benefit to industry if the monitoring of motor condition could be done actively, be non-intrusive and run on a continuous basis using an unmodified, standard motor. Ideally, this form of monitoring would require no input from maintenance personnel and would signal potential failure conditions as and when they arise – not months later when manual checks are performed.

This approach tends towards requiring the motor to operate as a 'transducer' (since no other equipment will be fitted to the motor for diagnostic purposes), effectively using only the equipment fitted as standard to a typical motor in order to 'feed-back' information to a higher-level diagnostics system for the purposes of fault detection.

Condition-based monitoring of fixed-speed AC motor applications using the motor as a transducer is not a new research area. There are systems available on the market that can be wired non-intrusively into an existing AC motor application to monitor the motor behaviour and alarm when abnormal conditions exist. However, these systems rely on the motor operating at a continuous fixed-speed and coupled directly to the 3-phase supply. This is known industry-wide as Direct On-Line – DOL operation Systems that rely on the motor operating in a DOL mode cannot be utilised on inverter-driven motor systems because the voltage, frequency and phase angles of motor current will vary as the motor speed is changed. As the use of inverter technology in industry becomes more widespread, the opportunity to perform diagnosis using these systems is no longer possible and manual measurements required once again.

It follows that any new method developed to use the motor as transducer for the purposes of monitoring both the condition of the motor and the mechanical load that it drives must be compatible with AC inverter-driven motor systems.

# Research Aims and Objectives

The aim of this research is to advance motor condition monitoring methods into the field of inverter driven motor systems, rather than the fixed-speed non-inverter driven systems that have been the focus of much research up to now.

It is important to determine at the outset, whether any existing research has been undertaken into the specific area of using the AC motor as a transducer for detecting electrical and electromechanical faults on an inverter-driven motor system. This will ensure that the research is not duplicating any existing work and makes a valuable contribution to research in this field. A study of all elements of inverter-driven motor systems will be required, from AC motor technology used through to the inverter-drive systems available on the automation market. This will include details of how modern flux-vector closed-loop and open-loop inverter systems operate, because any system that relies on the inverter to provide fault diagnosis will have to be compatible with the latest control methods available.

In order to test and simulate fault conditions, it will be important to have a test rig that contains all of the equipment required to perform theses tests satisfactorily. Therefore, the design of a test rig, together with subsequent test and validation is incorporated into this research as a key contribution. A series of tests run on healthy and faulty mechanical equipment will then be carried out. The most appropriate condition monitoring method will be used for the fault diagnosis of the test rig based on the differences between data sets for healthy and faulty gearbox.

The main objective of this project is to investigate the operation of an inverter-driven motor system with a view to determining whether the existing output signals on a typical AC inverter drive contain sufficient information so as to allow this to be used for purposes of condition monitoring and fault diagnosis on the driven motor system. The AC inverter must be from a latest-generation of drive and must not be modified from its original factory-delivered state. This will ensure that all results from the research are relevant to and useable with the current generation of modern inverter drives without requiring any modification.

The project objectives can be divided up into several parts and these are given below:

– Investigate actual motor condition monitoring techniques with a view to determine whether any existing research has been undertaken into the specific area of using the AC motor as a transducer together with the AC inverter signals for detecting electrical and electromechanical faults on an inverter-driven motor system.
– Research the latest state-of-the-art control strategies implemented in modern electrical drives.
– Design a practical test rig which will enable to measure relevant experimental data.
– Test and commission the operation of the rig to ensure design criteria are satisfied.
– Change the open-loop configuration of the test rig into the closed-loop configuration in order to increase the system performance and the accuracy of the test results.
– Investigate the signals received from the inverter drive to ascertain their usefulness in detecting fault/non-fault conditions on the faulty equipment.

# Methodology Review

**Objective 1.** Investigate actual motor condition monitoring techniques with a view to determining whether any existing research has been undertaken into the specific area of using the AC motor as a transducer together with the AC inverter signals for detecting electrical and electromechanical faults on an inverter-driven motor system.
**Achievement 1**. It was important to ensure that the research undertaken is not duplicating any existing works. From the literature review, it became clear that the area of using the inverter drive output signals to monitor and detect faults in the driven equipment is not one that has been studied in any detail. Therefore, the research work could continue in the knowledge that any results obtained would be a valuable research contribution in this field.

**Objective 2.** Research the operation of modern AC Flux-vector controllers with a view to using the latest inverter controller methods for these tests.
**Achievement 2.** The use of a Parker 690+ AC Vector Drive ensures that this test rig is using one of the most modern AC vector inverters on the market. Operation of the drive in true closed-loop mode with motor feedback encoder gives a high level of performance from a standard AC asynchronous motor. Results obtained from this rig can then be stated to be from with the most up-to-date drive technology and therefore the research is not restricted to use on old technology.

**Objective 3.** Design a test rig, using equipment that will meet the demands of the research work to be undertaken
**Achievement 3.** The test rig design was successful as the most up-to-date drive equipment had been specified and incorporated into the rig, whilst keeping the project cost within the budget constraints. This equipment could also be upgraded in future if the test rig research demands changed.

**Objective 4.** Test and commission operation of the rig to ensure design criteria are satisfied. This will also involve running simulated test runs on the rig and analysing any results obtained.
**Achievement 4**. After designing and specifying the test rig from a clean sheet, the rig was then commissioned to ensure that the performance of the rig was up to the designed standard. However, after successful commissioning, initial research work was attempted on the test rig for an application involving detecting motor gearbox faults. After running a series of tests, it was impossible to create identical test conditions for any test run. If any two sets of results could not be compared under like-for-like test conditions, then no further research could be carried out.

**Objective 5.** Design and implement improvements to the test rig if these improvements can be proven to return more accurate test results.
**Achievement 5**. A design to automate the test rig was developed to meet the conditions for repeatable tests. The incorporation of a PLC (Programmable Logic Controller), together with means of programming test conditions into the PLC, was shown to provide the test conditions required of the rig.

**Objective 6.** Perform simulated tests to prove that the test rig is providing accurate and repeatable test conditions
**Achievement 6.** From thorough testing, it was found that the test rig PLC modifications carried out as part of this research provided consistent control signals to operate the test rig and therefore maintained identical test runs. This was important as a research project commissioned by David Brown had to guarantee the same test conditions for each run to determine if there were different test results obtained from healthy and faulty gear sets. The modifications allowed this work to be carried out satisfactorily and results detailed in provide conclusive proof of this.

**Objective 7.** Use the test rig to run a series of tests on healthy and faulty equipment.
**Achievement 7.** The PLC-automated test rig was eventually required to satisfy research demands on a key application involving motor gearboxes from a major manufacturer. This allowed both healthy and faulty gear sets to be exchanged in order to introduce the desired faults.

**Objective 8.** Investigate the signals received from the inverter drive to ascertain their usefulness in detecting fault/non-fault conditions on the faulty equipment
**Achievement 8.** Data was collected from the gearbox test rig and analysed using MATLAB. From a series of tests performed on the healthy and faulty gear sets, some clear differences in the signals received from the inverter were noted. This provided an important step forward in the research to show that there is good potential in using these signals to detect downstream mechanical faults. The detection method is novel as it uses the drive signals to monitor the load, rather than the motor currents.

# Conclusions based on research

• The decision to design and build a test rig using the most up-to-date closed-loop drive technology provided an important starting point for this research. Closed-loop vector drive technology is unlikely to advance much further than it is at present, except by incorporating the technology into ever smaller drive footprints, so any results obtained will remain valid for the foreseeable future. A modern closed-loop drive (such as the Parker 690+ unit) can provide the feedback signals required by an external data-logging system without any modification. Three analogue outputs were used in this case and this allowed the internal feedback signals of motor speed, current and torque to be ported out for measurement by external instrumentation with ease.

• The importance of selecting a mechanical fault that is typical of what will be encountered in industry is vital to ensure that the research will have value in industry. This came in the form of a true research project commissioned by David Brown to determine if gearbox faults could be detected by using the AC motor as transducer. Originally, this research was to be performed using a direct online(DOL) AC motor running at fixed-frequency but the principle of using the inverter drive signals to detect the fault was to be used instead. The gearbox chosen was a standard two-stage gearbox using two sets of helical gears. David Brown defined the faults to be simulated and provided actual faulty gear sets for this purpose. Having real-world faults present in the gearbox that were specified by the manufacturer provided ideal fault test conditions and paves the way for this research to be used on the many applications that use helical gearbox technology in industry.

• In an environment where tests are to be performed on a repeat basis, there must be a guarantee that one test is run in an identical manner to another. Test runs initially performed on the non-automated test rig highlighted clear flaws in the testing methods used. Test conditions were that the motor was to run at a fixed-speed, with an increasing load applied in steps. Upon analysis of the first few tests, it could be seen that there was not one single set of test run conditions that could be compared to another. Whether this was the load setting, or the time taken to run at each load not being the same, it was always the case that there were slight differences. Human beings are not robots and whilst every effort can be made to operate the test rig under the same conditions from one run to the next, in practise this will not happen – and didn't. It follows that without an absolute defined set of repeatable test conditions, it is impossible to compare any two sets of results and any research relying on these results would be invalid.

• The use of a PLC to automate the test rig provided a vital guarantee of consistent test conditions. When the results of two identical tests are analysed and compared against each other, an assurance can be given that any deviation from the expected conditions is as a result of factors external to the control system, rather than anomalies in the test procedure itself. In this research, automation allowed a reliable base line data source to be obtained from the series of load tests run on the healthy motor gearbox unit. Knowing that the test conditions would be identical, load tests run on the known faulty motor gearbox set could be run and results of the two tests compared like for-like.

• From the tests, it has been shown that for a particular mechanical fault introduced, the inverter drive signals have provided sufficient information to allow a difference between healthy and faulty gear sets to be observed. The data has been analysed and feedback provided to David Brown who are pleased with the results obtained.

• Although the data was captured and analysed using a low-sampling frequency (1 second interval), meaning that only a time-domain visualisation could be carried out, the difference between healthy and faulty gearbox data could still be clearly seen. Because of the low signal-processing overhead that this brings, application of these methods will become easier to incorporate in general automation equipment. Memory storage becomes less of an issue, as does the processing overhead on the hardware – it is not desirable for the monitoring software to take up the majority of processing time on equipment who's primary function is controlling the plant or equipment. The appeal of this method of fault diagnosis is therefore greatly enhanced for both automation equipment manufacturers and end-users.

• Monitoring methods such as MCSA rely on a high level of data storage and analysis, with a significant cost and performance implication on the equipment used to perform the analysis. As this used standard drive output signals, the cost and complexity to implement this method is significantly reduced over other methods. This should ensure that the technology is more readily embraced by industry than other methods.

• There is significant interest from industry in motor and mechanical sub-system condition monitoring– as shown in the work commissioned for David Brown. The customers of Optima Control Solutions Ltd. have regular vibration analysis checks carried out on key plant equipment. Often, this has shown to be valuable in detecting early failures. In July 2010, vibration analysis led to a new inverter motor being replaced only six months into service. The unit had failed due to an assembly issue in production (early end roller-bearing failure). Had this remained undetected for a year or so, the unit would have to be replaced at the end user's cost. As it stood, the unit was replaced free of charge by the manufacturer, saving the user hundreds of pounds. Bringing the cost and availability of condition monitoring systems down is key to getting established in customer sites. If this is as simple as linking up to drives and monitoring the key output signals, then this method of detecting mechanical failure has a high commercial value.