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Increasing the Reliability and Availability of the Electric Motor Using Combined Static and Dynamic Diagnostics

SUMMARY

The aim of this paper is to point out the importance of early diagnostics and assessment of the condition of the electric motor in increasing the reliability and availability of the plant. Electric motors are unavoidable elements in every production process. As the complexity of the process increases, the number of electric motors involved in it increases. By increasing the number of electric motors, the possibility of cancelling and interrupting production increases. It is therefore very important to monitor the situation and detect defects at an early stage so that timely repair or replacement can be planned, without affecting the production process. Modern diagnostic methods that can be used both during the operation of the electric motor, and with the dismounted and dismantled electric motor are presented in the paper. With good organization and testing schedule and a combination of static and dynamic diagnostic methods, the reliability and availability of the plant can be significantly increased. With increased reliability and availability, a reduction in maintenance costs is achieved. In this article, some examples from the author's practice are given, when serious engine defects were discovered. These cases confirm the value of predictive testing to increase reliability of electric motor.

KEY WORDS

reliability, availability, diagnostics, MCSA

INTRODUCTION

Modern industrial plants cannot be imagined without an electric motor. They represent the driving force of most of modern industrial processes. Also, according to some estimates, in electric power consumption, electric motors participate up to 50%.

With the increasing complexity of the process, the number of engaged electric motors is also increasing. With the increase of their number in the industrial process, their importance for the reliability and availability of the plant is growing. In order to prevent unplanned shutdown and thus loss of production, the quality maintenance of electric motors plays a very important role.

Electric motors produced more than thirty years ago were mostly oversized and many of them still work.

By contrast, nowadays, manufacturers under constant cost-cutting demands, reduce the material needed for production to minimum rates. In this way, electric motors become more sensitive to operation beyond nominal parameters, even for a short time.

In addition, in modern industrial plants, electric motors are connected via frequency inverters, for better control process. In this operations mode, insulation suffers from increased stress due to large du/dt, as well as due to the existence of higher harmonics. [1]

Especially sensitive are the older electric motors that are not even designed for such a mode of operation, and very often in the process of automation of the plant, old electric motors are retained, and only the control equipment is installed. Because of this, it is necessary to monitor the condition of the electric motor from its installation in the plant and throughout the entire life time.

In order to achieve the best maintenance results, it is necessary to make a proper approach, along with defining test methods and condition assessment, the priorities and the time schedule of the test. In this way, the electric motor is monitored from its installation and its the record of its working history is kept. By doing this, it is achieved that every defect and the problem in the electric motor are noticed at the very beginning, which is followed and responded adequately before the problem becomes a serious defect that will cause huge and unnecessary costs.

After the repair, it is necessary to assess the condition to determine whether the repair was effective. Namely, in practice, it is often the case that the electric motor that was on external service breaks down again, very soon after the installation. This happens very often, because in many

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electric motor services shops not enough attention is given to the initial symptoms of failures.

Using a good post evaluation method will help to avoid unnecessary waste of time and shift the blame for electric motor failure from the service engineer to the owner. Also, when a defect is observed, the question that arises is whether to repair or replace the electric motor. According to a 2014 study conducted by *Plant Engineering* magazine for the Electrical Apparatus and Service Association (EASA), just more than one-half of plants have a policy of automatically replacing failed electric motors below a certain horsepower rating. While that horsepower rating varied depending upon the plant's installed motor population, the average rating was 30 hp. [2]

In the past, the decision to repair or replace an electric motor was primarily driven by the cost of energy and related potential savings. In many cases, this is still a major factor. However, a number of other elements that influence the true life-cycle cost of operating a motor should be considered.[5]

Symbols			
du/dt	- voltage change rate, V/s	f_1	- mains frequency, Hz
FFT	- Fast Fourier Transformation	%FLA	- Percent of full load, A
F_p	- Pole pass frequency, Hz	N_r	- Rotor bars number
F_{ecc}	- Frequency of eccentricity, Hz	DA	- Dielectric absorption

2.THE OBJECTIVE AND APPROACH TO THE MAINTENANCE OF ELECTRIC MOTORS

The basic maintenance goals are known:

- preventing unplanned downtime;
- reduction of costs;
- increase productivity;

Usually, only some of the goals are achieved in maintenance. This mostly depends on the approach and the way used to reach the goal.

Three basic approaches to maintenance are:

- corrective maintenance (intervention after process event);
- planned maintenance (preventive);
- maintenance by condition (predictive);

Each of these approaches produces maintenance costs. It is shown that the maintenance by condition is most favorable from the point of view of the cost. Due to good results achieved, more attention is paid to this maintenance approach. Figure 1. shows the ratio of costs of maintenance according to Schneider Electric[3].

Figure 1. Cost of maintenance (Schneider Electric)

In case of maintenance by condition approach, and if there are many electric motors in the factory, a good test plan should be made and priorities defined. A decision should be made to maintain an electric motor or to let it work.

In order to define priorities, the following questions need to be asked:

- Is the motor easy to replace? If yes, is there a spare one?
- Would the purchase of a new motor cost less than repairs of the old one?
- Is the motor redundant and uncritical?

If all the answers are positive, this electric motor is not a priority for testing and monitoring. If the answer to any question is negative, it is necessary to include the electric motor in the test plans.

Three keys for quality maintenance of the electric motor can be defined. Those are:

- Quality control;
- Trending;
- Repairing;

Quality control implies that only electric motors of satisfactory quality are introduced into the production process. Therefore, it is necessary to check whether the purchased electric motor meets the defined quality criteria before installing it. It ensures that only the best electric motors are included in the production process. Trending implies that the electric motor is monitored from its installation, it is periodically examined and the trends of vital parameters are made. This achieves that any problem or deviation of the parameters of the electric motor is detected on time.

The third quality maintenance key is troubleshooting and repair. By timely detection of the defect, it can be planned to switch off the electric motor at a convenient time and to repair it at the stage when it will cause the least cost. By applying a third maintenance key, one working cycle of an electric motor is finished. After the repair and successful quality control, the electric motor can return to the production process again.

In order to achieve high quality predictive maintenance, using three quality keys, appropriate methods for testing and assessment of the condition of the electric motor should be applied. In order to avoid unnecessary stopping of the production process for testing, the best results are given by a combination of methods that enable testing of the electric motor before installation and later in operation, without disconnection.

3. METHODS OF ELECTRIC MOTORS ASSESSMENT

3.1 List of diagnostic methods

Traditional testing of the condition of an electric motor involves the analysis of very little data. Most often it is only the resistance of the insulation to the ground.

Modern diagnostic methods developed in recent years represent a comprehensive examination and assessment of the condition of all assemblies of electric motors, stator, rotor and air gap. The rating of both electric and magnetic circuits is completed. Due to the numerous data obtained, a correct estimate of the condition of the electric motor can be carried out and the need for its maintenance.[4]

The basic division of the test method is made according to whether the electric motor is tested while it is switched off and disconnected from the electric circuit, or the test is carried out in normal operation, at nominal load and in real conditions in the plant. Based on this, two methods are distinguished:

- Static (offline);
- Dynamic (online);

Static testing is performed with a deenergized electric motor, which is separated from the rest of the electric circuit. The analyzer injects currents and voltages of a precisely defined level and frequency, on the basis of which all parameters of the electric motor are determined. The advantages of this method are:

- Safety, since the test is carried out without mains voltage; - Possibility of detailed direct insulation analysis; - Possibility to evaluate electric motor condition before installation;

The disadvantages of static methods are:

- Requires motor shutdown, if already in operation; - No mechanical parts rating can be given; - No power quality rating;

Dynamic testing is carried out on an electric motor in operation, at nominal load and in real operating conditions in plant. The analyzer performs acquisition of the electric current and voltage of the electric motor and, based on the measured values, calculates the parameters necessary for the assessment of the condition. This method uses FFT to calculate the spectrum of the current. An analysis of the components in the spectrum takes place in a state evaluation. [6]

The advantages of a dynamic method are:

- Testing during work in real conditions;

- Does not require disconnection and termination of production;
- The ability to evaluate motor mechanics [7];
- Evaluation of the start-up of the electric motor (if it was switched off);

The disadvantages of the dynamic method are:

- Need to connect measuring probes to energized circuit; - There is no direct assessment of the state of insulation;

3.2 Fault zone in an electric motor

All defects and problems in the electric motor can be divided into six zones. [8] Those are:

- Power quality;
- Connection circuit;
- Stator;
- Insulation;
- Rotor;
- Air gap;

The first two fault zones include the assessment of the voltage level of both the current and the current supply circuit, which supplies electricity to the motor. Static fault zone includes insulation between turns and internal winding connection. Rotor fault zone refers to the condition of the cage and lamination of the core. Finally, the air gap as a fault zone refers to the quality of the air gap and the distribution of the magnetic field inside. Each fault zone should be analyzed to reliably assess the overall state and health of the electric motor.

The static (offline) electric motor test enables the evaluation of the electric motor in five of the six fault zones. With this method, it is not possible to evaluate the power quality.

On the other hand, dynamic (online) testing also evaluates in five of the six areas of failure. However, it is not possible to give a direct assessment of the insulation state.

An approach to the analysis of the electric motor across the error zone allows a more complete assessment of the condition and health of the electric motor.

4. TESTS TO ASSESS THE CONDITION OF THE ELECTRIC MOTOR BY FAULT ZONE

4.1. Dynamic (online) tests

Dynamic testing is based on the measurement and acquisition of all current and voltage of the electric motor. On the basis of the measured values, the FFT signal is performed, thus obtaining spectra of currents and voltages. An analysis of the current and voltage spectrum is carried out by the state estimation. This method begins to be applied extensively in recent years. The physical basis of this method is based on the fact that every defect of the electric motor modulates the flux of the motor, creating the rotation of the component as a further product of the characteristic of the components, which superimpose the basic harmonics [9]. By detecting and isolating the current components, the defect of the electric motor can be detected at the earliest stage, which allows monitoring the development of defects and reacting at the appropriate time, before serious damage is caused, which can cause great repair costs. Also, this prevents unplanned production losses and losses due to this. The advanced dynamic analyzers in a short interval of time perform a series of tests from which the state of the electric motor is evaluated by automatic or subsequent analysis.

These tests are: [6]

- Rotor evaluation test,
- Air gap assess test (Eccentricity test),
- Stator and power circuit test (Power test),
- Asses of mechanical parts (Demodulation test).

As an illustration, in Figure 2, a spectral diagram of the current is used to evaluate the rotor. This is case from TPP Ugljevik. The two components at the Fp distance from the base accordion represent the pole pass frequency [6]. Based on their value, the condition of the rotor cage is evaluated. Serious defect of rotor bars is detected at early stage and prevented catastrophic failure of electric motor.

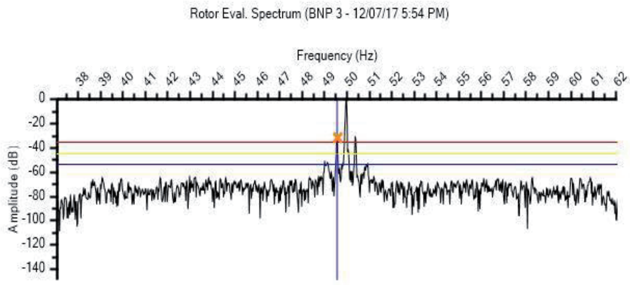

Figure 2. Rotor evaluation spectrum

Figure 3 shows a high-frequency spectral diagram of the current used to estimate the air gap.[6] This case is from Eating Oil Rafinery Bimal Brcko. Detected is air gap eccentricity which caused serious vibration and damage bearings.

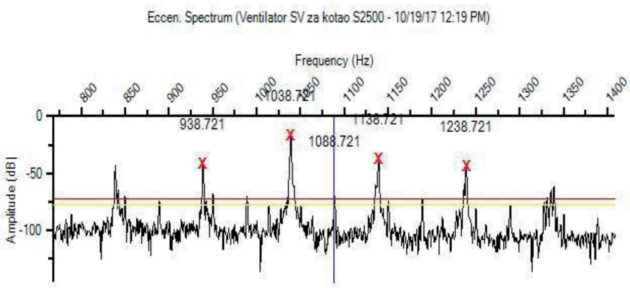

Figure 3. Eccentricity spectrum

One of the novel techniques for air gap asymmetry detection, especially for static eccentricity, is using measuring coils that are installed on the stator teeth.[12] This is an efficient method, but requires additional coils that must be installed during the manufacture of the electric motor.

For the difference, current spectrum analysis does not require additional part and additional cost of electric motor. The estimation of the state of the air gap, that is, the detection of the gap asymmetry is performed on the basis of the level of the four characteristic components in the spectrum, located at a distance of 1x and 2x from the eccentricity frequency f_{ecc}, given by the expression (1).

$$f_{ecc}=N_r \cdot n/f_1 \quad (1)$$

Similarly, in other tests, identification of components in the spectrum is characteristic of certain defects. Power test, as a result, in addition to the spectrum, provides numerous numerical data with the interpretation of the state of the stator and the connecting circuit.

The estimation of the state of the electric motor by spectral current analysis is based on the IEEE and NEMA standards and also on the EASA Standard AR100-2020. [11]

4.2 Static (offline) tests

For static testing it is necessary to ensure that the motor is disconnected from the power supply and that the shaft does not rotate.

The static analyzer generates DC voltage and current signals or an AC signals of defined frequency, and it injects them into an electric motor.[10]

Measured parameters are:

- Resistance to ground,
- Capacitance to ground,
- Resistance of winding,
- Inductance of winding.

Based on the measured parameters, the assess is made in five of the six error zones:

- Insulation,
- Air gap,
- Power circuit,
- Stator,
- Rotor.

There is no direct assessment of insulation.

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Tests carried out are:

- AC Standard test,
- Polarization index,
- Rotor influence check,
- Step voltage test.

AC Standard Test is a short but detailed analysis of the electric motor and its current circuits in five of the six fault zones.

Polarization index PI is the insulation test. Continuous measurement of insulation resistance and resistance ratio are performed after ten minutes and after one minute under voltage.

At the same time, the Dielectric Absorption DA is calculated, which represents the ratio of the insulation resistance after one minute and after thirty seconds.

In Figure 4. a PI test diagram is shown.

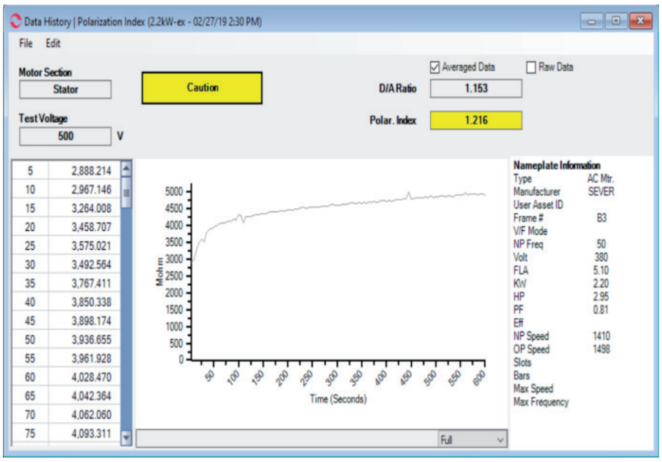

Figure 4. Polarization Index diagram

Step Voltage is ***Overvoltage test*** of insulation system and is not intended as a routine test

It is used to determine the insulation performance when the results of the AC Standard test and the PI are not consistent and sufficient.

Figure 5 shows the Step Voltage test diagram.

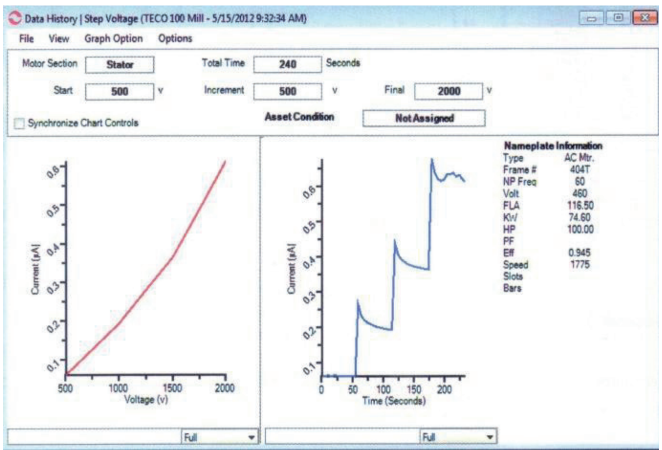

Figure 5. Step voltage test

The Rotor influence check RIC is test performed to obtain a graphic representation of the influence of the residual rotor magnetism on the Stator winding Inductance. This test is used to assess stator, rotor and air gap.

Figure 6 shows one RIC test.

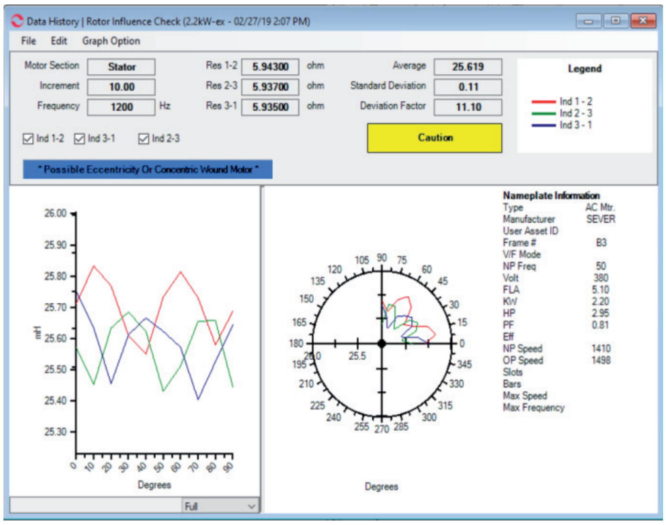

Figure 6. RIC test

5. CONCLUSION

Due to the importance of electric motors in automated industrial processes, it is very important to have a good maintenance strategy for these equipement. Some cases from practice are shown that predictive maintenance gives the best results in terms of cost reduction and increased reliability of the plant. To this end, it is necessary to monitor the electric motor from its installation and commissioning for the entire duration of its lifetime. By installing only those electric motors that meet quality criteria, periodic testing during operation, and the trend of data obtained by testing, any deviation of the parameters from the normal can be detected at the earliest stage.

Further, this defect can be monitored and reacted in time before the motor failure causes the loss of production and the large repair costs. In practice, it is shown that the best results in the predictive maintenance of the electric motor provide a combination of static and dynamic test methods. Advanced analyzers have already been developed.[10] By performing a series of tests both off and on the energized motor they provide a comprehensive and reliable assessment of the condition. Based on this assessment, maintenance activities are planned, which will contribute to increasing the reliability and availability of plants, while minimizing maintenance costs.

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