Multicriteria diagnosis of synchronous machines
Condition Assessment

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Abstract

Develop a smart multivariate method capable of early fault detection is the aim of this research. It is intended to identify which mechanical or electrical signals are best suited to monitoring and prediction of faults in electrical machines.

It is strongly believed that this method for acquiring data would allow timely and reliable detection of faults, even further when used in combination with an automated monitoring algorithm or process.

1. Justification of research

Principally used in high power operations and widely used as alternating current generators. Synchronous Machines can be found where constant speed operation, power factor control and/or high operating efficiency are required. They are doubly excited machines i.e. two electrical inputs are provided to it; brushless or supplied by an external DC source. Its more maintenance charges and high initial capital have done, that Synchronous Machines, are underestimated over induction motors in common low-power requirements industrial application.

Favored for its ruggedness and simplicity induction motors are widely used in common industrial application and the number of papers devoted to fault detection and condition monitoring techniques[1][2] are more meaningful and specialized, than the number of papers devoted to synchronous motors (SM). Researching for relevant information about fault diagnosis in synchronous motor has led to literature related to permanent magnets wind turbines generators or motors, synchronous generator, and less often, to synchronous reluctance motors[3].

Power factor correction is an important characteristic of the SM that should be taken into account when selecting it for an industrial application. Due to their ability to correct power factor on the motor power supply, and thus improve energy efficiency, SM are increasingly the motor of choice in high power, heavy load applications. In addition to this, in applications that require power factor correction, synchronous motors also provide high torques and constant speed under load variation, resulting in low operating and maintenance costs [4].

A rough rule of thumb is that SM are less expensive than squirrel-cage motors if the rating exceed 1HP per rpm [5]. In Fig.1, and for standard construction motors, it is possible to appreciate in which general areas of application is more reliable either synchronous or induction motors.

All these advantages explain the use of the SM in different applications as large compressor and fans.
in chemical and petrochemical applications; or water and wastewater plants; fans, pumps, and compressors in steel plants; mills and crushers in cement works; and pulp and paper extruders.

Perhaps, all these special features have made more complicated, expensive, and less accessible to carry out experimental tests on fault detection in SM. This is one of the main reasons why this research is focused on developing an efficient and complete test-rig to perform and test different non-intrusive faulty conditions on synchronous motors.

Satisfying its high torque characteristics at low speed, and in applications where wide speed adjusting range is necessary, SM have proven their ability to improve stability in VDF applications. This is why in a further step of this research is intended to test the machine under all possible fault scenarios driven by a LCI designed and modeled for this purpose.

Last but not least, this research only takes into account traditional brush/ring SM construction. It is assumed on this research, this traditional construction, represents the most widely use of the assets already installed and running at the present time.

2. Synchronous Machine Test-rig

There is available a SM with different configurable fault scenarios and was designed for condition monitoring experimentation. Its construction is adapted to non-invasive diagnosis methods. This machine was designed on 70's and manufactured with the participation of Dr. Eng. Konrad Weinreb in Saint Petersburg in Russian Academy of Sciences.

![Fig.2. Front connection panel](image)

![Fig.3. General view of the rotor](image)

![Fig.4. Location of thermistor](image)

![Fig.5. Magnetic flux sensor](image)

The number of slots and the distribution of the coils cannot be placed in a standard classification. By using standards machine design formulation; Pitch factor is 16/21 but, the coils are not symmetrically distributed. There are 2 coils distribution:

- 4-turns coils
- 3-turns coils

2.2. Description of the rotor:

On the shaft of the machine four poles are placed. They are made of steel sheets type ST3 of 1 mm thickness.

In each pole four round holes are placed. On each pole a field coil is placed which is powered by DC current. It is divided on two parts.

- First part is 10% of the coil
- Second part is 90% of the coil.

Using the terminals situated on the rotor it is possible to make an asymmetric field winding.

A group of sensor was installed originally in the machine. Most of these sensors are destroyed or in bad condition. After a long maintenance process new and modern sensors are placed in the rotor:

- Eight Rogowski coils to measure the current in eight damper bars and two extra Rogowski coils to measure the current of the end rings.
- A thermistor installed in each pole, four in total. Fig.4.
- Four Hall Effect sensors. The ideal location is in the surface of each pole. Fig.5.

### Tab.1. Machine Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Power [kW]</td>
<td>7.5</td>
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<tr>
<td>Voltage [V]</td>
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<tr>
<td>Phase winding voltage [V]</td>
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<tr>
<td>Current [A]</td>
<td>15.8</td>
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<tr>
<td>Rotational speed [rpm]</td>
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<tr>
<td>Power factor</td>
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<td>Frequency [Hz]</td>
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<tr>
<td>Field voltage [V]</td>
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<tr>
<td>Efficiency [%]</td>
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<td>Mass [kg]</td>
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<td>Protection Level</td>
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<td>IS01</td>
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<tr>
<td>Assembly</td>
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</tr>
</tbody>
</table>

2.1. Description of the stator:

On its interior diameter 42 slots are arranged. In these slots there is arranged dual layer winding made of enamelled wires type ПЭТ155 with 0.95/1.04 mm diameter.

In each layer there are two turns consisting of 6 wires. The endings of particular coils are placed on a terminal panel.
2.3. Rotor-signal-collector

In order to extract the information from the sensors a special set of brushes & slip-rings was designed, Fig.6. The analog differential signals are transmitted outside the rotor through rotatory silver – graphite contacts specially designed for this experimentation.

The total number of rings is 50; split in two sections with 25 rings each. This design is based on the idea of keeping constant the carbon brush – ring contact as much constant over the time as possible. High quality transmission of signal is always desirable, and in order to achieve this, special shielded cable was selected and the number of connections reduced to the minimum possible to maximize the isolation from environmental noise/interferences or own machine electromagnetic emissions.

One special feature of this rotor-signal-collector (RSC) is the central bearing. This is a bearing with miss-alignments capabilities, up to 4° of deviation. This is necessary when the machine will be tested under different types and severities of eccentricities.

2.4. DC generator as load system

There is available a DC generator connected to the motor via a Cardan coupling. It is also planned to attach a Torquemeter for future load torque oscillation analysis and increase the number of measurement available.

By connecting different sets of resistive loads and regulating the field current to the generator, different load levels will be simulated. One experiment to carry out will be determining the maximum overload level of operation on which the SM can be exposed without damage.

In a further step of this research is intended to use a dynamic control to the field current in the DC generator and simulate different load condition or behavior associated to main SM applications.

2.5. FEM model

To support this experimental research a FEM model of the SM is under design. After extract all the parameters from the machine; it is on course the detection of the “slot number 1” in the stator. It is believed that by starting all the experiment in the same position; in this case the slot where the current of the phase A reach after the star-up, will provide extra information.

The software used to create the model is Opera 3D v.15R2. Current status of the model can be appreciated in Fig.7.

3. Data acquisition System

This multivariate research seeks to read and extract as much relevant signals as possible. It is believed that by using advanced techniques and high specialized equipment it will be possible to reach one of the main goals of this research:

“Using available tools in order to recognize associated variables related with fault conditions in the system”.

To detect which parameters are associated with a specific type of fault, a National Instrument NI-USB 6255 acquisition card is available. Most relevant features are:

- 80 analog inputs (16-bit); 1.25 MS/s single-channel (750 kS/s aggregate)
- 2 analog outputs (16-bit, 2.8 MS/s); 24 digital I/O (8 clocked); two 32-bit counters

The values of the currents and voltages are measured by dedicated transducer. The type chosen for the stator currents is a current transducer LEM HY 25-P per phase and a voltage transducer per phase as well, LEM 25-P. Both types of transducer are mounted in a PCB designed (and currently in manufacturing process) for conditioning the signal. In the Fig.8, it is possible to see a representation of the PCB.
For the field current and voltage was designed another PCB with a LEM HY 15-P and LV 25-P. The field voltage is supplied to the rotor winding via a rectifier; Multicomp, cm1504 - bridge rectifier, 15A, 400V.

Each type of transducer is supplied by an independent source. The type of source chosen is a “VxI Power Limited” linear power supply PCB mounting encapsulated +/- 12V, 250mA; with a rated power of 5W.

4. Data processing

In order to extract and identify characteristic parameters associated to each fault condition in this research will be used ready tool-box and/or high-level programming language such as MATLAB-Simulink.

Using available and simple tools is the way in which this research will reach its second main goal:

- Validation and characterization of the acquisition system.

Multivariate statistics is the processing algorithm chosen to preprocess the raw data and analyze it. In order to extract periodic waveforms (as three-phase system is) from noisy data the algorithm chosen is:

- Time synchronous averaging (TSA)

To measure uncertainty and insignificant trends in the process (signal) variation:

- T2 and Q statistics
- Time–frequency analysis
  - The idea of STFT is to divide the whole waveform signal into segments with short-time window and then apply Fourier transform to each segment

The algorithms are under testing.

5. Conclusion and further work

This research is still working on the lab set-up configuration. So far, fault scenarios configurations available are:

- Healthy machine.
- Rotor winding fault.
- 10% of turns shorted.
- 90% of turns shorted.
- Stator winding fault.
- Unbalance / asymmetries.
- Short circuited turns.
- Static eccentricity: Five different severities of faults 10, 20, 30, 40 and 60 %. It is possible to change the angular position of minimum air gap from 0 to 360 degrees with 15 degrees step.
- Dynamic eccentricity: Four different severities of faults 10, 20, 30 and 40 %.
- Mixed eccentricity (static + dynamic). Proposed configuration: 20% static and 30% dynamic eccentricity. 30% static and 30% dynamic eccentricity. 30% static and 20% dynamic eccentricity.
- Mixed fault (mixed eccentricity + rotor winding fault)

The third main goal to pursue is:

- Implementation and optimization within industrial process.

After realize all the experimentation and having identified which signals are more relevant for each type of fault, the last step is contacting to one of the Early Stage Researchers member of my project group hosted by an industrial company; Energy Smartops, and validates my results within real industrial process [14].

6. Bibliography


7. More useful bibliography for this research


[22] P. Neti, A. Dehkordi, and A. Gole, “A new robust method to detect rotor faults in salient-


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