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MULTICRITERIA DIAGNOSIS OF SYNCHRONOUS MACHINE USING MCSA

Abstract: This paper discusses the detection of internal faults in the stator and rotor windings of synchronous machine. The motor current signature analysis, allows using low cost equipment to detect the faults by monitoring the coils currents. The process of detection is fully optimized, to predict the faults in machine before damage. It was shown, how using the stator current harmonic spectrum of the healthy machine as a reference data, the detection of faults can be reliable performed.

Keywords: synchronous machine, stator faults, rotor faults

1. Introduction

The existing requirement to reduce production costs and to expand the return on investment, including CO$_2$ emissions decreasing is a new way of operating existing processes. More integrated systems are leading to new industrial processes and new ways of operating existing processes. Integrated systems demands continuous information of the assessment of their components; as well as the control and operation of processes in rotating machinery and electrical equipment. It becomes more integrated by giving new opportunities for energy saving using equipment management, automation, and optimization. Synchronous machines (SM) are used mostly in high power operations and as alternating current generator. In general, SM can be found where constant speed operation, power factor control and/or high operating efficiency are required. Moreover, sufficient 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 Variable-frequency Drive applications.[1]. Addressing technology gaps at the interfaces between the processes, mechanical and electrical domains, and realizing energy savings from integrated operation are the cases that motivate an extended research on multicriteria diagnosis of synchronous machines. For example different angles and levels of rotor static eccentricities, stator and rotor interturn faults, and combined faults types are experimentally studied by introducing these faults into a 7.5 kW salient poles synchronous machine. In addition to, a unique rotor-mounted sensing system [2] was specially designed particularly to collect data from different sensors installed over the rotor. It is strongly believed that this method for acquiring data would allow reliable detection of faults, even further when used in combination with an automated monitoring algorithm or process.

2. Stator and rotor inter-turn fault detection

Initially used to study anomalies and fault condition in induction motors the so-called motor current signature analysis (MCSA) has been proven to be a tool for detecting faults such as broken rotor bars, air gap eccentricity, shorted winding, etc.[3] [4]. MCSA can identify these problems at an early stage and thus avoid secondary damage and complete failure of the motor.

Detecting stator and rotor winding short circuits has been analyzed for several years already. In 1996, a novel method of detecting short circuits in the both the stator and rotor windings of synchronous generators has been proposed [5] by detecting changes of the harmonic content in the rotor and the stator current spectrum. More recently, new diagnostic tools to determine when significant insulating aging has occurred were introduced such as polarization-depolarization current, dielectric spectroscopy and on-line leakage current monitoring [6]. Searching for documentation associated to stator and/or rotor short-circuit fault, most of the available literature relates to the monitoring of failures in synchronous generators [7], [8] or in permanent magnet SM [9]. In [10] the effects of stator interturn short-circuit are analyzed using the field current. The same author in [11] added a rotor search coil voltage signature analysis to identify winding short-circuit in synchronous motors.
3. Experimental platform configuration

A salient pole synchronous machine (SPSM) ready for non-invasive fault diagnosis tests under different severity levels is available. Running as a generator or as a motor, it is possible to set-up either mechanical or electrical faults and combined of both as well. Running as a motor only stator, rotor and combined interturn short circuit faults are discussed in this paper. The features of this machine are described in Table 1.

*Table 1. SPSM parameters*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power [kW]</td>
<td>7.5</td>
</tr>
<tr>
<td>Voltage [V]</td>
<td>400</td>
</tr>
<tr>
<td>Current [A]</td>
<td>15.8</td>
</tr>
<tr>
<td>Rotational speed [rpm]</td>
<td>1500</td>
</tr>
<tr>
<td>Power factor</td>
<td>0.8</td>
</tr>
<tr>
<td>Frequency [Hz]</td>
<td>50</td>
</tr>
<tr>
<td>Number stator-slots</td>
<td>42</td>
</tr>
<tr>
<td>Field current [A]</td>
<td>8.56</td>
</tr>
<tr>
<td>Field voltage [V]</td>
<td>50</td>
</tr>
<tr>
<td>Efficiency [%]</td>
<td>85.2</td>
</tr>
<tr>
<td>Mass [Kg]</td>
<td>263</td>
</tr>
<tr>
<td>Protection level</td>
<td>IP23</td>
</tr>
<tr>
<td>Assembly</td>
<td>IM100</td>
</tr>
</tbody>
</table>

The stator of the machine consists of 42 slots with double layer windings. The configuration of the winding can be modified, all the ends of every group of windings are accessible allowing simulation of many fault conditions to be done.

All experiments were carried out under the same machine configuration, and special attention was given to guarantee the repeatability of the experiments. The data was collected at 25kSamples/s during two seconds. A National Instrument NI-USB 6255 acquisition card is available. Most relevant features are as follows: 80 analog inputs (16-bit) 125 MS/s single-channel (750 kS/s aggregate).

3.1. Stator short-circuit fault

Stator winding is represented in Fig. 1. Each phase consists of two parallel branches of one group of three coils and another of four coils in series. In [12], the utility of the circulating current was used for fault detection in SM. Simulations of different levels of stator interturn short-circuit was made by placing a variable resistor in parallel with the phase “c” (second parallel branch) in a group of four coils. Similar experiment can be found in [13].

![Fig. 1. Stator winding configuration](image1)

Different levels of short-circuit were obtained controlling the deviated current from 0 to 2 amperes, at 0.25 amperes of increments with the motor running at 60% of rated power.

3.2. Rotor short-circuit fault

The rotor is a salient 2p poles rotor with configurable field winding as well. In this case, Fig. 2, it is possible to shorten 90% or 10% of the coils that creates the pole.

![Fig. 2. Rotor winding configuration](image2)

The experiments were carried out for different load levels with 90% of shorten coils in pole 4.

4. Data-Set

To allow direct comparison of the results, the data-set was standardized to mean of 0 and a standard deviation of 1. Using Matlab latest release functions and tools, all data is presented in tables and processed all together as a set. For 10Mb of data, representing one of the cases studied, the average processing time is 3.87 seconds, which it may be suitable for online condition monitoring purposes.
5. Results

In general properly designed electrical machines and no fault condition, it is expected to have a symmetrical flux distribution in the air gap. All machines have constructional asymmetries. In fact, these asymmetries, already have been exploited to perform fault detection [14]-[17]. Consequently the magnetic field distribution will be affected. The machine was loaded at 60% of rated load, and no fault condition, Fig. 3 shows the average power spectral density of stator current $I_a$ for 2 seconds, within 95% of confidence bounds. Using this healthy machine spectrum as a reference, seems logical to assume if the amplitude of the measured faulty signal is located outside the confidence intervals, the machine is no longer operating under symmetrical condition. Therefore, a fault condition is detected. When a difference is detected in a particular frequency, and the variations found are not as significant, the level of uncertainty is higher than that established by confidence bounds.

Fig. 3. PSD spectrum of stator current $I_a$ in symmetrical condition

In the Fig. 4 it is represented the first odd harmonics and stator-harmonics for stator fault in the second parallel branch of the phase “c” (See Fig. 1). From the Fig. 4, it is easy to identify the appearance of a higher peak at 250 Hz for all level off fault. The variation detected is only 10dB. Therefore, looking at all harmonics levels, it is possible to understand how the amplitude remains constant, and under different short-circuit severities, for all harmonics with the exception of fifth harmonic. Looking at the spectra of the motor running with fault in the rotor, Fig. 5, it is possible to appreciate how the even harmonics 2 and 6 have greater peak than upper bound machine running on healthy state. More meaningful are the two side peaks that appear at 25Hz and 75Hz.

Fig. 4. Stator current harmonics for fault in parallel branch of the stator winding

Moreover, Fig. 6, analyzing the spectrum of both faults the results are a combination of each spectrum.

Fig. 5. Stator current spectra for shorten one coil in the field winding of the rotor

Fig. 6. Stator current spectra for combined faults

6. Conclusions

One of the aims of the extended research on Multicriteria diagnosis of synchronous machines, is to use available tools in order to identify associated variables related with faults in the system. This paper has shown how it is
possible to on-line detect slow rising short-circuits in the stator and/or rotor by only using a regular data acquisition card connected to a standard PC/laptop, using as a reference the spectrum of the healthy machine.

7. Bibliography


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Additional information

Financial support from the Marie Curie FP7-ITN project "Energy savings from smart operation of electrical, process and mechanical equipment– ENERGY-SMARTOPS, Contract No: PITN-GA-2010-264940 is gratefully acknowledged.