Bearing Fault Analysis of Permanent Magnet Synchronous Motor(PMSM) using Current Signature Analysis

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Abstract *– This paper presents an tentative study of the broken bearing fault finding for a permanent magnet synchronous motor (PMSM) by using Motor Current Signature Analysis (MCSA) is considered the most trendy fault finding method now a day because it can effortlessly sense the general machine fault such as turn to turn short ckt, cracked /broken rotor bars, bearing deterioration etc. which could be costly to repair. The permanent magnet synchronous motor used industrial principle. With the industrial enlargement, it has become essential to supervise the situation of the machine. There are many situation monitoring methods together with vibration monitoring, thermal monitoring, chemical monitoring, but all these monitoring method require costly sensors or particular tools where as Motor current signature analysis out of all does not require additional sensors.*

Index Terms – ***PMSM drives, fault detection, eccentricity, bearing damage.***

1. INTRODUCTION

The breakdown of a synchronous motor has frequently a severe effect on the operation of a system. In some cases the breakdown results in vanished manufacture, even as in others it may expose human being security. In such applications it is advantageous to use a synchronous motor capable of continuing to operate in the occurrence of any single point breakdown. Such a synchronous motor is termed fault tolerant [3] and the development of a fault tolerant synchronous motor is the absolute mean of the research existing here.

The common necessities for a fault tolerant synchronous motor system are summarize below:

- superior efficiency propose over the working speed vary to healthier utilise the power supply,
- Electrically and physically isolated phases to avoid phase to phase short-circuit, circulation of the fault into the adjoining phases and decrease inverter faults,
- superior winding inductance to maximum value the winding short circuit current,
- effectual cooling to permit as regards 25% overloading capacity to be utilised throughout impression and clamber.

It is a obligation that the fault does not ultimately negotiation the procedure of healthy phases by improperly disturbing the frequent input or the frequent output. Thus in the occasion of any fault, fast achievement must be in use to avoid the faulted phase from illustration too much current or applying important braking torque to the shaft. fast fault detection is also main in the fault tolerant synchronous motor system, to allow correct situation fault stroke to be taken.

Permanent Magnet Synchronous Motor (PMSM) are now broadly used in lots of manufacturing as applications require elevated system dependability, elevated efficiency and comprehensive high-speed operation. Such applications consist of power routing in automotive vehicles, aerospace/aircrafts, military power drive applications and Robotics. In lots of the serious drive applications, it is essential that the drive comprising the motor and the converter in fault , be capable to run stable and gather support drive needs for a phase of time previous to the system can be repaired [5]. Along with the PMSM, the core permanent magnet synchronous motor is becoming accepted in elevated performance applications where need high-speed operation and exact torque control due to some its useful features which contain high torque to current ratio as well as high power to weight ratio, high efficiency, low noise and healthiness [7].

The most important faults of electrical machines, and hence of PMSM, can generally be classified as the following [11] [6]:

- Mechanical faults, like static and/or dynamic air-gap irregularities, Bent shaft (akin to dynamic eccentricity), and bearing and gearbox failures
- Electromagnetic faults, like stator faults resulting in the opening or shorting of one or more of a stator phase winding, irregular connections and demagnetization of the permanent magnet.

approximately 50 % of all motor failures are correlated to mechanical faults, and they lead to a noise and vibrations, and even to the total damage of the machine and the mechanics coupled to it if the failure is not detected and isolated.

1.1 Bearing Faults.

still under normal working conditions with balanced load and good arrangement, exhaustion failure may take place. cracking or spalling of bearings may occur when exhaustion causes tiny pieces to rupture loose from the bearing. Other than the ordinary internal working stresses caused by vibration, inherent eccentricity, an bearing currents[4] due to solid state drives, bearings can be also blemished by lots of other outer causes, like irregular mounting.

At time bearing faults may visible themselves as rotor asymmetry faults, which are frequently roofed under the type of eccentricity-related faults. Otherwise, the ball bearing allied errors can be categorized as [10] outer bearing race errors, inner bearing race errors, ball error, and train error.

It should be distinguished that exact information about the bearing construction is necessary to analyze the precise characteristic frequencies.

1.2 Eccentricity-Related Faults

Machine eccentricity is the situation of uneven air gap that exists between the stator and rotor [9]. When eccentricity becomes huge, the resultant unequal radial forces (also known as unbalanced magnetic pull or UMP) can cause stator to rotor rub, which result in a severe scratch to stator core and windings. There are two types of air-gap eccentricity: the static air-gap eccentricity and the dynamic air gap eccentricity. In the case of the static air-gap eccentricity, the location of the smallest radial air-gap length is permanent in gap. If the rotor-shaft assembly is suitably hard, the level of static eccentricity is not momentous.

In case of dynamic eccentricity, the middle of the rotor is not at the middle of the revolution and the location of smallest air-gap rotates with the rotor. This misalignment may be caused due to a number of factors such as a curved rotor shaft, bearing put on or misalignment, mechanical resonance at dangerous speed, etc.

It has been exposed [8] that only a fussy grouping of machine pole pairs and rotor slot number will award increase to major only static or only dynamic eccentricity-associated mechanism in the stator current.

Among the methods to identify motor failures, Motor Current Signature Analysis (MCSA) has become one of the most popular. MCSA is based on the analysis of the exact current harmonic mechanism that appears in the stator current due to unbalance of the magnetic fields inside the motor in case of fault.

This paper deals with mechanical fault finding in the PMSM, specially eccentricities and broken bearings, by using MCSA method applied to self-possessed stator currents in the frame *dq0*.

2. VECTOR CONTROL OF THE PMSM.

The permanent magnets used in the PMSM are of a recent unusual-earth array with high resistivity, so induced currents in the rotor are insignificant. In calculation, there is no dissimilarity between the back EMF formed by a permanent magnet and that formed by an excited coil. Hence the arithmetic model of a PMSM is related to that of the wound rotor SM. The following assumptions are made in the derivation [1]:

1. Saturation is ignored while it can be taken into account by constraint changes
2. The induced EMF is sinusoidal.
3. Eddy currents and hysteresis losses are minor.
4. There are no field current dynamics.

With these assumptions, the stator *d*, *q* equations of the PMSM in the rotor reference are:

$$[v_{qd0}] = [R][i_{qd0}] + \frac{\partial}{\partial t}[\lambda_{qd0}] + \omega\lambda_{qd0}$$

$$[v_{qd0}]^T = [v_q \quad v_d \quad v_0]$$

$$[i_{qd0}]^T = [i_q \quad i_d \quad i_0]$$

$$[R] = diag[r_s \quad r_s \quad r_s] \qquad (1)$$

$$[\lambda_{qd}]^T = [\lambda_d \quad -\lambda_q \quad 0]$$

$$[\lambda_{qd0}]^T = [M_{qd0}][i_{qd0}] + [\Phi_{PM}]$$

$$[\Phi_{PM}]^T = [0 \quad \Phi_{PM} \quad 0]$$

$$[M_{qd0}] = \mathrm{Diag}[L_q \quad L_d \quad L_0] \qquad (2)$$

Where index this *v*, *i*, *L*, λ, are voltages, stator currents, inductances and stator flux linkages. Sub-index *d*, *q* and *0* represent values in *dq0* frame. *rs* and ω are the stator resistance and inverter frequency, respectively, and Φ*PM* is the flux linkage due to the rotor magnets linking the stator.

The electric torque is

$$T_e = \frac{3}{2}\,\frac{p}{2}\left[\Phi_{PM}\, i_q + (L_d - L_q) i_q\, i_d\right] \quad (3)$$

and the equation for the motor dynamics is

$$J\,\frac{d\omega}{dt} = T_e - T_l - B_\omega\,\frac{\partial\theta}{\partial t} = \omega \qquad (4)$$

p is the number of poles, *T1* is the load torque, *B* is the damping coefficient, ω is the rotor speed and *J* is the moment of inertia.

If i_d is forced to be zero, then the torque is directly proportional to the *q* axis current. In addition, the introduction of a negative i_d will decline the air gap flux.

Vector control for PMSM drives provides the de-coupling control involving the torque and flux components, and is capable to achieve superior performance characteristics related to that of a DC motor, so vector manage is a popular manage method for PMSM [2]. But due to the manufacture property of PMSM, its vector control drive is only corresponding to a DC motor with no-compensation winding, its transient performance is precious, thus some other control strategies are also developed. Otherwise, in the most papers, whether the maximum torque manages for PMSM exists and its maximum torque manages is the similar theory with vector control has not been proposed and analyze.

3. EXPERIMENTAL RESULTS

Some experiments have been carried out for different two motors with broken bearing and rotor eccentricity, correspondingly. The motors were driven at irrelevant, medium and low speed. Stator currents were acquired and their harmonics in *abc* and *dq0* frames have been obtained and represented in the paper. For a three couple of poles, power supply from the inverter is three times the rotor frequency in Hz, which is obtained as rotor speed in rpm divided by sixty. All the subsequent harmonic representations have been interrelated to this rotor frequency, which changes for each rotor speed. For the first motor, one ball in the middle of the eight of the bearing was unnaturally damaged, while for the second motor a dynamic eccentricity was created by changing the midpoint of gravity of the rotor. Table I shows the parameters of the motors, which was controlled by a power converter running the manage scheme shown in Fig. 1. For the suggestion of this paper, i_d reference was fixed to zero, then controlling torque with i_q depict *q* and *d* axes stator current for a nominal torque and rotor speed in a healthy motor.

Table No. 1

Table-1:Nominal data of permanent magnet synchronous motor

Parameter	**Rating**	**Unit**
Voltage	240	V
Speed	60	Rpm
Torque	3	Kg.cm
Supply	1 phase ac	
Current	1	A
Inner bearing diameter, Di	2	Cm
Outer bearing diameter, Do	4.5	Cm

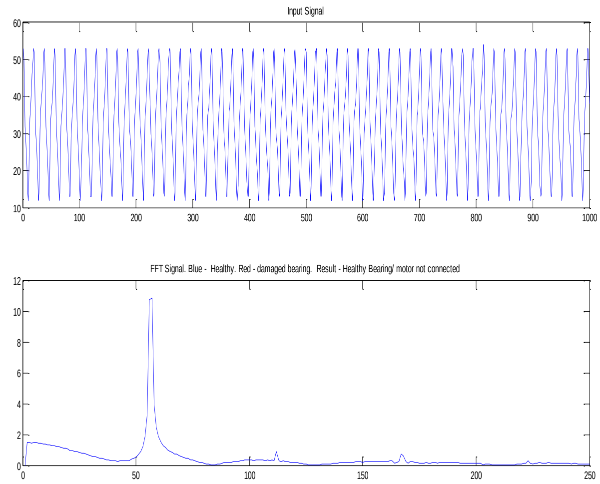

Fig-1: Stator current harmonics for a PMSM for healthy motor.

Fig.1 show the harmonic content of the stator current for a healthy motor. The curves have been normalized to a rotor frequency for every case. For the bearing damaged the harmonics first and fifth around the main one, i.e., the third harmonic from the rotor point of view, could be used to detect the failure, because they present in case of fault an increment of at least 30% over the corresponding one of the healthy motor. Of course, the higher the speed, the greater the harmonic increment, making easier the fault detection. Moreover, it is well known [7] that damaged ball in the internal ring produces specific fault mechanical frequencies given by

$$f_{ORF\_B} = \frac{Di}{D0 + Di} N_{bfr} \qquad (5)$$

where: *Di* : inner diameter, *Do*: outer diameter, *Nb*: number of rolling elements, and *fr*: rotor frequency.

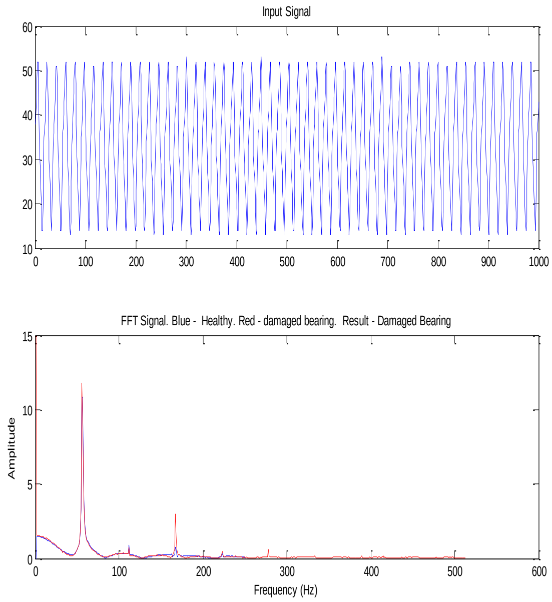

Fig- 2: Stator current harmonics for a PMSM for Healthy and bearing fault.

This mechanical frequency, which is 50 Hz for the bearing considered, will induce on the stator current (due to flux unbalance) harmonics at a frequency difference between them and the supply frequency. For the experiment carried out, with the motor running at 60rpm, the new current harmonics are at 50Hz minus *fORF_B*, i.e., 41.80 Hz. If subsequent rotor and fault harmonics are considered, the complete list of current harmonics in Table II due to mechanical unbalance by bearing damaged are obtained. Also, Fig,2 shows these specific harmonics along the stator current spectrum for a motor running at 60 rpm. The rest of the harmonic spectrum does not give useful information for fault detection, because of the presence of numerous harmonics due to motor and power converter, even for a healthy motor.

It can be concluded that bearing damage causing an eccentricity in the rotor movement produces specific fault harmonics at frequencies of rotor and its third and fifth harmonics, plus additional frequencies due to mechanical unbalances. The harmonics due to rotor eccentricity can not be clearly discriminated from the general harmonic content except in the main harmonic sidebands. However, the low amplitude of these fault harmonics regarding those of the healthy motor invalidates the stator current spectrum harmonic analysis method to detect eccentricities in the rotor. In fact, the motor used in the experiments was modified by adding an additional weight in the rotor axis of 50 g., which is quite small and not able to create a rotor eccentricity, except for a very high speed. Instead of using stator current spectrum, harmonic decomposition of zero component current in *dq0* frame is proposed here to detect eccentricity harmonics in the faulty motor, despite its low amplitude. As zero component current collects the sum of the effects of thirds components, it is assumed that harmonics 3, 6, 9, 12, 15, 18,… of this *i0* current component could show better than harmonics of the phase current the eccentricity fault. Fig.2 show the *i0* stator current harmonics, which have been related to rotor frequency. As expected, the third harmonics of the rotor frequency show the effects of the eccentricities for every speed, and could be used to detect this kind of fault, even in case of a small fault. Of course, the detection is much more easier at a high speed, because the mechanical unbalance becomes larger.

4. CONCLUSIONS

The different types of faults, such as mechanical faults, like static and/or dynamic air-gap irregularities, Bent shaft , bearing and gearbox failures and electromagnetic faults, like stator faults resulting in the opening or shorting of one or more of a stator phase winding, irregular connections and demagnetization of the permanent magnet together harmonic's amplitudes variation for the full speed range, suggest us to consider not a specific harmonic to detect fault conditions in the PMSM, but a combination of them. By this way, specific faults such as broken bearing become easier to detect. Besides, the harmonic frequencies appearing for the mechanical unbalance due to damaged internal ring can help for proper eccentricity detection.

The experimental results shows demonstrate the possibility of using these method to detect broken bearings in a PMSM.

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