DISTURBANCE ANALYSIS OF 3 PHASE INDUCTION MOTOR IN FUEL OIL PUMP WITH MOTORCURRENT SIGNATURE ANALYSIS METHOD IN PT X

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Abstract
The Equipment of Powerplant is a vital component in a power generation wiring installation, so reliability needs to be maintained at all times. Especially the 3-phase induction motor. Failure of an equipment component will result in the cessation of a process. To avoid this, operation and maintenance should be appropriate. The damage occurring to the induction motor is known through monitored indicators deviating from its normal value state. Current Motor Signature Analysis (MCSA) is one of the analyze methods for alternatives in analyzing and determining the type of electrical motor damage.So, we can determine the cause and corrective action. The deviation of operating parameters is the increase of motor temperature from normal condition has been done by using Motor Current Signature Analysis (MCSA) method at load 83% from motor maximum load. Based on the Standard Electrical Apparatus Service Association (EASA) on the Rotor Bar Damage Severity Level Chart, the motor fuel oil pump results identified as the damage of the rotor bar i.e. the level of condition 3 / medium level C: 3 (53 dB), meaning there is a marginal condition error motor rotor bar, there may be 1 error rotor bar (crack / damaged) thus causing the motor temperature rise. Further recommendations are in accordance with EASA standards, i.e. monitoring / checking should be done periodically with more frequent intervals and monitored its progress.

Keywords: *Induction Motor, Motor Current Signature Analysis, Rotor bar Fault*

INTRODUCTION

The supply of electrical energy from the power plant will be maintained one of its aspects if supported by reliable power equipment. PT X which has responsibility in the operation and maintenance of steam power plant with a capacity of 1x625 MW, one of the main objectives is to maintain the reliability of power plants and electrical supply of excellent electricity.

Since the electrical generator unit equipment is a vital component of an installation, its continuity needs to be maintained at all times. Failure of an equipment component will result in the cessation of a process. To avoid this, proper operation and maintenance must be implemented. The Breakdown Maintenance model is an option to avoid.

Equipment that is very important in the process of electricity generation and the most widely used is electric motors, especially 3-phase induction motors. Background research on electric motors is due to the findings of the observed parameters of electric motors in Fuel Oil Pump that deviates from its normal condition. The Current Signature Analysis (MCSA) motor is one of the analytical methods to facilitate the analysis of electric motors operating by knowing the change of specific symptoms through the measurement of electric motor operating parameters, to find and determine the cause and recommend corrective action based on the Condition Monitoring principle.

Induction Motor

An electric motor is a dynamic electric engine that converts Alternating Current electrical energy into mechanical energy (rotary motion). Induction motors are very widespread in the world of power generation industry, especially as propulsion equipment such as pump drive, conveyor belt, compressor, elevator and many others.

Main Components of Induction Motors

The induction motor has a main part and supporting part in its construction. The main parts of the induction motor are stator, rotor and body or stator housing. The stator is a stationary part of the induction motor. The stator is made of a soft iron plate arranged in such a way that there is a coil or winding inside it. The rotor is a rotating part and connected to the load. While the body or stator housing is where the stator is placed.

Induction Motor Working Principle

The working principle of the induction motor or the occurrence of motor rotation is that when the stator coil is supplied with three phase voltage, there will be a rotating field. The stator swivel field will affect the conductor that exists on the rotor, so that on the rotor arises induced voltage. The voltage occurring on the rotor causes the current to flow on the rotor conductor. Furthermore, currents inside the magnetic field give rise to force (F) on the rotor. When the initial coupling generated by force (F) on the rotor is large enough to bear the load coupling, the rotor will rotate in the direction of the stator rotary field. If Ns = Nr then the voltage will not be induced and the current does not flow on the rotor anchor coil, so no coupling is generated. Couple on the motor will occur when Nr <Ns [1].

3-Phase Voltage and Current

The induction motor to be discussed in this research is supplied by a 3 phase system. In the 3 phase system the three phase voltages are different angles of 120^o or 2π / 3 radians in radians unit.

$Va = Vm \cos(\omega t)$ (1)

$Vb = Vm \cos(\omega t - 2\pi/3)$ (2)

$Vc = Vm \cos(\omega t + 2\pi/3)$ (3)

$Va + Vb + Vc = 0$ (4)

$Ia = Im \cos(\omega t - \phi)$ (5)

$Ib = Im \cos(\omega t - \phi - 2\pi/3)$ (6)

$Ic = Im \cos(\omega t - \phi + 2\pi/3)$ (7)

Since the symmetric phase shift of 120^o the sum of the three phases is zero [2].

Sync Speed, Asynchronous and Slip

The speed of the rotating field of the motor is called the sync speed. For induction motor with P (number of poles), sync speed in (Rpm).

$$Ns = \frac{120 \cdot f}{p} \quad (8)$$

Since the rotor rotates at asynchronous speed which is usually slower than synchronous speed. The speed difference is called the slip rate.

$$S = \frac{nsyn - nasyn}{nsyn} \quad (9)$$

Synchronous speed depends on the frequency of the source voltage and the number of poles. Asynchronous speed or rotor speed depends not only on the frequency and number of poles but also on the motor load torque. The higher the load torque the higher the slip while the rotor speed becomes slower [3].

Induction Motor Rotor Frequency

The frequency at the rotor is not exactly the same as the stator frequency. If the rotor is locked so that it does not move (nr = 0) rpm, then in this condition the rotor frequency (f2) will be equal to the stator frequency (f1) or f2 = f1, where in this condition the motor slip equals 1 (s = 1). However, if the rotor rotates at the speed of (approximating) the synchronous spin nr ≈ ns, then the rotor frequency will be close to zero (f2 ≈ 0), where in this condition the slip on the motor equals 0 (s ≈ 0) [11].

Disturbance in Induction Motors

There are several methods already used to detect and diagnose induction motor damage, grouping into 5 namely:

a. Noise monitoring

The noise acoustic signal spectrum of the air-gap eccentricity is used to analyze the damage.

b. Torque monitoring

This method successfully used to detect rotor bar crack, stator unbalance due to deflection of winding

c. Flux monitoring

Airgap flux from an induction motor contains many harmonics. Flux observations provide accurate information about engine conditions. The changes in airgap, winding, voltage and current are reflected in the harmonic spectrum.

d. Vibration monitoring

This method is used to detect mechanical damage, because mechanical damage creates unique harmonics with different frequencies and power levels in vibration signals.

e. Current monitoring

This method is the most secure and non-destructive, by reading the current signal and converting it to the frequency domain with fast fourier transform [4].

Motor Current Signature Analysis (MCSA)

MCSA is a condition monitoring method on a three phase induction motor by analyzing the current through the stator winding. The MCSA procedure, taking the current from the stator winding uses the sensor of the current transformer in the probe of a special MCSA measuring instrument then the data will be analyzed in the form of time and frequency domain spectrum using the FFT (fast fourier transform) process to identify the existence of the frequency of electrical damage [5] [10].

MCSA Method Application

a. Broken Rotor Analysis

Broken rotor bars are usually found when the sidebands frequency slip appears around its frequency line. The standard is when the frequency of sidebands measured exceeds -35dB or often known as "35dB decreases".

b. Static Eccentricity Analysis

Eccentricity is defined as an asymmetrical air-gap condition that stays between the stator and the rotor. Static eccentricity can be found within the high frequency spectrum. Static eccentricity occurs when the frequency center (Center frequency / CF) does not reach the peak within the spectrum but is constructed as a result of the multiplication of the running frequency (RF) by the number of rotor bars (RB) on the induction motor.

c. Dynamic eccentricity Analysis

Dynamic eccentricity is different from static eccentricity, in dynamic eccentricity state there will also be running speed sideband around static eccentricity sideband from basic frequency.

d. Stator Analysis

Stator winding problems are found by identifying stator slot passing frequencies (SP). Center frequency (CF) in the stator analysis can be determined by multiplication of the number of stator slots by running speed. Problems are found when the sideband appears around the slot passing (SP) at the center frequency (CF).

e. Unbalanced Electric current and Voltage Analysis

Based on the NEMA MG-1 Flow Analysis and unbalanced voltages are found by calculating, the maximum value at less average value, then dividing by the mean and times 100%. The maximum limit of unbalance current is 3% and the maximum limit of unbalance voltage is 5% according to IEEE Standard 519 according to IEEE Standard 519 [6].

RESEARCH METHODOLOGY

Location and Object Research

The research was conducted in PT X. This research was conducted in August 2017 until November 2017.

Research Method

The method used in this research is the method of data collection and analysis. Here are the results of field observations on the performance of electric motors that cause the increase in winding temperature of the motor at the time the motor is operated. Here's an explanation of the steps of writing a paper:

a. Determine the background of the issues to be discussed in this study.
b. Determine the formulation of the problem to be discussed in this study.
c. Determine the limitations of the issues discussed so that the research discussion is more focused and focused on the objectives.
d. Field observation
   Field observation is the first step in this research, which is done to observe the data of routine monitoring results that have been done.

f. Study of literature

Literature study is done by searching information and references in the form of text book such as manual book, operation and maintenance guidance, information from the internet and other sources such as discussion or dialogue with related fields i.e. employees of PT. X

g. MCSA Measurement On Three Phase Induction Motor With All Test Software Pro OnLine II

The process of taking this data using measuring tools and Software MCSA (Motor Current Signature Analysis) is All Test Pro OnLine II.

h. Measurement Data Analysis
From the results of analysis using Software ALL Test Pro 6.2, the output data of current spectrum in time domain and frequency domain will be analyzed. The resulting spectrum results will represent the induction motor condition.

i. Research Writing
Establish the results of research in the form of Journal in accordance with the rules and guidelines in force.

Research Object Data

Data name plate on induction motor of research object shown in table 1:

Table 1. Motor Induction Information Name Plate

Model Type	DCY25-80x7	Torque	289 NM
Motor	YB2280M-2	IP	54
Head	5.0 MPa	Current	152 A
Capacity	30 m^3/h	Freq.	50 Hz
Speed	2970 r/min	Weight	560 KG
Power	90 kW	Noise	94 dB
Voltage	400 V	Years of Product	2008
Numb. rotor bar	34	Numb. stator slot	42
PF	0.91	Isolation class	F
By	Jiamusi Electric machine co., LTD		

Measurement Process

a. Preparation tools used
- Safety Wearpack
- ATPOL II Pro
- Current Probe 3000 A (FX-3000A)
- Voltage Probe
- Laptop

b. Measurement Process

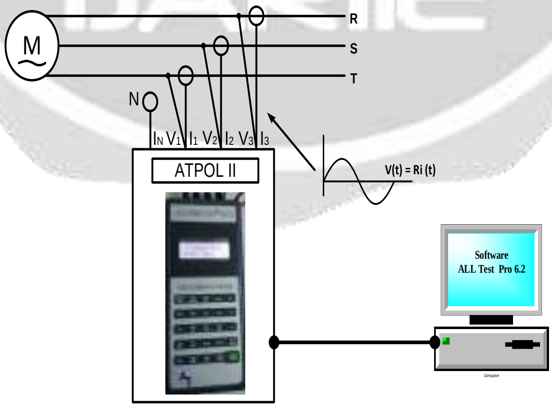

Figure 1. Testing Process Circuit

Measurement steps are carried out as follows:
- Work preparing (start motor and prepare equipment).
- Taking tools from carrying case.
- Connect each Voltage and Current probes to ATPOL II.
- Install the probe on the Source (Busbar, Power Cable, and Current Transformer) sections.

- Install the Voltage Probe (V1, V2, V3) according to the order of phase (e.g. R, S, T, then attach V1 to phase R, V2 on Phase S, & V3 at T phase).
- Install Current probe (I1, I2, I3) in order of phase. For example R, S, T, then attach I1 to phase R, I2 in phase S, and I3 in phase T. Be sure to use the Current probe according to the measuring Range.
- Setting ATPOLL II & Measuring Motor (motor in operating condition). The data retrieval process is done for one minute after completion of capture data [7].

Analysis Process with ALL Test Pro 6.2 Software

1. Preparing for Work
2. Turn on Computer / Laptop
   Double click on ALL Test Pro 6.2 Software.
3. Set File Menu
   - Open Folder and select the file that to be analyzed
   - Then right click on mouse, select header
   - Enter the motor data to be analyzed and click okay tick
   - Data Analyzing [8].

Results and Discussion

Disturbance on Fuel Oil Pump Motor

The disturbance in motor fuel oil pump is indicated from monitoring from Central Control Room for Fuel Oil Pump motor temperature increase gradually. The increase in motor temperature becomes faster when the motor is restarted after a few moments. These incidents occur repeatedly so that more specific analysis needs to be done [9].

Fuel Oil Pump Motor Specification

Data name plate induction motor used at the time of measurement can be seen in table2 below:

Table 2. Motor Testing Data

	Value	Unit
Serial Number	YB2280M-2	
Model Number	DCY25-80x7	
Power	90.0	KW
RPM	2970.0	Rpm
Poles	2	
Phases:	3	
Voltage	400.0	Volt
Full Load Current	152.00	Amp
Numb of rotor bars	34	
Numb of stat slots	42	
Torque	289	Nm
CT Ratio	1.000	
PT Ratio	1.000	
Service Factor	115	
Insulation Type	F	
Ambient Temperature	91.4	F°
Power factor	0.910	

Field Identification Data

Based on the result of field identification obtained deviation parameter of motor at the time of operation. Abstracting of daily monitoring data parameters is an increase in winding temperature of the motor by approaching the alarm limit of 110 ° C, at the time of data retrieval rise in temperature is clearly visible at the beginning of the motor start can be seen in Figure 2.

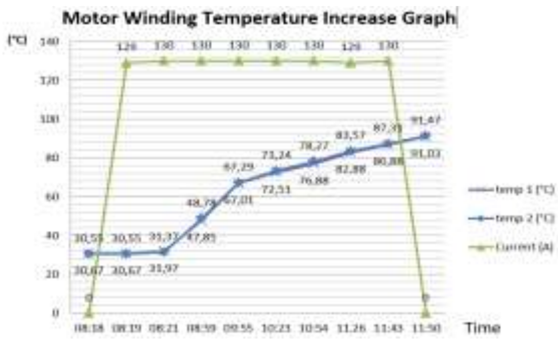

Figure 2. Motor Winding Temperature Increase Graph

MCSA Test Results on November 3th, 2017

Based on the phenomenon that occurs in the operating induction motor, that is winding temperature of the motor increase, therefore data is taken by MCSA (Motor Current Signature Analysis) method and get the following measurement result:

a. Raw Current Spectrum Current signal in time domain as shown in Figure 3 below.

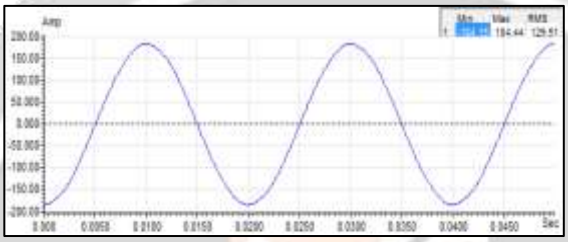

Figure 3. Raw Current Spectrum

b. Raw Current Frequency Spectrum Current signal in frequency domain as shown in Figure 4, 5, 6, 7 below.

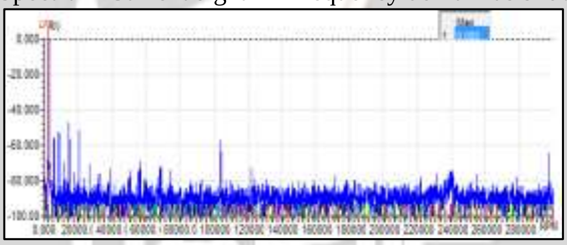

Figure 4. Raw Current Frequency Spectrum

c. Demodulated Current Trace

	Phase-1	phase-2	phase-3	Average /Total	Unit
Power Factor	0.891	0.883	0.89	0.888	-
Real Power	27.04	26.78	27.16	80.98	KW
Reactive Power	13.809	14.207	13.941	41.957	KVAR
Apparent Power	30.362	30.315	30.529	91.206	KVAR
Running Current	129.2	129	129.8	129.3	Amp
Line Voltage	407.2	407.1	407.3	407.2	Volt
Impedance	3.152	3.156	3.138	3.148	
Motor Load				82	%
Output Power				74.25	KW
Motor Efficiency				91.7	%

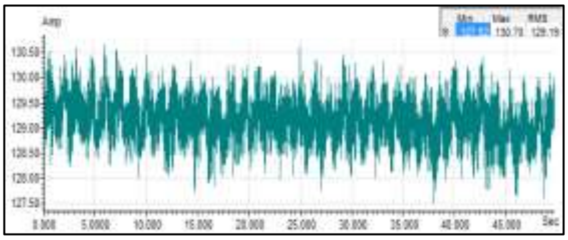

Figure 5. *Demodulated Current Spectrum*

d. Raw Voltage Spectrum

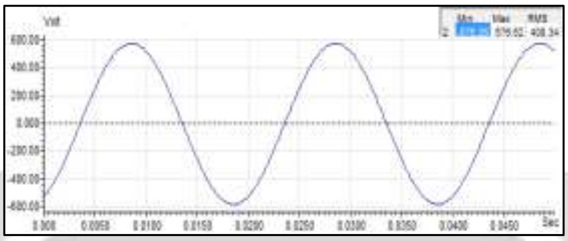

Figure 6. Raw Voltage Spectrum

e. Raw Voltage Frequency Spectrum

Table 3. Motor Parameter Test Result

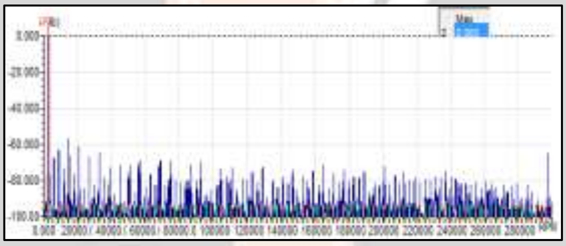

Figure 7. Raw Voltage Frequency Spectrum

Running Speed = 49.561 Hz [2973.6 RPM]
Pole pass frequency = 0.732 Hz [44 RPM]

Analysis of Rotor Bar Damage Data

The rotor bar analysis is performed to determine the extent of damage to the rotor bar. The current spectrum of the measurement results in the frequency domain (Raw current spectrum) can be shown as in Figure 8, 9 below:

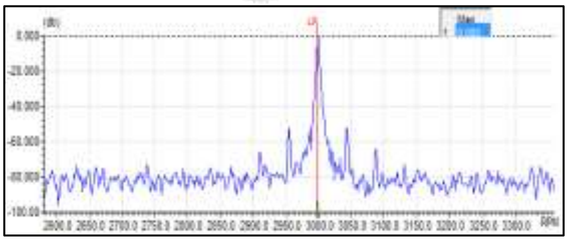

Figure 8. Interfered Motor Current Spectrum

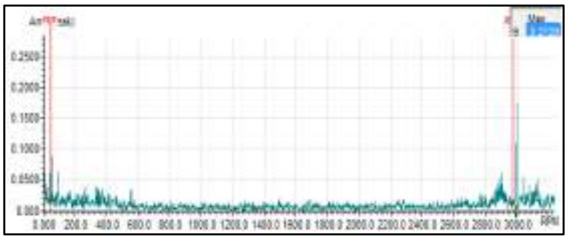

Figure 9. Demodulated Current Spectrum

The amount of running speed is:

$$Running\ speed = \frac{Rotary\ per\ minute\ (Rpm)}{60\ second/min}$$

$$= \frac{2973.6\ Rpm}{60\ second/min}$$

$$= 49.561\ Hz$$

From the calculation results, obtained magnitude value running freq. speed of 49.561 Hz. Next to find the value of the frequency of synchronous speed (frequency slip), results can be as follows:

$$Slip\ Frequency = \frac{2\ x\ Line\ frequency}{Pole}$$

$$= \frac{2\ x\ 49.957}{2}\ Hz$$

$$= 49.957\ Hz$$

Given the value of running speed frequency and synchronous speed frequency (frequent slip), next can determine the amount of side band frequencies that occur around the frequency line are:

Sideband Frequency = (synchronous speed frequency – running speed frequency*) x pole*
Sideband Frequency = (49.957 – 49.561) x 2
Sideband Frequency = 0.792 Hz

Based on the sideband frequency value of 0.792 Hz, then it can be interpreted that the sideband that appears around the frequency line value is:

Sideband Frequency_12 = Frequency Line ± Appeared Sideband Frequency
Sideband Frequency _1 = 49.957 Hz – 0.792 Hz = 49.165 Hz
Sideband Frequency _2 = 49.957 Hz + 0.792 Hz = 50.749 Hz

The value of the sideband frequency that appears between the frequency lines can be shown in Figure 10 below.

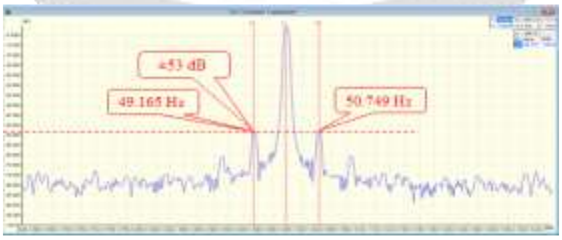

Figure 10. Side Band Frequency next to Line Frequency

Table 4. EASA Electrical Apparatus Service Association Standard

Condition	dB Value	Rotor Condition	Action
1	>60	Excellent	None
2	54-60	Good	None
3	48-54	Moderate	Trend
4	42-48	Rotor Fracture or High	Increase Test

		Resistance Joint	Intervals and Trend
5	36-42	Two or more bars cracked or broken	Confirm with motor circuit analysis
6	30-36	Multiple cracked or broken bars and end ring problems	Overhaul
7	<30	Multiple broken rotor bars and other severe rotor problems	Overhaul or Replace

To know indication of rotor bar damage can be seen amount of decrease that happened between frequency line with sideband frequency. The determination of the presence and absence of rotor damage shall be in accordance with the standard table of the EASA (Electrical Apparatus Service Association). Based on EASA standard table it can be seen that the sideband Frequency value that appears between the frequency lines is 53 dB so it can be said that the Fuel Oil Pump motor is identified as a rotor bar failure i.e. condition level 3 / moderate level C: 3 (45- 54 dB).

Static Eccentricity Analysis

Testing of static eccentricity is done on load motor condition. The current spectrum used in this analysis uses the current spectrum in the high frequency domain. The test results are shown on the Figure 11 below.

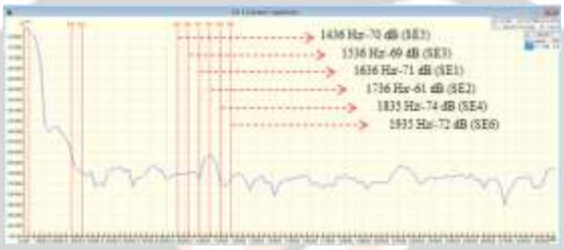

Figure 11. High Frequency Domain Current Spectrum

By calculating each running speed frequency, can be determined the frequency of static eccentricity, that are:

Static Eccentricity Frequency
= (Rb X Rf) ± (N X Lf)
= (34 X 50) ± (N X 49.561)
= 1700 ± (N X 49.561)

Static Eccentricity Frequency
= 1700 Hz ± (1 X 49.561)
= 1650 Hz ± 1749 Hz

Static Eccentricity Frequency
= 1700 Hz ± (2 X 49.561)
= 1600 Hz ± 1799 Hz

Static Eccentricity Frequency
= 1700 Hz ± (3 X 49.561)
= 1551 Hz ± 1848 Hz

Static Eccentricity Frequency
= 1700 Hz ± (4 X 49.561)
= 1501 Hz ± 1898 Hz

Static Eccentricity Frequency
= 1700 Hz ± (5 X 49.561)
= 1452 Hz ± 1947 Hz

Static Eccentricity Frequency
= 1700 Hz ± (6 X 49.561)
= 1402 Hz ± 1997 Hz

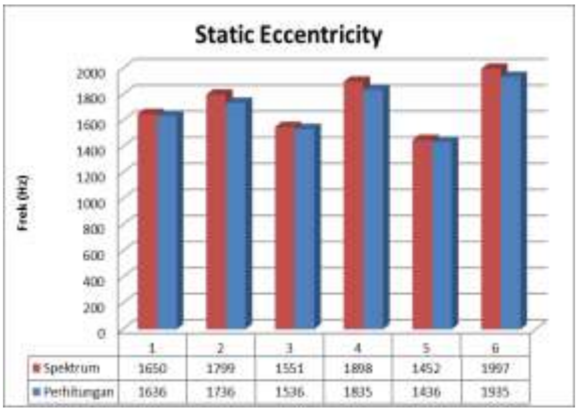

Figure 12. Static Eccentricity Comparison

Based on the comparison of current spectrum results in high frequency that static eccentricity value is not the same and much different from the calculation results. And based on current spectrum pattern at low frequency also does not show any static eccentricity disturbance.

Analysis of Current and Voltage Balance

a. Current Balance Analysis

Data of current quality measurement shown as in table 5 below.

Table 5. Motor Current Quality Test Result

	Time			
	RMS	**Peak**	**CF**	**THDF**
Current 1	129.2	184.84	1.431	0.988
Current 2	129	183.14	1.42	0.995
Current 3	129.8	184.56	1.422	0.994
Average	**129.33**	**184.18**	**1.424**	**0.992**

THDF = 99.3 %

***** *CF = Crest Factor* = $\frac{\textit{(waveform peak)}}{\textit{(waveform rms)}}$

***** *THDF = Transformer Harmonic De-rating Factor* = $\frac{\sqrt{2}}{CF}$ *(%)*

% Unbalance current

$$= \frac{I\ tertinggi - I\ rata\text{-}rata}{I\ rata\text{-}rata} x100\%$$

$$= \frac{129.8-129.33}{129.33}\ x\ 100\%$$

$$= 0.36\ \%$$

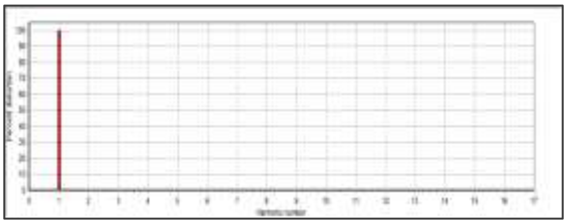

Figure 13. Current Harmonic Distortion Plot

Based on the experimental data, results the current imbalance value is 0.36%, the motor industry has set the maximum unbalance current maximum level of 10% with measured THD-I equal to 0.677%. So it's still within safe limits.

b. Voltage Balance Analysis
Voltage balance data can be seen in table 6 below.

Table 6. Motor Voltage Quality Test Result

	Time		
	RMS	**Peak**	**CF**
Voltage 1	407.2	577.21	1.418
Voltage 2	407.1	574.07	1.41
Voltage 3	407.3	575.43	1.413
Average	**407.2**	**575.57**	**1.413**

**VDF = Voltage De-rating Factor*
= 100 - (voltage unbalance, %)², %
VDF = (100 – (0)²) x 100 % = 100 %
% Unbalance Voltage

$$= \frac{V\ tertinggi - V\ rata\text{-}rata}{V\ rata\text{-}rata} \times 100\%$$

$$= \frac{407.3 - 407.2}{407.2} \times 100\%$$

= 0.02 %

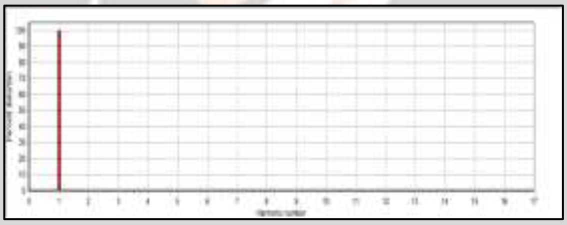

Figure 14. Voltage Harmonic Distortion Plot

Based on the result of experimental data obtained equal to 0.02% voltage imbalance value, motor industry has set maximum unbalance level of Voltage maximum 5% with THD-V measured equal to 0,248%. So it's still within safe limits. The final result of the analysis performed by Motor Current Signature Analysis method on the motor obtained the results as in Figure 15 below.

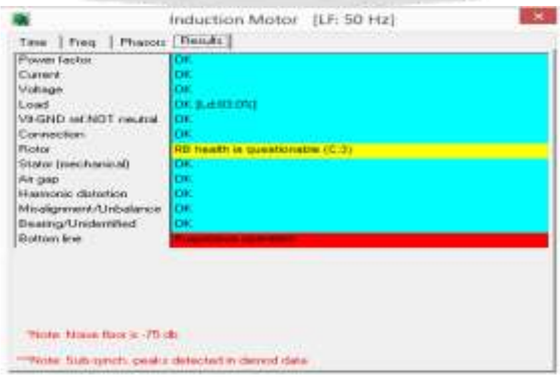

Figure 15. Atpol II Final Report Analysis

Conclusions and Recommendation

Conclusion

MCSA (Motor Current Signature Analysis) method is suitable to analyze and detect cause of damage on 3 phase induction motor. MCSA is done online monitoring. This method analyzes the motor current spectrum by converting it from time domain to frequency domain (low frequency and high frequency).

Testing on the motor is done when the motor is operated with a load of 83% of the maximum motor load. From the test results obtained the results, found that the motor Fuel Oil Pump identified rotor bar damage i.e. the condition level 3 / moderate level C: 3 (53 dB) according to EASA standard, there may be 1 rotor bar fault (crack / damaged) that causes temperature motor rises, then there is no damage due to eccentricity on the motor, 0.36% for current balance and the voltage on the motor is still within the normal limit of 0.02%.

Recommendation

After analyzing the possible source of the problem then the authors provide some recommendations to overcome the disruption of the motor such as in accordance with the standard EASA (Electrical Apparatus Service Association) should be monitored / checked periodically with more frequent intervals and monitored its development. Because there is a marginal condition fault on the motor rotor bar. Furthermore, to obtain the results of a more complete analysis can be tested with other methods such as motor and pump vibration testing, Infrared Thermovision testing or testing with other technologies.

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