Haar and Symlet Discrete Wavelet Transform for Identification Misalignment on Three Phase Induction Motor Using Energy Level and Feature Extraction

P P S Saputra\textsuperscript{1*}, Misbah\textsuperscript{1}, Eliyani\textsuperscript{1}, R Firmansyah\textsuperscript{2}, D Lastomo\textsuperscript{3}

\textsuperscript{1}Department of Electrical Engineering, Universitas Muhammadiyah Gresik, Gresik, Indonesia
\textsuperscript{2} Department of Electrical Engineering, Universitas Negeri Surabaya, Indonesia
\textsuperscript{3}UPMB Institut Teknologi Sepuluh Nopember, Indonesia

*pressa@umg.ac.id

Abstract. Currently induction motors are widely used in industry due to strong construction, high efficiency, and cheap maintenance. Machine maintenance is needed to prolong the life of the induction motor. As studied, bearing faults may account for 42% - 50% of all motor failures. In general it is due to manufacturing faults, lack of lubrication, and installation errors. Misalignment of motor is one of the installation errors. This paper is concerned to simulation of discrete wavelet transform for identifying misalignment in induction motor. Modelling of motor operation is introduced in this paper as normal operation and three variations of misalignment. For this task, haar and symlet discrete wavelet transform in first level until fifth level is used to extract vibration signal of motor into high frequency of signal. Then, energy signal and other signal extraction gotten from high frequency signal is evaluated to analysis condition of motor. The results show that symlet discrete wavelet transform at the first to fourth level and combined with feature extraction of sum type can identify normal motor and misalignment motor conditions well.

1. Introduction
Currently, induction motors are used in industry due to strong construction, high efficiency, and inexpensive maintenance. The motors are placed in various environments and conditions that can cause damage to the motor parts. Motor maintenance is required to extend the life of the induction motor. Damage to winding insulation and bearing is the most common type of damage. Bearing errors can cause 42% - 50% of all motor failures [1-5]. Bearing motors cost between 3% - 10% of the actual motor cost, but the hidden costs involved in downtime and lost production combine to make bearing failure a rather expensive abnormality. In general it is due to manufacturing faults, lack of lubrication, and installation errors. Misalignment of motor is one of the installation errors.

Misalignment is a condition where deviation occurs at the centre point between two axes that are looking (the pivot pair is not on one axis). If misalignment occurs in the clutch it will accelerate the damage clutch, bearing and produce excessive vibration [6]. The past method used to detect machine defects is predictive maintenance, one of the maintenance methods based on the condition of the equipment being checked. The trick is that the operator must go to the field to check the condition of...
the machine by touching (touching) the machine directly. This method is less reliable because of the need for a shutdown condition so it takes time and cost much larger. Therefore, to overcome one of the above problems developed a method to detect the type of motor damage from the characteristics of the vibration signal. Utilization of the vibration signal generated due to the occurrence of misalignment on the motor will be processed using discrete wavelet transform (DWT). Several types of wavelets with multiple derived levels will be used to filter vibration signal into low and high frequencies signal. And then, high frequencies signal will be extract into some characteristics. Then, characteristic of signal will be analyzed the effect of the difference between a normal motor with a motor that experienced misalignment.

2. Experimental Setup and Study Case

Experimental circuit scheme and set up are shown in Figure 1 (a) and (b), respectively which consists of an induction motor 0.5 HP, 1400 rpm, 220 volt, 50Hz and generator as mechanical load. In order to investigate the misalignment fault, three conditions of misalignment occurrence are investigated. There are 1mm, 1.5mm and 2mm misalignment of motor. For each case, the motor vibration is captured by a monitoring system. In this research, the monitoring system consists of piezoelectric sensor for vibration measurement, microcontroller, and storage devices for save vibration data.

![Figure 1. (a) Motor and generator circuit as load (b). Motor vibration data retrieval process](image)

The analog data from the stator current of the motor is converted into digital data using A/D converter and then displayed through the computer to know the waveform to be analyzed. This digital data is sent to the computer via a serial cable (RS-232).

3. Discrete Wavelet Transform

Discrete wavelet transform (DWT) is presented in this research because it has simple calculation and relatively small time interval continuous wavelet transform. Other name of dilatation/scaling parameter is Low Pass Filter (LPF) and Other name of translation parameter is High Pass Filter (HPF) [7,8]. Both of this parameter is used if we will do wavelet transform and inverse wavelet transform. HPF and LPF filter with different cut off frequency is used to transform signal. High frequency signal or detail signal is output from HPF and low frequency signal or approximation signal is output from LPF.

Firstly, original signal is passed away in LPF and HPF filter. Then, it will be produced approximation signal (cA) and detail signal (cD) whose length is a half of sampling/ frequency of original signal. This analysis is called first level of decomposition. Then, output of LPF or called approximation signal is used to the next level of decomposition. And we will use output of HPF or called detail signal to processing and analysis. This decomposition process is repeated until desired level of decomposition as seen in Figure 2. Combination of the last of approximation and detail signal is called wavelet coefficient, contained information of transformation result signal compressed.
4. Energy Level and Feature Extraction

After the discrete wavelet transforms from the motor vibration signal, then we will look for the characteristics of the detail signal or high-frequency signal from the wavelet transform. Detailed signal taken is the signal detail level one to fifth. The discrete wavelet transforms performed are haar discrete wavelet transform and symlet discrete wavelet transform. The type of signal characteristics to be taken is the mean, sum and energy level of the signal. Mean means the detailed signal of the transformation is searched for its average value. Sum is a signal of transformation is sought its absolute value, then summed, as formula (3):

\[ S = \sum_{n=1}^{n=k} |d(n)| \]  

(3)

Meanwhile, the signal energy level is calculated by squaring each component of the signal, then summed according to the equation [7,8,9]:

\[ e = \sum_{n=1}^{n=k} (d(n))^2 \]  

(4)

The result of taking characteristic extraction of these signals, will then be analyzed to determine the difference between normal motor and misalignment motor. It is also expected that the level / severity of misalignment that occurs can also be identified.

5. Analysis and Discussion

The experimental motor is then operated within a certain period of time. The result of motor vibration will be captured by the sensor and will then be stored and processed according to the system to be applied. The results of data retrieval from normal motors and motors having misalignment 1mm, 1.5mm and 2mm are as shown in the Figure 3.
5.1. Discrete Wavelet Transform

Furthermore, motor vibration data will be transformed using haar and symlet discrete wavelet transform. The result of the transformed data is the detail signal at first level to the fifth level. The higher the level, the expected identification process will be easier. Sample of signal transformed at first level to fifth level can be seen in Figure 4-5.

Figure 3. Third level of decomposition of Haar Wavelet

The curve above is the result of the Haar discrete wavelet transform from first level to fifth level. The same treatment was applied to the data for symlets discrete wavelet transform. The higher the level of wavelet transform used, the less data is generated as it is divided by approximation signals or low frequency signals. The data above looks cannot be used for the identification process because it is still random and looks the same between the first to fifth level on normal motor data and motor that experienced misalignment. So it takes the next process to process the data so that the data becomes simpler for the identification process.

5.2. Energy Level and Feature Extraction

Detailed signals at first level to fifth level obtained from the transformation will be extracted. Patterns or feature extraction to be taken are max, sum and signal energy level. The sample of results of the signal characteristics can be seen in Table 1-2.
The feature extraction of ICCOMSET 2018 classifies misalignment well, but cannot identify the level of misalignment on the motor. The perfectly distinguish the condition of the motor in feature extraction means that the result of feature extraction failed to identify the misalignment motor and the normal motor. The results can be seen in Table 3.

|        | Normal | 1mm  | 1.5mm | 2mm  | Normal | 1mm  | 1.5mm | 2mm  |
|--------|--------|------|-------|------|--------|------|-------|------|
| Level 1| Max    | 1.1E-2| 0.024 | 0.025| 0.043  | 0.0112| 0.011 | 0.051| 0.038|
|        | Sum    | 0.833 | 2.929 | 2.967| 3.27  | 0.551 | 2.89   | 3.048| 3.161|
|        | Energy | 0.0064| 0.021 | 0.032| 0.037 | 0.0064| 0.021  | 0.038| 0.034|
| Level 2| Max    | 1.1E-2| 0.015 | 0.026| 0.025 | 0.0122| 0.015  | 0.024| 0.03  |
|        | Sum    | 0.5065| 1.96  | 1.849| 1.721 | 0.8745| 1.888  | 1.878| 1.603|
|        | Energy | 0.0031| 0.018 | 0.021| 0.018 | 0.0036| 0.016  | 0.025| 0.015|
| Level 3| Max    | 1.4E-2| 0.017 | 0.034| 0.026 | 0.0134| 0.024  | 0.033| 0.023|
|        | Sum    | 0.3189| 0.766 | 0.917| 0.884 | 0.3339| 0.83   | 1.225| 0.852|
|        | Energy | 0.0016| 0.006 | 0.011| 0.009 | 0.0019| 0.008  | 0.021| 0.006|
| Level 4| Max    | 1.4E-2| 0.017 | 0.034| 0.026 | 0.0134| 0.024  | 0.033| 0.023|
|        | Sum    | 0.3189| 0.766 | 0.917| 0.884 | 0.3339| 0.83   | 1.225| 0.852|
|        | Energy | 0.0016| 0.006 | 0.011| 0.009 | 0.0019| 0.008  | 0.021| 0.006|
| Level 5| Max    | 0.0092| 0.015 | 0.111| 0.021 | 0.0099| 0.013  | 0.079| 0.017|
|        | Sum    | 0.0895| 0.217 | 0.597| 0.224 | 0.1192| 0.191  | 0.902| 0.249|
|        | Energy | 3.7E-4| 0.002 | 0.026| 0.002 | 6.2E-4| 0.001  | 0.045| 0.002|

If the misalignment gets bigger, the vibration of the motor will increase. The feature extraction of results of discrete wavelet transform must show an increase in value between the normal motor and the misalignment motor. In addition, motors with a high misalignment rate will show higher feature extraction results compared to motors with low misalignment. The yellow color in the table above means that the result of feature extraction failed to identify the misalignment motor and the normal motor because feature extraction value of normal motor is equal to or more than the misalignment motor. And the green color shows a linear increase in feature extraction value of the normal motor to feature extraction value of the motor with 2mm misalignment which means feature extraction can perfectly distinguish the condition of the motor in various conditions being tested. Meanwhile, the remaining shows feature extraction has been able to identify the normal motor and the motor that has misalignment well, but cannot identify the level of misalignment on the motor. The result of classification can be seen in Table 3 below.
Table 3. Classification results of feature extraction of haar and symlet discrete wavelet transform

|          | Data 1       | Data 2       | Data 3       | Data 4       |
|----------|--------------|--------------|--------------|--------------|
| max      | level 1-5    | level 2,4,5  | level 2-5    | -            |
| Haar     |              |              |              |              |
| sum      | level 1-5    | level 1-5    | level 1-5    | level 1-2    |
| energy   | level 1-5    | level 1-5    | level 1-5    | -            |
| max      | level 1-5    | level 1-5    | level 2-5    | -            |
| symlet   |              |              |              |              |
| sum      | level 1-5    | level 1-5    | level 1-5    | level 1-4    |
| energy   | level 1-5    | level 1-5    | level 1-5    | -            |

We can see in Table 3 above, that symlets discrete wavelet transform results in the best classification of motor conditions compared to haar discrete wavelet transform, especially for feature extracting of sum type. Total of cases successfully classified is 19 cases. Furthermore, the feature extraction of energy type successfully identifies 15 motor condition in first – fifth level transformation. While, feature extraction of max type succeeded in identifying the condition of the motor as much as 15 cases as well. In haar discrete wavelet transform, 17 cases were successfully identified by sum type feature extraction, 15 cases can be identified by energy type feature extraction and 15 cases can be identified by max type feature extraction.

From the results of this analysis, it can be seen that the feature extraction that is best for classification of motor conditions is the sum type feature extraction. And in the case of misalignment on this motor, the use of symlet discrete wavelet transform is better than haar discrete wavelet transform to produce feature extraction for motor classification.

6. Conclusion
This research concerns how to classify misalignment in induction motor. Haar and symlet discrete wavelet transform and then energy level and feature extraction signal is used to find pattern misalignment in induction motor. The result shows that the symlet discrete wavelet transform produces a high frequency signal which is better at processing motor misalignment signals than haar discrete wavelet transform. And feature extraction of sum type shows a good classification in distinguishing normal motor and misalignment motors.

7. Reference
[1] Harmouche J, Delpha C and Diallo D 2015 IEEE Transactions on Energy Conversion 30 376–83
[2] Thorsen O V and Dalva M 1999 IEEE Transactions on Industry Applications 35 810–8
[3] Barker S 2000 Power Engineering Journal 14 182–9
[4] Cornell E P, Owen E L, Appiarius J C, McCoy R M, Albrecht PF and Houghtaling D W 1982 Improved motors for utility applications. Final Report General Electric Co.
[5] Asfani D A, Surya Saputra P P, Yulistya Negara I M, Satrijadi Hernanda I G N and Wahyudi R 2013 International Conference on Quality in Research (Yogyakarta: IEEE Conference)
[6] Starr A and Rao B K N 2001 Condition monitoring and diagnostic engineering management (UK: Elsevier)
[7] Asfani D A, Negara I M Y and Surya P P 2015 Proceedings of the 3rd IIAE International Conference on Intelligent Systems and Image Processing (Japan: The Institute of Industrial Applications Engineers)
[8] Jettanasen C, Ngaopitakkul A, Asfani D A and Negara, I M 2017 IEEE 10th International Workshop on Computational Intelligence and Applications (Hirosima: IEEE Conference)
[9] Asfani D A, Purnomo M H and Hiyama T 2014 International Journal of Innovative Computing, Information and Control 10 2277-94