SinkrOn
JURNAL & PENELITIAN TEKNIK INFORMATIKA
Sinkron : Jurnal dan Penelitian Teknik Informatika
Volume 8, Number 2, April 2023
DOI : https://doi.org/10.33395/sinkron.v8i2.12207
e-ISSN : 2541-2019
p-ISSN : 2541-044X

Short Circuit Failure Detection in Induction Motor Using Wavelet Transform and Fuzzy C-Means

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Submitted : Feb 15, 2023 | **Accepted** : Feb 22, 2023 | **Published** : Apr 1, 2023

Abstract: Induction motors need to be monitored regularly because it involves the company's productivity. The induction motor monitoring method in this study uses a motor current variable which is transformed using the Discrete Wavelet Transform. Discrete Wavelet Transform (DWT) is used in this study because the results are satisfactory for detecting a short circuit in the stator winding of an induction motor. Of the many types and levels of discrete wavelet transforms, the haar wavelet transform at the third level is used in this study. Furthermore, the results of the discrete wavelet transform are processed using the Fuzzy C-means method. Fuzzy C-Mean (FCM) is the grouping approach that each part has a member degree of cluster according to the fuzzy logic algorithm. Motor modeling is shown in this article as normal condition, final fault current, and initial fault current. For this analysis, a combination of wavelet transform and Fuzzy C-means is used to classify motor currents into three motor states. The motor current is processed by Haar DWT level 3 to generate a high frequency signal. Then the high frequency signal is processed to get the energy signal. The energy signal is then fed to Fuzzy C-means to identify its condition. The results show that fuzzy C-means produces an error of 0% for the normal case, 33.3% for the initial error case and 0% for the final error case.

Keywords: Short circuit Detection; Induction Motor; Wavelet Transform; Haar Wavelet; Fuzzy C-means;

INTRODUCTION

Since their first invention, induction motor has become an important part of the factory. It's because induction motor has solid construction, are inexpensive to purchase and cheap in maintain, has high and simple to operate. Induction motor is used in a moist, hot environment, dirty, etc., that can cause damage to components of motor. Predictive inspection is importance to extend motor life, maintenance motor from breakdowns, and find failures in induction motors early.

Long operation, wet environments and frequent vibrations can put this motor in a dangerous condition and result in serious damage. Research related to induction motor that have been carried out shows that induction motor faults are divided into bearing failures (41%), rotor faults (10%), stator faults (37%), and etc. (12%) (Thomson, W.T & Fenger, M., 2003). Stator winding harm is most of common type in electrical fault after mechanical damage fault (bearings). The cost of rewinding the motor is much cheaper than the purchase price of the motor. However, costs caused by the downtime which occurs, so that output results are not achieved, makes fault of motor windings is very expensive.

Due to the development of digital signal processing technology, all signal information and characteristics have been extracted. In connection with this development, some detection methods of

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induction motor has been explained for a long time. Monitoring of motor via Motor Current Signature Analysis (MCSA) lately stuck attention of researchers and is used to detect problem in motor. MCSA works on the spectral analysis of motor current and already has been well applied to discover rotor fractures (Xu Bo-qiang & Li He-ming & Sun Li-ling, 2004), air gap abnormalities (Osheiba, A.M. Darwish, et al., 2006), and short circuits between windings in the stator (R Beran, L., 2008), and other mechanical problems (Tong Liu & Jin Huang, 2005). Furthermore, many factory cases have been applied with MCSA since 1980 and produced good output results (M. E. H. Benbouzid, 2000).

MCSA, which works using the FFT principle, is suitable for continuous signal processing such as the case of harmonics, the case of motor vibrations, etc. (D. A. Asfani et al., 2013). However, it will be a problem that the input signal in the MCSA is a non-stationary signal such as the case of a short circuit in an induction motor. So that other signal processing methods are needed.

Therefore, the next generation of digital signal processing is used in this study, namely the wavelet transform (P. P. S. Saputra et al., 2019). Wavelet transform has windowing techniques with changing sizes. Wavelet analysis allow use of long time interval (wide windows) that more exact information of low-frequency is required and shorter windows that information of high-frequency is required. Furthermore, the wavelet transform method and combined with Fuzzy C-means are used to detect short circuit faults in induction machines.

LITERATURE REVIEW

Discrete wavelet transform

Wavelet analysis converts a distorted signal into a dissimilar time-frequency scales. This results in another severe signals with a dissimilar frequency resolution. So, we shall distinguish and process every signal to obtain analysis data.

The basic wavelet transform filter processing is shown in Fig. 1. First, the original signal is surpassed through the LPF and HPF filters. Furthermore, an approximation and detail signal will be generated which is half the length of the original sample/signal frequency. This process is the first level of decomposition. Furthermore, the HPF output or also called the signal of approximation is used for level of next decomposition. This process of decomposition is repeated up to the certain level is shown in Fig. 1. The combination of the approximation signal and the last detail is called the wavelet coefficient which contains the compression of the transformed signal.

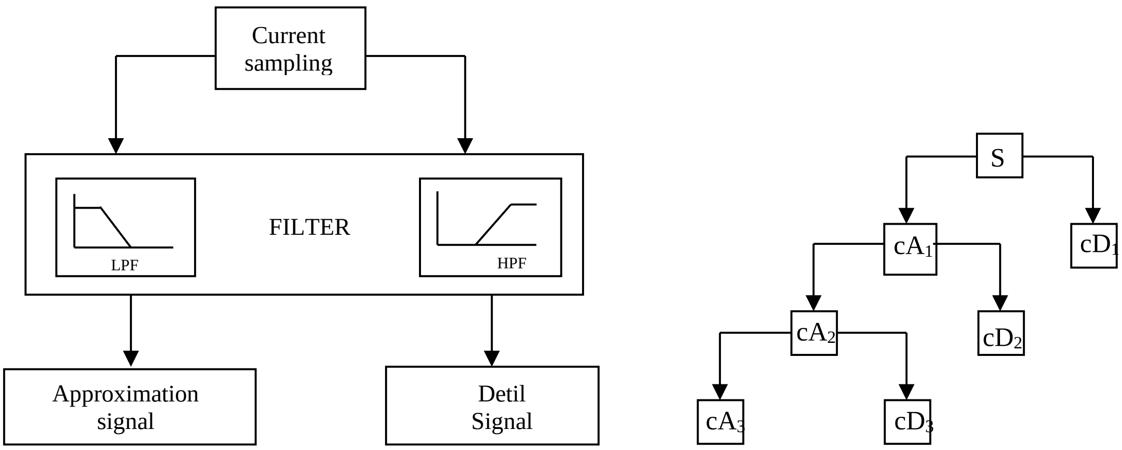

Fig. 1. First and third degree Wavelet Transform decomposition

Fuzzy C-Means

Clustering is partitioning data into the most similar data groups. This data can be categorical, numeric, or both (B.Simhachalam & G.Ganesan, 2014). Clustering algorithms ability is to declare basic data structure which could be utilized for various applications such as taxonomy of numerical, classification, medicine, economics, pattern recognition, artificial intelligence, ecology, identification and modeling. Fuzzy clustering utilizes degrees of membership that permit object to have some simultaneously clusters, with membership different levels.

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Fuzzy logic is needed to divide the problem into the desired output set. Then, there is Fuzzy cluster as a method to specify optimum cluster in vector space according on the Euclidian form for interval among vectors (Shabari S. B. et al., 2017). One of fuzzy analysis, namely Fuzzy C-Mean is frequently utilized to agglomerate data.

Fuzzy C-Mean (FCM) is the grouping approach that every part has a member degree of cluster according on fuzzy logic algorithm. Fuzzy C-Mean utilizes partitions of fuzzy so that every point of data could be a member of more than a group with diverse weights among 0 and 1. The weight will be higher the closer the data points are to the cluster center. The total weight value of each object must be one (N. Chetty et al., 2015).

Fuzzy C-means operates by setting the initial partition matrix as follows (1):

$$\mu_f(c) = \begin{bmatrix} \mu_{11}\lfloor u_1 \rfloor & \mu_{21}\lfloor u_1 \rfloor & \cdots & \mu_{c1}\lfloor u_1 \rfloor \\ \mu_{12}\lfloor u_1 \rfloor & \mu_{22}\lfloor u_2 \rfloor & \cdots & \mu_{c2}\lfloor u_2 \rfloor \\ \vdots & \vdots & \vdots & \vdots \\ \mu_{1N}\lfloor u_1 \rfloor & \mu_{2N}\lfloor u_N \rfloor & \cdots & \mu_{cN}\lfloor u_N \rfloor \end{bmatrix} \quad (1)$$

Furthermore, each membership will be modified with the following (2):

$$\mu_{ik}(y_k) = \left[\sum_{g=1}^{c} \left(\frac{|u_k - v_{fi}|^2}{|u_k - v_{gi}|^2} \right)^{1/(w-1)} \right]^{-1} \quad (2)$$

After being modified, then the objective function of each cluster is calculated with (3):

$$P_t(c) = \sum_{k=1}^{N} \sum_{l=1}^{c} (\mu_{ik})^w \left| y_k - v_f i \right|^2 \quad (3)$$

METHOD

The steps for detecting short circuit cases, as shown in Fig.2, are recording the motor current in short circuit state and normal state. Then, motor current is transformed with the haar wavelet transform at the third level so that the amount of data is reduced. Then the results, squared and summed to get the signal energy. These results are used as input to Fuzzy C-means to obtain a grouping of motor conditions depending on the type of damage.

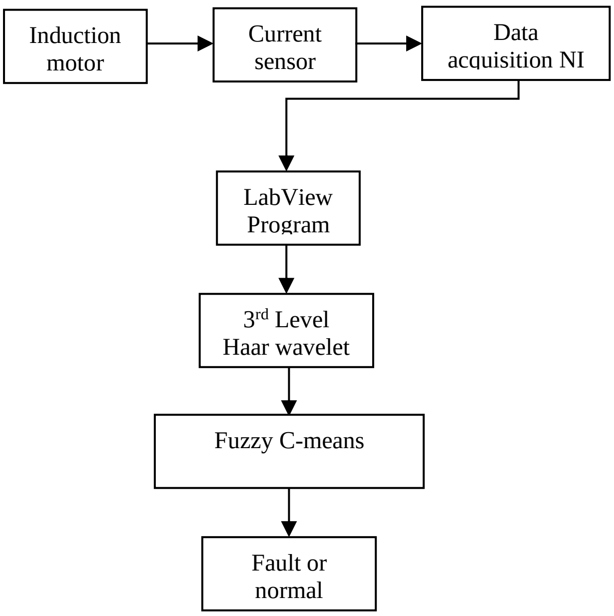

Fig. 2. Research flow

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System Modeling of Induction Motor Short Circuit Damage Symptoms

Laboratory scale experiments have been carried out to obtain the motor current spectrum. The three-phase induction motor utilized in this study has 36 slots. Each slot consists of 61 windings. Modification of the stator winding is carried out so that it can represent a short circuit scenario as shown in Figure 3. The position of the switch is varied so that the number of windings that are shorted also varies, which is calculated in percent as shown in table 3. The duration of the short circuit is regulated using a microcontroller and SSR so that it is synchronized within 50ms as shown in Figure 4. The short circuit event was recorded with the National Instrumentation PXIe-5112 data acquisition tool. The current spectrum is recorded with a sampling frequency of 10 kHz to capture the transient currents at the start short circuit (SC) and end of the short circuit (SC).

Table 1. Variations of Short Circuit Windings

Number of Cases	Case Type	% Winding
40	Normal	-
80	Start SC	1.3% - 6.5%
80	Middle SC	1.3% - 6.5%
80	End SC	1.3% - 6.5%

A total of 290 dataset is acquired. 250 data is used for training and 50 data other for testing.

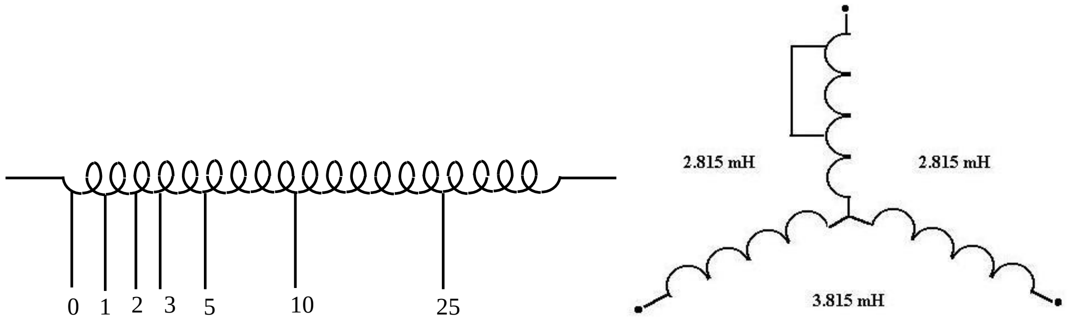

Fig. 3. Modification of winding

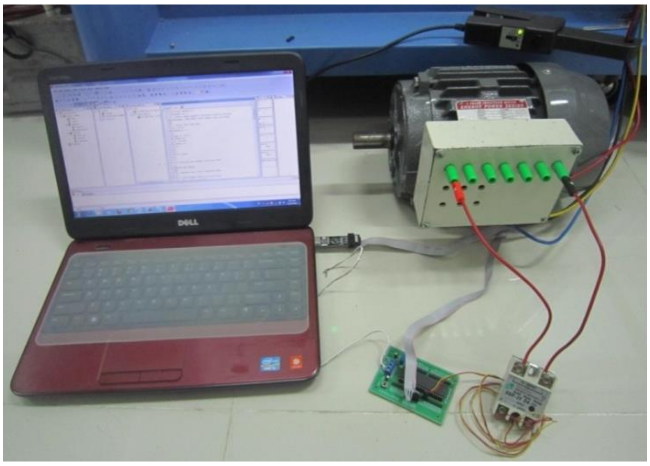
Fig. 4. System of data taking

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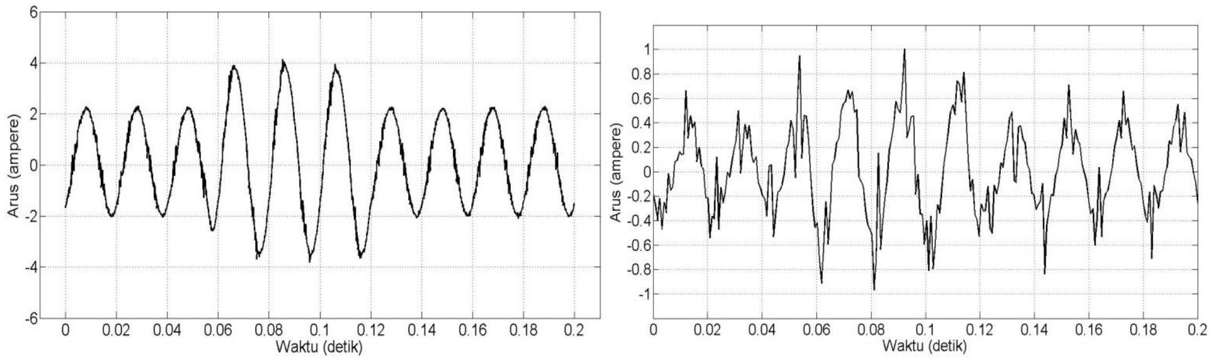
RESULT

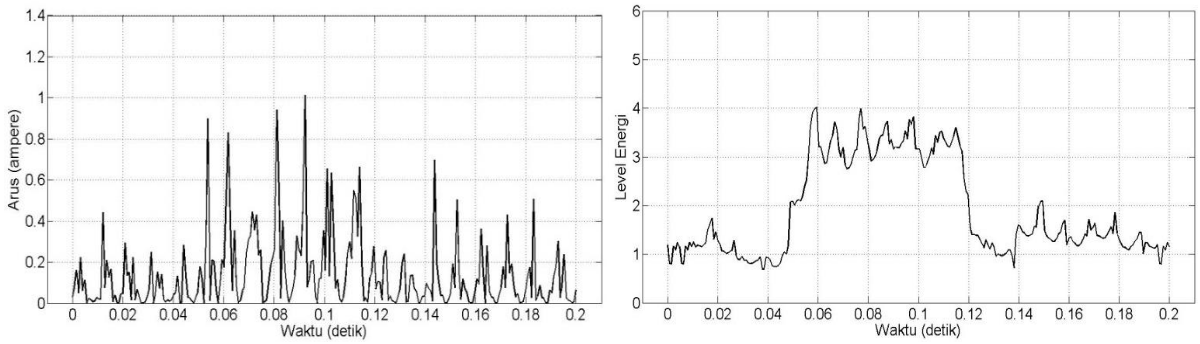
Result of Wavelet Transform on Induction Motor Current

Current characteristics of induction motor while short circuit happens could be seen in Fig. 5. Happen of short circuit current begins at 0.054 milliseconds and it ends at 0.13 milliseconds. In this occurrence, short circuit current amplitude is 3.82 A.



(a) (b)

Fig. 5. (a) Induction motor short circuit current (b) Haar Wavelet third level high frequency signal



(a) (b)

Fig. 6. (a) High frequency signal square (b) Energy level

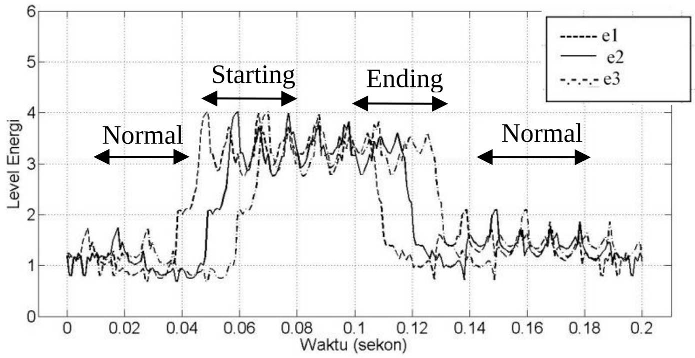


Fig. 7. Energy Level e_1, e_2, and e_3

Fig. 5-7 shows short-circuit current signal on the motor and the high-frequency haar wavelet transform results at the third level. As displayed in the figure, the third level of wavelet transform generates a high-frequency signal so we know begin and end of short circuit current obviously. Fig. 6(a) shows the square of HF signal in the third order of wavelet transform. It can be observed that among the

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beginning and end of the disturbance has a high signal. Fig. 6(b) shows the signal energy level obtained from the sum results within a certain time range from Fig. 6(a). This indicates that during a short circuit case an increase in the energy level occurs. Thus, the start and end of a short circuit can be explored according to their energy levels.
Fig. 7 shows the input variables e_1, e_2, and e_3. In fact, these variables is got from signal e_2, but it is forwarded 10ms to get e_1 and delayed 10ms to get e_3. The values of e_1, e_2, and e_3 will be utilized to process normal current, starting and end fault current. The characteristics of e_1, e_2, and e_3 at normal current, starting and end fault current is described in table 2 as follows:

Table 2. Motor Current Energy Level

Case	Energy Level		
	E1	E2	E3
Normal	Low	Low	Low
Start SC	High	Middle	Low
End SC	Low	Middle	High

DISCUSSIONS

Fuzzy C-Means

Current characteristic of motor while short circuit happen is described in Figure 6. Short circuit current starts at 0.055ms and disappears at 0.12ms, that it has 65ms of time length. For this phenomena, the amplitude of short circuit current is 3.82 A.

Fault current and normal current, specifically start and end fault is processed with Fuzzy C-Mean. The Fuzzy C-Mean inputs are the normal current, initial fault current and final fault current, e_1, e_2, and e_3. 240 datasets for training will also be evaluated using Fuzzy C-Mean to check accuracy of the method. Afterwards, 50 datasets for testing shall be entered into Fuzzy C-Mean to evaluate the robustness of Fuzzy C-Mean analysis. Fuzzy C-Mean results on some dataset for training is shown in table 4.

Table 3. Simulation results of the training dataset using Fuzzy C-Mean

Case	Error (%)
Normal	0
Start SC	0
End SC	20

Table 3 shows that the Fuzzy C-Mean is accurate for classifying each case. Fuzzy C-Mean produces an error of 0% for the normal current case, 0% for the initial fault case and 20% for the final fault case with 10 wrong data. These 10 wrong data are considered normal cases by Fuzzy C-means.

For the Fuzzy C-Mean results on the 50 datasets to be tested can be seen in table 4.

Table 4. The results of the simulation of test data using Fuzzy C-Mean

Case	Error (%)
Normal	0
Start SC	33.3
End SC	0

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Table 4 shows that the Fuzzy C-Mean is accurate for classifying each case. Fuzzy C-Mean produces an error of 0% for the normal flow case, 33.3% for the initial fault case with 5 wrong data and 0% for the final fault case.

CONCLUSION

This research paper show us the ability of Haar wavelet transform in third level combined with Fuzzy C-Mean to identify temporary faults in stator winding of induction motors. In method proposed, identification according to start and end short circuit using energy level is presented. The energy level is got from the high-frequency signal of the third level Haar wavelet transform. Furthermore, the normal current energy levels, initial and final short circuit fault currents are used as inputs for Fuzzy C-Mean. Experiment in lab was done to get 290 datasets which were varied by the number of short-circuited windings of the induction motor stator winding. The 290 datasets are divided into 240 datasets for training and 50 datasets for testing. The results show that the Fuzzy C-Mean gives an error of about 0% for the case of normal motor current and final short circuit current and an error of 33.3% for the initial short circuit current.

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