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VIBRATION FAULT DETECTION AND CLASSIFACTION BASED ON THE FFT AND FUZZY LOGIC

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ABSTRACT

Vibration fault exhibit a multifaceted and nonlinear behavior generation in rotated machines, for example in a steam turbine (ST). Vibration fault (VF) is collectedin the form of acceleration, velocity, and displacement via the vibration sensor. This fault damages the turbines if it strays into the danger zone. This paper first models the VF in a time domain to transfer the frequency domain via an FFT technique. The signals were applied to the fuzzy system to be used by the VF for classification via sugeno and mamdani Fuzzy Inference System (FIS) to generate the signal that will reflect the VF in the event it is embedded into the protection system. The Membership Function (MF) sets depends on practical work in a power plant, and the ISO is interested in ST vibration zones. The outcomes of the sugeno fuzzy property is the generation of stable and usable signals that can be used within the protection system, mostly owing to its efficiency in detecting vibrational faults. The results from this work can be utilized to prevent VF from generating on ST via increased processing that will feed signals for ST controls.

Keywords: vibration fault, signal processing, fuzzy system.

1. INTRODUCTION

Detecting faults on a machine is quite the challenge. Classifying the faults is also a challenge, as the classification is reliant upon the results (Londhe, Patre, and Tiwari, 2014). Thus, the investigator utilized many methods to discriminate faults into categories of neural, fuzzy, FFT, and the wavelet, which are hybridized in some work to increase the accuracy of the decisions (Raj and Murali, 2013) (Xiao *et al*., 2013) (Marichal, Artes, and Garcia-Prada, 2010) (Muralidharan and Sugumaran, 2013). Vibration faults damages the machines, causing in lost revenue via increased maintenance and time (Li-juan, Chun-hui, Min, and Yong, 2013). VF is classifiedinto three zones, based on the International Standardization Organizations ISO 10816-2 as normal, alarm, and danger zones (ISO, 2001). The signal was modelled in the time domain related to VF that is unsuitable for detection or analysis. Thus, the signal transfers itself to the frequency domain to make it convenient for computer applications, identification, and classification of the data (Muralidharan and Sugumaran, 2013) (Marichal *et al*., 2010). The fuzzy system has two type of FIS: sugeno and mamdani FIS (SONG, LIU, and ZHU, 2012) (Guney, K; Sarikaya, 2009). Thesetypes are linked via design steps, such asfuzzification, design rules, and defuzzification the data. These steps will implement the fuzzy by constructed the input and output MF based on the values close to MF (Jha, Hayashi, and Yadava, 2014).

The fuzzy is utilized to detect or control the VF by hybridizing with other techniques. (Gabriel and Chhatre, 2013) merged the fuzzy with Hilbert-Hung to monitor the vibration in rail travel. The fuzzy is hybridized with wavelet in (Hashemi and Safizadeh, 2013) to detect the vibrations on a gear box. The accuracy was augmented to extract thefuturecurve of the speed and vibration by the hybridized fuzzy with the Support Vector Machine(SVM), as discussed in (Xiao *et al*., 2013). (Muralidharan and Sugumaran, 2013) proposed detection of faults by designing the algorithm using Rough set-wavelet-fuzzy techniques. Precup R. *et al*. (Precup and Hellendoorn, 2011) suggested the adaptation of sugeno FIS for use with complex control system to improve the stability of the control. Rav and E. *et al.* (Ghotbi Ravandi, Aminian, Monfared, and Sarrafi, 2011) observed fuzzy adaptive with neuralnetwork giving the ability of resetting the MF itself with time. The FFT was modified to generate the envelope signal that represent the VF for it to be applied to the neural technique to detect the vibration on the bearing of the machine, which shows the envelope signal increasing the accuracy of the fault discrimination (Marichal *et al*., 2010). Eventually, (Nezhad, Zand, and Hoseini, 2013) applied the sine, square, and shot signal on the sugeno. The outcome of the test showed the fuzzy system generating linear signal to represent the non-linear signal applied on the fuzzy.

The construction of this report includes research methodology (section 2), with (section 3) showing the modelling. The implementation of the fuzzy is detailed in (section 4), while (section 5) compiles the simulation results from MATLAB. The work in concluded in (section 6).

2. METHODOLOGY

This work follows the following steps; First, generatethe VFsignal. Second, the signal was transferred to thefrequency domain by the FFT technique. Third, the FFT signal is modifiedto generate anenvelope curve representing the FFT data. Fourth, design the fuzzy system based on the mamdani and sugeno FIS.Eventually, the signal of the FFT and the modifiedFFT are applied

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ontoboth FIS system to compare between the results MATLAB is utilized to design the algorithm this work.

3. MODELING OF VIBRATION SIGNALS

The acceleration mode was utilized in the work; thus, the VF will represent via the acceleration signal. The signal of the VF is modelled and shown in the next section, where the signal will simulate the VF related to the ST. After that, the signal is transferred to the frequency domain via digital signal processing containing FFT and filtering.

3.1 Acceleration vibration signal

As previously mentioned, the vibration signal mode has the acceleration, displacement, and the velocity, wherein this work will model the correlation signal to represent the VF of the ST(Li-juan *et al.*, 2013) (Lilo, Latiff, Aminudin, and Ilijan, 2014). Thus, the signal is implemented by the MATLAB algorithm based on the Equations 1 and 2, with the design of the max speed being 3000rpm.

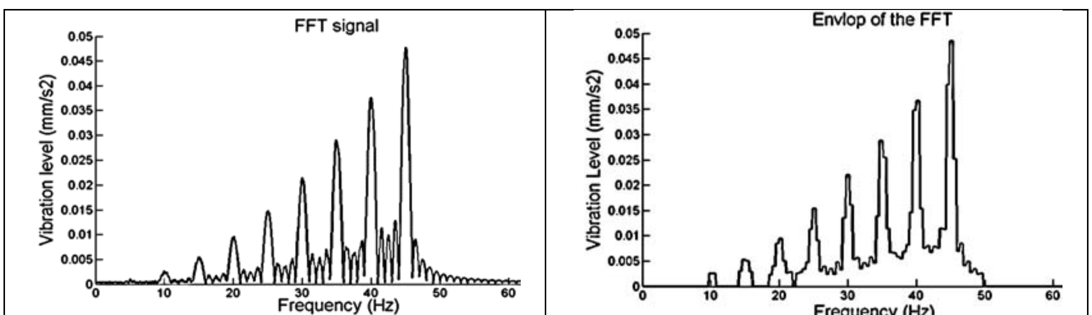
$$a=- A \sin (\omega t) \quad (1)$$

$$A= \omega V \ (mm/s^2) \quad (2)$$

where V= amplitude of the velocity, a=harmonic signal of acceleration A=acceleration amplitude, ω=2πf, t=time, f=frequency (depending on the machine speed) [19] (Mobley R. Keith, 1999) (De Silva and Clarence W., 2007).

3.2 Signal - processing vibration signal

The methods utilized to extract the future signals are; FFT, wavelet, chain code, and others (Xiao *et al.*, 2013). Therefore, the signal will be transferred from the time to frequency domain based on the FFT, as shown in Figure-1 (Muralidharan and Sugumaran, 2013). Moreover, the vibration signal, with noise, can be removed based on the filtration of the signal, where those two steps represent the digital signal processing on the signal (Deng and Zhao, 2013) (Marichal *et al*., 2010). The signal produced by the FFT technique is still complexed value and do not give the actual indicator to the vibration fault, thus, the signal modifying to generating the envelope signal of the FFT (Marichal *et al*., 2010), which is shown in Figure-2. However, the VF will be represented by two signals; first one is the FFT signal; the second is the envelope data of the FFT, where the fuzzy techniques will be used to classify the VF value.



(a) (b)

Figure-1. Molding of VF (a) FFT model (b) envelope signal of the FFT.

4. DESIGN OF FUZZY SYSTEM

The fuzzy technique has two kinds of the FIS utilized in the different application as control and protection (Gabriel and Chhatre, 2013) (Guney, K; Sarikaya, 2009). These types of the FIS are called sugeno and mamdani. Most researchers select the FIS type, based on the trial-and-error which is sitting the MF. In both methods, the methodology of the design the fuzzy system is similar, but differ in the last step related to the selection of the output of the system, where the Sugeno generates constant values to represent the situation of the input data. Thus, design fuzzy need the flow of these steps: Fuzzification, the fuzzy operator, design the rule weight, output aggregation, and defuzzification the production (Jha *et al*., 2014). This work will design three input MFs, based on the ISO10816-2 and experience about the ST behavior. The three input are vibration fault, the speed of the machine, and the power generation value. The output MFs were designed on the sugeno FIS to provide constant value which is reflex of the VF situation (Precup and Hellendoorn, 2011) (Jassbi and Serra, 2006), the output MFs have represented the start-up and the power generationconditions. On the other hand, mamdani output MFs is designed to generate values that are proportional to the input vibration faults. The details pertaining to the design for both types are shown in Table-1. The fuzzy system of the sugeno is illustrated in Figure-3, while Figure-4 shows the input MFs of the sugeno type.

Table-1, detail of the fuzzy parameters.

FIS type	Sugeno FIS	Mamdani FIS
Input MFs	"trap me, zmf" (3)	"trapmf" (3)
Output MFs	"constant" (2)	"trimf" (2)
Defuzzification	"wtaver"	"centroid"
Implication	"min"	"min"
Aggregation	"max"	"max"

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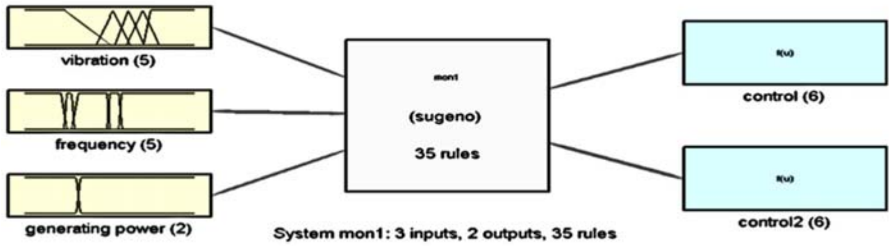

Figure-2. Sugeno fuzzy FIS.

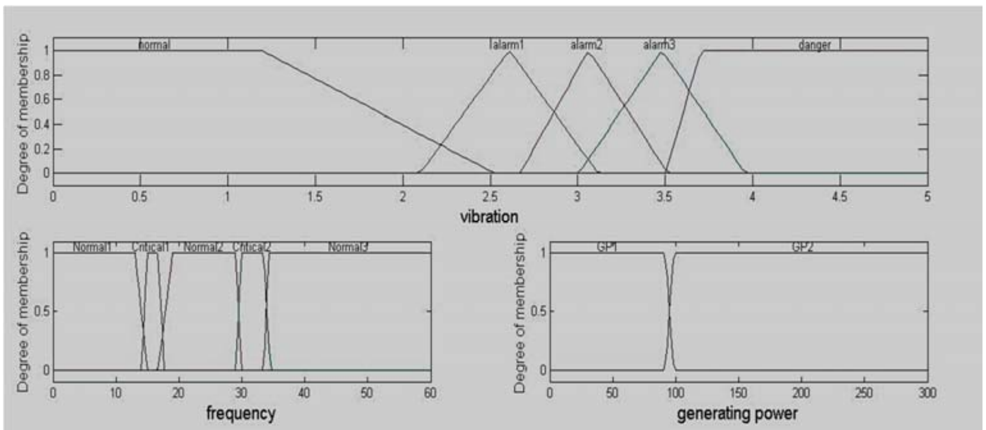

Figure-3. Input membership functions for sugeno type.

5. SIMULATION RESULTS

The primary intention of this work has protected ST from VF via the generation of signals that are proportional to VFs. The signal can shut down the ST or send an alarm to the operator if the VF crept into the alarm zone. On the otherhand, the work is interested in selecting which FIS is convenient for use with protection system and observes the effect of modifying the FFT signal upon the stability of the Fuzzy system. The results of the applied different levels of the VF on the fuzzy systems are shown in Figures 5 and 6. The outputs of the sugeno FIS with the applied two types of signals that are related to the FFT and the FFT are modified which are shown in the figure5. This result shows the usage of FFT signal being modified to signal a more stable than applied FFT without alterations. The comparison between the throughput of the sugeno in Figure-5 and the outcome of the mamdani in Figure-6 shows the result of the sugeno type beingacceptableinthis work. Thus, the result of the sugeno with FFT modifications is betterthan the other outputs, and is usefulingeneratingsteadysignalstoprotect the ST from VFwithout compromisingthe stability of the system's control. Figure-7 show the completed processing of generation signal, transfer to FFT mod and filtration, and application on the fuzzy to produce a constant value used for protection.

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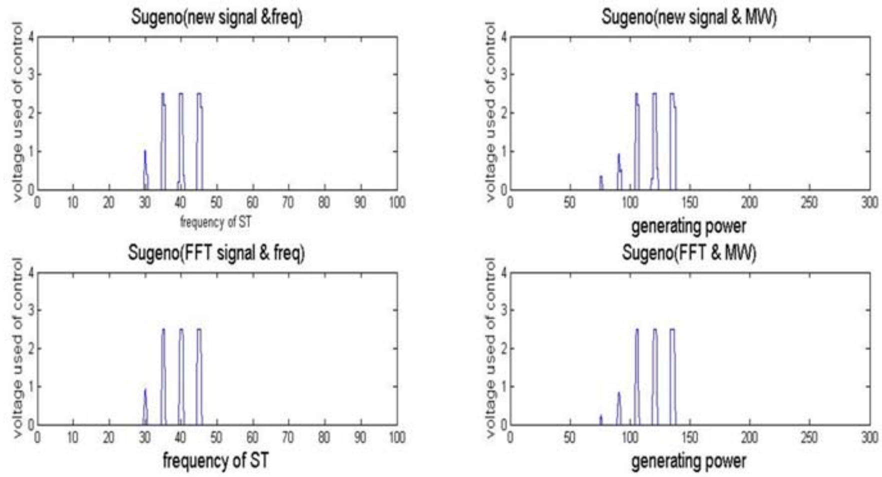

Figure-4. output signal of sugeno fuzzy method.

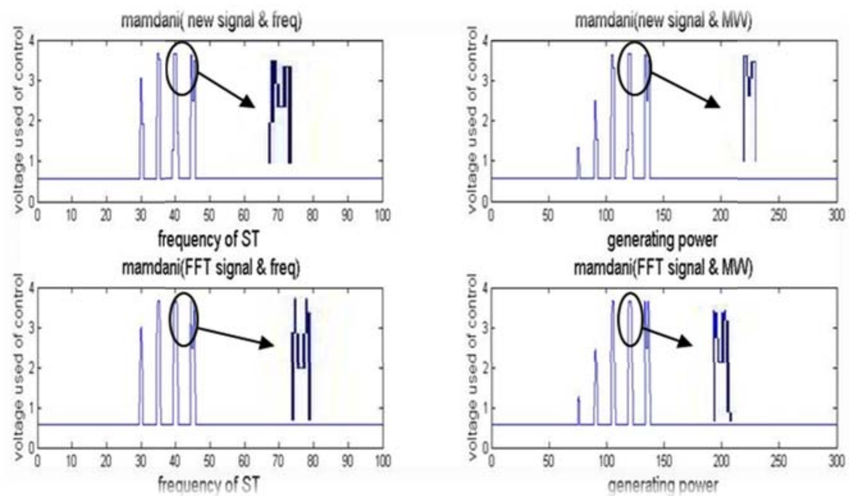

Figure-5. Output signal of sugeno fuzzy method.

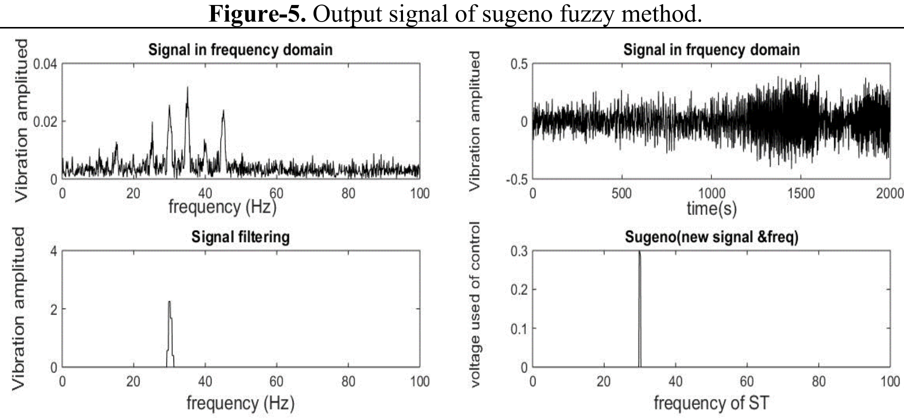

Figure-6. Completed processing of the simulation.

6. CONCLUSIONS

This simulation hasbeen designed to diagnose the VF on ST based on the modified FFT and fuzzy technique. The result of this work is the generation of a signal proportional to VF being used to protect the system of theST, but should simultaneously be stable to maintain system control. This work verifies the ability of the fuzzy with modified FFT to discriminate between the VF and generation signal for protection. The sugeno is a convenient method to protect and control, as it is capable of generatingstable signals to represent nonlinear and complex signals. The design showed that the fuzzy with signal processing is efficient in detecting faults on the ST to protect or control the ST from damages or failures.

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