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Comparative Analysis between PI and Wavelet Transform for the Fault Detection in Induction Motor

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Abstract

Squirrel cage Induction motor is widely used in industries because roughest construction, highly reliable, low cost, high efficiency, user friendly and maintenance is minimum as compare to other motor. Induction motor monitoring has a challenging task for researcher engineers' and industries. In this paper we will discusses the fundamental fault in induction motor. The PI & wavelet transform is considered the most popular fault detection method now a day because it can easy detect the common fault in induction machine such as turn to turn s/c, broken rotor bar, bearing deterioration & open circuit faults etc. According to IEEE-IAS most severe fault is bearing fault (44%), then second is stator winding fault (26%), and last is rotor broken bar fault (8%) and other fault is (22%). Another survey according to Allianz most severe fault is stator winding fault (66%), then rotor fault (13%) and bearing fault is (13%) and other is (13%). (4). There are many methods for detection the fault basically conventional method and other is signal processing technique. Automatic fault detection is widely used in industries because save the maintenance time and money. The overall problems are subdivided into two distinct key modules: (a) operation and control, (b) fault diagnosis. In this paper we proposed a method of comparative analysis between PI & Wavelet Controller for fault detection in Induction motor and find out which one is the best. In this paper we consider only two faults: (a) Broken rotor bar fault, (b) short stator winding fault. Basically bearing is the outer portion of the motor so bearing fault detection is easy as compare to short stator winding fault or broken rotor bar fault.

Keywords: Wavelet transform, PI Controller, and Fault Diagnosis, Operation and Control

Introduction

Squirrel cage Induction motor are widely used in many purpose such as pump, blower, fan compressor, etc. The studies of Induction motor behavior during operation is very tough job. Under operating condition the component of Induction motor are subjected to thermal, mechanical, and electrical stress. The stress is increase during transient's state such as supply and load change and many cause temperature is rise. If occurrence the mechanical faults in an Induction motor results asymmetry in winding or air gap eccentricity, which lead to change the air gap space increase the harmonics distribution. The harmonic spectrums of the stator current under study state condition which can be obtain by using power-gui FFT analysis. When the motor is heavy loaded or change in the load dynamically that case motor drawn more current that's why motor is over heated and create the insulation problem due to motor winding insulation is failure that case motor will be short circuited. If we control the temperature rising problem so 90% fault is under controlled. But temperature rising is not under controlled because motor is run continually without any interruption and reset. These developing faults should be detected and corrected in time to prevent catastrophic failures. So apply the condition monitoring methods. There are several condition monitoring including temperature monitoring, chemical monitoring, vibration monitoring, and acoustic emission monitoring are available in market. All this condition monitoring methods required different types of expensive sensor and specialized tools where as current monitoring out of all dose not required addition sensors. There are several methods available for detection the faults, basically current monitoring is most popular method because if we find out the nature of current so easy to decide motor is healthy or faulty. When three phase balance system the all three phases current are equal and the neutral current is zero. But system is unbalance so three phases current are unequal and also change the magnitude & phase angle of all three phases. Present time many methods are available including conventional methods and signal processing techniques. In conventional methods are PID, PI, PD, etc. but in signal processing techniques have FFT, STFT, Fuzzy controller, Haar Transform, Hilbert Transform, and Wavelet Transform. This paper includes an introduction of wavelet controller and PI controller. A feature coefficient function is defined to reflect the corresponding broken rotor bar faults and short stator winding fault. Researchers have found many diverse methods of fault detection in induction motor. The stepwise process is the following section.

Wavelets and its Application for Fault Detection

Wavelets analysis allows representing functions of time satisfying certain mathematical requirements Unlike Fourier analysis, in wavelet analysis the scale used to analyze the signal plays an important role. In wavelet analysis, the signals are processes at different scales or resolutions. Thus, if we look at the signal with a wide window, we will identify general characteristics, whereas if a small window is used then we obtain detailed information about it [5]. Another important feature that makes wavelets interesting is that they allow the analysis of choppy and non-stationary signals.

Continuous wavelet transform

Unlike Fourier transform, the technique based on wavelets allows to perform, through a multi-resolution analysis (MRA), several overlapped projections of the signal. For a signal f (t) the generating function of the MRA can be expressed as [18]

$$\varphi_j^k(t) = 2^{-j/2}\phi(2^{-j} t - k) \quad 1$$

Where ϕ is the so called mother wavelet, j indicates the decomposition level and k is the time shift factor. The wavelet coefficients obtained by applying an orthogonal wavelet are [18]

$$d_k^j = \int_{-\infty}^{\infty} f(t)\, \varphi_k^j(t)\, dt \quad 2$$

$$\omega(m,n) = \int_{-\infty}^{\infty} f(t)\, \Psi_{m,n}(t)\, dt \quad 3$$

Where φ_k^j is the wavelet analyzing function obtain form Haar. Morlet etc could be used.

The discrete wavelet:

Multi-resolution analysis (MRA) Let s(n) be a discrete-time signal to be decomposed into its approximate and detailed versions using the MRA. The first level decomposition coefficients are a1(n) and d1(n), where a1(n) is the approximate version of the original signal s(n) and d1(n) is the detailed representation of the original signal s(n) which are defined as [5],

$$DWT(m,k) = \frac{1}{\sqrt{m_0^m}} \sum x(n)\, g\left(\frac{k - nb_0 a_0^m}{a_0^m}\right) \quad 4$$

$$a_1 n = \sum_k^n h(k-2n) s(k) \quad 5$$

$$d_1 n = \sum_k^n g(k-2n) s(k) \quad 6$$

Where h(n) and g(n) are the decomposition filter of s(n) in $a_1 n$ and d_1n respectively. The next (second) decomposition level is based on $a_1 n$

$$a_2(n) = \sum_k^n h(k-2n) a_1(k) \quad 7$$

$$d_2(n) = \sum_k^n g(k-2n) a_1(k) \quad 8$$

Upper level decomposition can be obtain in a similar fashion. The coefficient a_2 and $d2$ are computed using the tree decomposition level algorithm allowing storing low frequency information of the signal as well as discontinuities.

Application to fault diagnosis

The first consideration before applying the MRA algorithm to obtain good signal decomposition is the selection of the most suitable wavelet for the desired purposes. There is no clear criterion to select the most adequate wavelet, but it is convenient to use only one type of wavelet for the whole decomposition process. It is also recommended to use high decomposition levels (greater than four). For lower levels the mother wavelet is located more in time and oscillates faster in a short period of time. As the wavelet goes to higher levels, it is located less in time and oscillates less due to the dilatation nature of the wavelet transform. Therefore, fast and low type of faults can be detected with one type of wavelet. A practical suggestion is to use a wavelet “similar” to the nature of the perturbation to be analyzed. In this study we have chosen the wavelet Symlet 8 [5]. Symlet is a family of wavelets that are almost symmetric and were proposed by Daubechies as a modification to the family of Daubechies wavelets (db). Both families have similar properties.

Application of the MRA

The MRA was carried out decomposing the original current signals into 10 levels, each one of them having its own detailed coefficients and a determined range of frequencies. a motor under failure and one without failure, respectively. The MRA of the stator current for both motors was done using the MATLAB Wavelet Toolbox, where the wavelet Symlet 8 with 10 decomposition levels was selected [4]. At the seventh level we could find important differences for the failed motor, since it contains the frequency components $f \pm 2sf$, which in this case are 42 and 58 Hz. The same is also true at the sixth level for the sane motor.

Transient suppression

The MRA carried out in the previous section allows a better comparison between the failed and sane motors. It can be noticed from Figs. 11 and 12 that the values should be close to those observed between 1 and 3 s, but the transient does not allow getting clearer results. For this reason a window was used to pre-multiply the envelope in order to suppress the transient effects. A Tukey window was selected which is of the cosine type graduated according to the parameter α. When $\alpha \leq 0$, the window becomes rectangular and when $\alpha \geq 1$ it becomes a Hanning window. Figure 13 shows the form of the Tukey window for different values of α [30]. In this study, a value of $\alpha = 0.225$ was chosen and the envelope was pre-multiplied by this Tukey window. Then the detailed coefficients were computed for the ninth level (sane motor) and tenth level (failed motor) suppressing successfully the transients. It is evident the improvement obtained by suppressing the transient in the wavelet decomposition allows a better comparison between the sane and failed motors and hence a better fault diagnosis. To complete the failure analysis, it remains to estimate the fault threshold. To this extent statistical analysis will be used in the next section to determine trends and mean values.

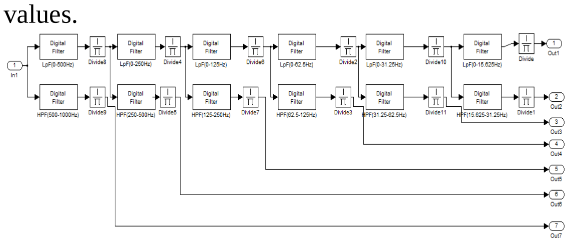

Fig: 1. Proposed analysis process algorithm

There are two characteristics of wavelet

1. A finite energy signal can be reconstructed when the admissibility condition is satisfied by the Type equation here. Wavelet without any need of decomposition values. As a result, the equation of admissibility equation is presented as follows:

$$\int \frac{|\Psi(\omega)|^2}{|\omega|} d\omega < +\infty \qquad 9$$

The Fourier transform is denoted by (ω) while the wavelet function is denoted by (t). The fourier transform is used to analyses the wavelet signals as well as reconstruct them without any information loss. The Fourier transform will be zero according to the admissibility condition which is given by the equation:

$$|\Psi(\omega)|^2 = 0 \qquad 10$$

The second important characteristic of the wavelet is:

$$\int \Psi(\omega) = 0 \qquad 11$$

2. A limited number of regularity conditions are been imposed in order to resolve the squared relationship that exists between wavelet transform's time bandwidth and the input signal which will then ensure a concentrated and smooth wavelet function in the domains of frequency and time. Down-sampling and filtering can be used to implement decomposition which can be iterated with success as presented in [72].

The total levels of decomposition denoted by (L) will be calculated based on the following equation:

$$L \geq \frac{\log\left(\frac{Fs}{f}\right)}{\log(2)} + 1 \qquad 12$$

$$D_{required} = \frac{f_s}{R} \qquad 13$$

All results shown in figure no. (4), (5), and (6),

For integral control action the actuating single consists of proportional error signal added with integral of the error single. Therefore, the actuating signal for integral control action is give by,

the following equation.

$$u = K_I \int e \, d\tau$$

13

In the PI controller we have a combination of P and I control i.e.

$$u = K_P e + K_I \int e \, d\tau \qquad 14$$

$$u = K_P e + \frac{1}{\tau_I} \int e \, d\tau \qquad 15$$

$$u = K_P \left(e + \frac{1}{\tau_N} \int e \, d\tau \right) \qquad 16$$

Where τ_I = "Integration time" [s]

τ_N = "Reset time" [s]

Integral Gain Factor

Ensures that under study state condition the motor speed (almost) exactly match the set point speed. A low gain can make the controller slow to push the speed to the set point but excessive gain can cause hunting around the set point. In lass extreme case it can cause overshoot whereby the speed passes through the set point and then approaches the required speed from the opposite direction. Unfortunately sufficient gain to quickly achieve the set point speed can cause overshoot and even oscillation but the other term can be used to damp this out.

Proportional Gain Factor

Given fast response to sudden load change and can reduce instability caused by high integral gain. This gain is typically many times higher than the integral gain so that relatively small aviation in speed is corrected while the integral gain slowly moves the speed to the set point. Like integral gain set to high, proportional gain can cause a hard oscillation of a few hertz in motor speed

Designing the PI Controller Routine

The PI control problem has to be converted form a theoretical continuous process into a real "discrete" system running on a microcontroller. What this mean in practice is that the measuring of the set point and motor speed and the calculation of the output is only performed a regular interval. In the context of a microcontroller, this

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is might correspond to some code run from a timer interrupt.

The PI controller can thus be expressed as: Output = Proportional Gain*(error_speed) + Integral Gain*S (previous_error_speed_) and **Final output** = [{(Output) or Proportional Gain*(error_speed) + Integral Gain*S (previous_error_speed_)} – (last_error_speed)]

PI Error Calculation

The PI controller compares the set point (SP) to the process variable (PV) or mean variable (MV) to obtain the error e, as follows:

$$e = SP - PV \qquad 17$$

Then the PI controller calculated the control action, u (t), as follows. In this equation, Kp is the process gain.

$$u = K_p e + \frac{1}{\tau_I}\int e\, d\tau \qquad 18$$

Where τ_I = "Integration time"

The above following formula represents the proportional gain.

$$Up(t) = Kp(e) \qquad 19$$

Implementing the Pi Algorithm With The Pi Functions

This section describes how the PI control toolbox function implements the PI algorithm. The PI algorithm used in the PI control toolbox

Error Calculation

The following formula represents the current error used in calculating proportional, integral, where PV is the filtered process variable.\

$$e(k) = SP - PV \qquad 20$$

Proportional Action

Proportional action is the controller gains times the error, as show the following formula:

$$Up(k) = Kp * e(k) \qquad 21$$

Trapezoidal Integration

Trapezoidal Integration is used to avoid sharp changes in integral action when there is a sudden change in the PV or SV. Use nonlinear adjustment of the integral action to counteract overshoot The following formula represents the trapezoidal integration action.

$$Ui(k) = Kp/Ti\Sigma \{[e(i) + e(i-1)]/2\}\,\Delta t \qquad 22$$

Where i = 1, 2, 3 …k

Controlled Output

Controller output is the summations of the Proportional, and integral action, as show in following formula:

$$U(k) = Up(k) + Ui(k) \qquad 23$$

Output Limit:

The actual controlled output is limited to the range specified for control output as follows:

If U (k) ≥ Umax then U (k) = Umax

And

If U (k) ≤ Umin then U (k) = Umin

The following formula shown the practical model of PI controller

$$U(t) = Kp\,[(SP-PV) + \frac{1}{T_i}\int_0^t (SP - PV)\, dt]$$

The PI function uses an integral sum correction algorithm that facilitates anti-windup & bumpless manual-to-automatic transfers. Windup occures at the upper limit of the controller output, for example, 100% when the error (e) decreases the controlled output is decreases, moving out of the windup area. The integral sum correction algorithm prevents abrupt controller parameters. The default range for the SP, PV and output parameter corresponds to percentage value; adjust the corresponding range accordingly.

Error Calculation

The current error used in calculating integral action for the precise PI algorithm is shown the following formula:

$$e(k) = (SP - PV_f)(L + (1-L) * \frac{|SP - PV_f|}{SP_{range}}) \qquad 24$$

Where SP range is the range of the SP and L is the linearity factor that produces a nonlinear gain term in which the controller gain increase with the magnitude of the error. If L is 1, the controller is linear. A valve of 0.1 makes the minimum gain of the controller 10% Kp. Use of a nonlinear gain term is referred to as a precise PI algorithm. Results shown in figure no. (2), and (3),

Results

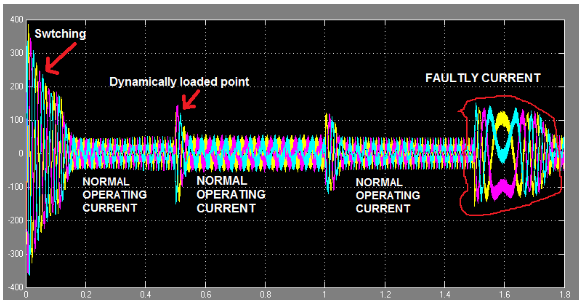

Fig: 2 Fault current in IM by using PI Controller

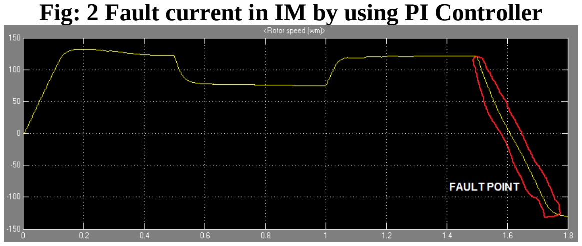

Fig: 3 Faulty speed in IM by using PI Controller

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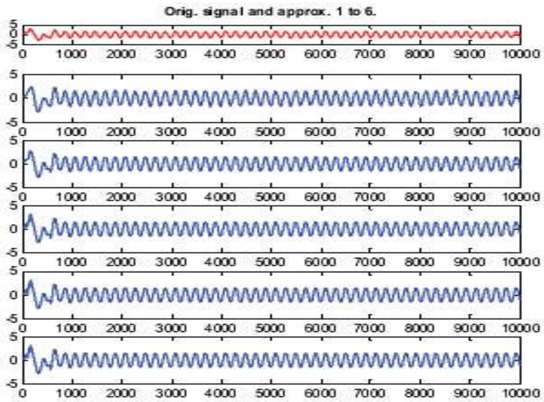


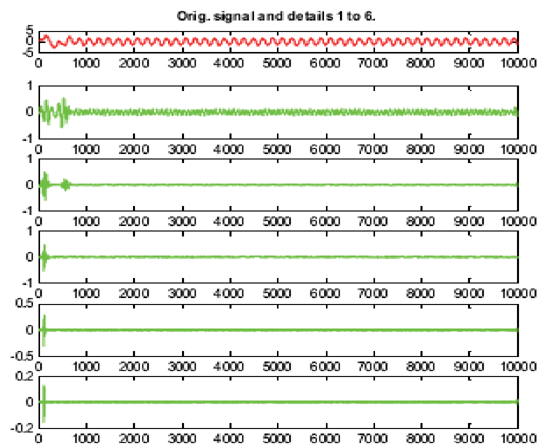
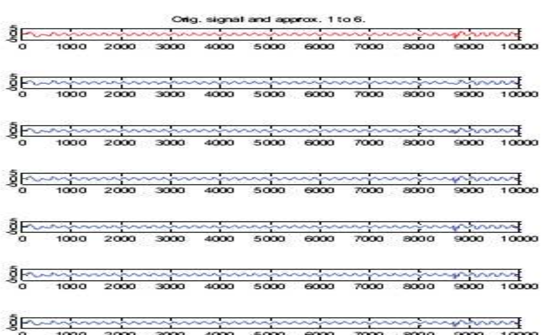


Fig: 4 Healthy case in IM by using wavelet



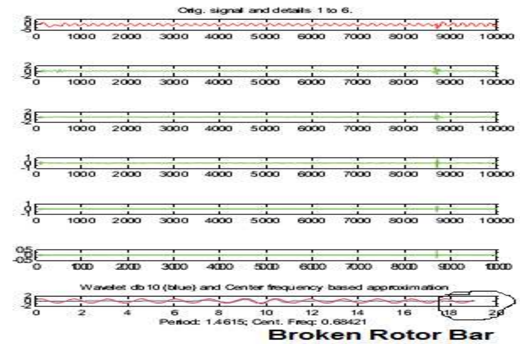
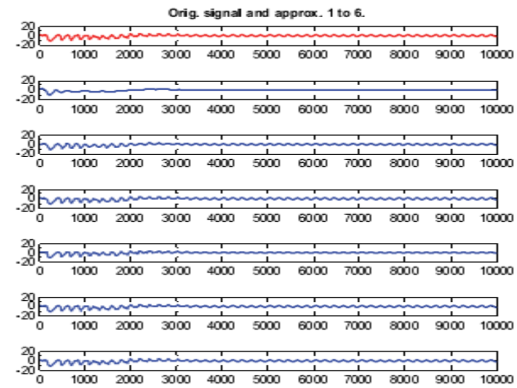


Fig: 5 broken rotor bar case in IM by using wavelet



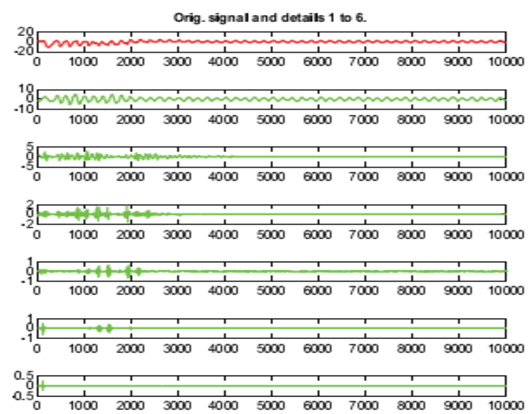


Fig: 6 Short stator winding fault in IM by using wavelet

Conclusion

A Squirrel cage Induction motor 5 hp 440 volts 50 Hz input supply fully loaded condition checked out the fault by using wavelet transform & PI controller. When we apply the PI controller (conventional method) & checked out the results so scope is shown large distortion in current. Due to faults change the nature of current and as well as speed. An Induction motor apply the PI controller easily find out the fault point but we cannot decide which fault is create. When we apply the modern signal processing technique (Wavelet) and find out faults. In these methods we can easily decide which fault is created. An Induction motor applies the wavelet transform and finds out two faults (1) Broken rotor bar faults, (2) Short stator winding fault.

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