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Short Communication

Numerical implementation of wavelet and fuzzy transform IFOC for three-phase induction motor

Sanjeevikumar Padmanaban [a,*], Febin Daya J.L. [b], Frede Blaabjerg [c], Nazim Mir-Nasiri [d], Ahmet H. Ertas [e]

[a] Research and Development, Ohm Technologies, Chennai 600 122, India
[b] School of Electrical & Electronics Engineering, Vellore Institute of Technology University, Chennai 600 127, India
[c] Department of Energy Technology, Aalborg University, Pontoppidanstraede 101, 9220 Aalborg, Denmark
[d] Department of Electrical and Electronics Engineering, Nazarbayev University, Astana 010000, Kazakhstan
[e] Biomedical Engineering Department, Engineering Faculty, Karabuk University, Karabuk, Turkey

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ABSTRACT

This article elaborates the numerical implementation of a novel, indirect field-oriented control (IFOC) for induction motor drive by wave-let discrete transform/fuzzy logic interface system unique combination. The feedback (speed) error signal is a mixed component of multiple low and high frequencies. Further, these signals are decomposed by the discrete wave-let transform (WT), then fuzzy logic (FL) generates the scaled gains for the proportional-integral (P-I) controller parameters. This unique combination improves the high precision speed control of induction motor during both transient as well as steady-state conditions. Numerical simulation model is implemented with proposed control scheme using Matlab/Simulink software and obtained results confirm the expectation.

1. Introduction

The speed control of three-phase induction motor (IM) is quite complex due to its nonlinear characteristics. Therefore, controlling the flux and torque parameters with proper decoupling is derived from speed reference feedback. Classical speed control (indirect/direct vector control) of IM drives uses proportional-integral (P-I) and/or proportional-integral-derivative (P-I-D) controllers that have constant gain values at all operating conditions. In addition, the slip calculation relies on rotor time constant, but it varies with operating conditions. These controllers are not adaptive in nature with respect to the operating condition. Neural network and fuzzy logic are said to be intelligent, used to overcome the above drawbacks [1–4]. But neural network controllers (NNC) do not involve analytical model of the complete system under test and do not have the ability to adapt it to change in control environment. Still, it is a tedious process to select appropriate neural controller architecture and its training neuron process. Moreover, FL is the simplest of intelligent controller versions and uses expert knowledge to drive the system even if the system is undefined and also with parameter variation issues [5,6].

Wavelet transform (WT) used to perform multi-resolution analysis of the feedback signals extracts and detects the components of frequency signal at any interval, but represents in another form. Recent trends of intelligent wavelet controller are focused on the application of controlling ac electric drives [2–8]. However a systematic development and implementation of a wave-let fuzzy based speed compensator for IM control is yet to appear. This article focused on a novel, simple and straightforward wavelet-fuzzy integrated controller for the IFOC speed control of IM drive and investigated in numerical simulation software (Matlab/Simulink).

2. Discrete wavelet transformation algorithm

The WTs are the extended method of Fourier transforms where the multidimensional time-frequency domain representation is allowed. The popularity of the WTs is mainly due to their ability to concentrate the energy of the processed signal into finite number of coefficients. The mathematical expression of a signal can be given in WT as follows [5–7,9]:

* Corresponding author. Tel.: +91-98431-08228.
E-mail address: sanjeevi_12@yahoo.co.in (S. Padmanaban).
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$$\omega t(\tau, s) = \frac{1}{s}\int x(t)\Psi^*\left(\frac{t-\tau}{s}\right)dt \tag{1}$$

where $s > 0$ depicts the window size, which determines resolution for the graded wavelet base $\psi(t - \tau/s)$ in time-frequency domains. The value of s parameter depends on frequency inversely. The discrete wavelet transform (DWT) of $x(t)$ signal can be written as:

$$WT_{m,n}x(t) = \int_{-\infty}^{\infty} x(t)\Psi^*_{m,n}(t)dt \tag{2}$$

where $\Psi^*(t)$ is the wave-let function representation and m, n are the dilation representation, the translational parameter. Discrete wavelet transform (DWT) is realized through cascaded stages of low- and high-pass-filter, followed by down sampling, which performs frequency dilation. The coefficients a^1 and d^1constitute the first level of decomposition and can be mathematically represented as:

$$a^1[n] = \sum_{k=0}^{N-1} g[k]x[n-k] \tag{3}$$

$$d^1[n] = \sum_{k=0}^{N-1} h[k]x[n-k] \tag{4}$$

The second level approximation and detailed coefficient of length $N/2$ is expressed as below:

$$a^2[n] = \sum_{k=0}^{N/2-1} g[k]a^1[2n-k] \tag{5}$$

$$d^2[n] = \sum_{k=0}^{N/2-1} h[k]a^1[2n-k] \tag{6}$$

The filtering and down sampling process is continued until the desired level is reached.

Several methods are proposed in the literature, but the minimal description length (MDL) data criterion is the best suited selection of the optimum wave-let function. The MDL criterion can be defined as [7,9]:

$$DL(k,n) = \min\left\{\begin{array}{l} \frac{3}{2}k\log N \\ +\frac{N}{2}\log\left\|\tilde{\alpha}_n - \alpha_n^{(k)}\right\|^2 \end{array}\right\} \tag{7}$$

$$0 \le k < N; \quad 1 \le n \le M$$

Here k and n are the indices. Integer N states the length of the signal while M expresses the wave-let filters. The $\widetilde{\alpha_n}$ is the wave-let vector, obtained by the coefficients of the signal which is transformed by the wavelet filter. Where $\alpha^{(k)}{}_n = \Theta^k\widetilde{\alpha_n}$ actually is a vector with k (non-zero) elements, Θ^k is the threshold value which keeps k largest element number in $\widetilde{\alpha_n}$ and keeping all elements to null. For the number of coefficients k, the MDL criterion giving the minimum value is considered as the optimum one. The level of decomposition depends on the signal as well as the wave-let used for decomposition. The Shannon entropy criterion is best suited to find the decomposition at optimum level of the speed error-signal for motor drive applications. For the entropy of a signal $x(n) = [\![\{x]\!]\_1, x\_2, x\_3 \ldots\ldots x\_N\}$, length N can be represented as [5]:

$$H(x) = -\sum_{n=0}^{N-1}|x(n)|^2\log|x(n)|^2 \tag{8}$$

According to the Shannon entropy based criterion, the entropy of the signal in the next level (p) is higher than the previous ($p - 1$), that is, if as below:

$$H(x)_p \ge H(x)_{p-1} \tag{9}$$

then decomposition of signals can be stopped at level ($p - 1$) and ($p - 1$) represents the optimum level decomposition. The output of a P-I-D controller is given by:

$$u = k_p e + k_i\int edt + k_d\frac{de}{dt} \tag{10}$$

In frequency domain, the proportional k_p parameter corresponds to the low frequency component, the integral k_i parameter corresponds to medium frequency component and the derivative k_d parameter corresponds to high-frequency component. The control signal for the compensator can be calculated from the approximate coefficients of DWT as [6–8]:

$$u_w = k_{d^1}e_{d^1} + k_{d^2}e_{d^2} + \ldots + k_{d^N}e_{d^N} + k_{a^N}e_{a^N} \tag{11}$$

where e_{d1}, e_{d2},. . ., e_{dN} corresponds to the error-signal of the detail-components and e_{aN} is the approximate components of the error-signal. The gains k_{d1}, k_{d2},. . ., k_{dN} are used to tune the approximate components of the error-signal. Gain k_{aN} actually tunes the low frequency component of the error-signal [6,7,9]. The schematic of the wave-let fuzzy based speed compensator is shown in Fig. 1. The error in speed, which is the difference between the reference and actual speed, is applied as source to both the WT block and fuzzy logic control block. The WT decomposes the speed error into approximate and details components up to level two using DWT. The FLC operates on the error (speed) and the derivative of the error (speed)

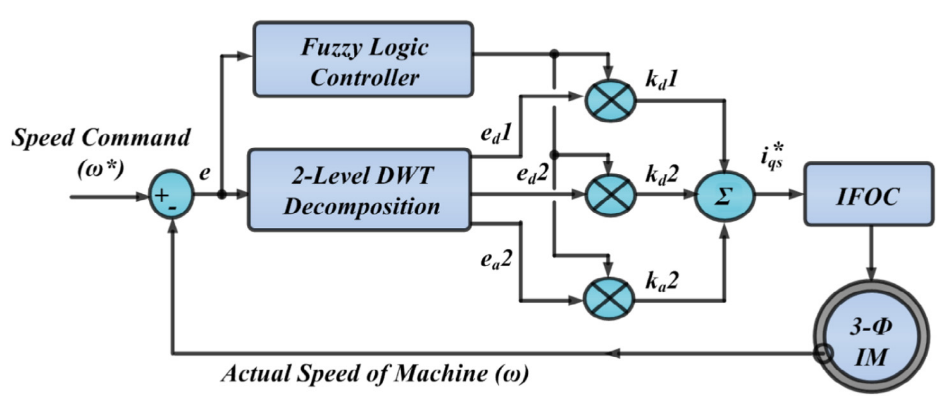

Fig. 1. Schematic of the proposed wavelet-fuzzy based speed compensator for IFOC IM drive.