Development and Implementation of a Simplified Self-Tuned Neuro–Fuzzy-Based IM Drive

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Abstract: A novel simplified self-tuned Neuro–fuzzy controller (NFC) for speed control of an induction motor (IM) drive is presented in this paper. The proposed NFC amalgamates fuzzy logic and a four-layer neural network structure. Only speed error is employed as input to the NFC so that the computational encumbrance of the NFC is reduced and it becomes congruous for authentic-time industrial drive applications. Predicated on the erudition of back-propagation algorithm, an unsupervised self-tuning method is developed to adjust membership functions and weights of the proposed NFC so that the performance will be kindred to that of the conventional two-input NFC. The consummate drive incorporating the proposed self-tuned NFC is experimentally implemented utilizing a digital signal-processor board DS-1104 for a laboratory 1/3-hp motor. The efficacy of the proposed NFC-predicated vector control of IM drive is tested in both simulation and experiment at different operating conditions. Comparative results show that the simplification of the proposed NFC does not decrement the system performance as compared to the conventional NFC. In order to prove the preponderating of the proposed simplified NFC, the performances of the proposed NFC are additionally compared to those obtained by a conventional proportional–integral controller.

Keywords: Back Propagation (BP), Digital Signal Processor (DSP), Indirect Field-Oriented Control (FOC), Induction Motor (IM), Neuro–Fuzzy Control, Real-Time Implementation, Self-Tuning.

I. INTRODUCTION

Induction motors (IMs) have been widely utilized as work horse in the industry over the years due to its low cost, and simple and robust construction. However, the control of IM is in volute due to its nonlinear nature, and the parameters change with operating conditions. Traditionally, the conventional fine-tuned-gain proportional–integral (PI) and PI–derivative (PID) controllers and their adaptive versions have been widely utilized for motor drives. However, the fine-tuned-gain and adaptive controllers often suffer from chattering in the steady state, parameter variations, and load perturbations.

Over the last two decades, researchers have been working to apply keenly intellecctual algorithms for motor drives due to some of their advantages as compared to the conventional PI, PID controllers and their adaptive versions. The main advantages are that the designs of these controllers do not depend on precise system mathematical model and their performances are robust. In this paper, a Neuro–fuzzy controller (NFC) is considered because of the prohibitions of both fuzzy logic control (FLC) and artificial neural network (ANN) controllers. A fuzzy controller utilized for speed control of motor drive has asymmetric membership functions which need much more manual adjusting by tribulation and error if optimized performance is wanted. On the other hand, it is profoundly tough to engender a serial of training data for ANN that can handle all the operating modes. The NFCs, which overcome the disadvantages of FLC and ANN controllers, have been utilized by authors and other researchers for motor drive applications. Despite many advantages of astute controllers, the industry has been still reluctant to apply these controllers for commercial drives due to high computational burden imposed by sizably voluminous number of membership functions, weights, and rules, particularly on self tuning condition. High computational burden leads to low sampling frequency, which is not sufficient for authentic-time implementation. In, only weights were tuned online, but the membership functions were fine-tuned to keep the computational burden at plausible level.

The membership functions we readjusted in simulation by tribulation-and-error procedure. Moreover, a high-torque ripple was observed due to the low sample rate for the conventional two-input NFC. An expeditious processor may be habitudated to implement such high computational perspicacious algorithms, but the high cost of the expeditious processor is another concern for the industry. Conventional NFCs conventionally utilize two inputs Δω and ω’ (speed error and expedient, respectively), which lead to an immensely colossal number of membership functions and rules. The adoption of ω’ can ameliorate the controller’s robustness. However, the arduousness of quantifying expeditious and precise expedient deteriorates this ability and even makes utilization of expedition unuseful. Therefore, in order to reduce
the computational burden, a simplified NFC with one input, three membership functions, and a four-layer structure is proposed in this paper. A supervised self-tuning method is developed predicated on the erudition of back propagation (BP) algorithms adjust the parameters of the membership functions and weights in order to minimize the square of the speed error between genuine and reference values. The performance of the proposed simplified NFC predicated IM drive is tested in both simulation and experiment. It is found that the proposed NFC does not decrement the system performance as compared to the conventional NFC. Moreover, the proposed NFC is found superior to the conventional PI controller.

Fig.1. Block diagram of the proposed simplified NFC-based IM drive.

II. CONTROL STRATEGY OF INDUCTION MOTOR DRIVE

The control of induction motor drive can be broadly classified into scalar control and vector control. The scalar control of IM drives with inverters is widely used in low cost applications and its main advantage is its simplicity. But for the applications which require high dynamics response than v/f control, vector control schemes are preferred. In this vector control, field oriented control and direct torque and flux controls are major classifications. Both of the schemes are having their own advantages and disadvantages. In this paper we are going to discuss only about the DTC scheme of induction motor.

A. Principle Operation of DTC

According to the DTC principle, an independent control of torque and flux can be achieved by the application of appropriate voltage vectors. This selection is based on the error between the estimated torque and flux. And their respective reference values should remain within the limits of hysteresis comparators as shown in Fig.3. The locus of stator flux vector from the basic equation governing induction motor operation of stator flux also plays a major role in the selection of desired voltage vectors.

B. Mathematical Model of DTC of Induction Motor

In direct torque control method the stator flux and stator torque can directly controlled the selection of the appropriate inverter switching states. In this, based on the measured voltage and current, the motor magnetic flux and torque are calculated. Stator flux linkage is obtained by the integrating the stator voltages. Estimated torque is obtained by the cross product of estimated stator flux linkage vector and measured motor current vector. These estimated values are then compared with their reference values. Depending on the error values obtained voltage vector selection takes place. Thus direct torque control is one form of the hysteresis or bang-bang control.

Fig.3. Basic DTC scheme.
Development and Implementation of A Simplified Self-Tuned Neuro–Fuzzy-Based Im Drive

resistance, flux etc dynamic behavior of motor also changes. So, the dynamic model is essential for analyzing the performance of the induction motor. In order to derive the dynamic model of the induction motor, Clark’s transformation is used for the transformation the three phase quantities into two phases direct and quadrature axes quantities.

III. NEURO-FUZZY CONTROLLER

Fuzzy logic is one of the emerging applications in the electrical engineering field which can be used to control various parameters of the real time systems. This fuzzy logic when combined with neural networks yields very significant results. Neural networks can learn from data. However, understanding the knowledge learned by neural networks has been difficult. To be more specific, it is usually difficult to develop in depth knowledge about the meaning associated with each neuron and each weight. In contrast, fuzzy rule based models are easy to be understood because it uses linguistic terms and the structure of IF-THEN rules. Unlike neural networks, however, fuzzy logic by itself cannot learn. The learning and identification of fuzzy logic systems need to adopt techniques from other areas, such as statistics, system identification. Since neural networks can learn, it is natural to merge these two techniques. This merged technique of the learning power of the neural networks with the knowledge representation of fuzzy logic has created a new hybrid technique, called as the term “Neuro fuzzy networks”. Adaptive Neuro-fuzzy inference system tunes the membership functions of fuzzy system using either back propagation algorithm or least square type of method. In this fuzzy rules are trained by this controller. Mamdani type is used here in order to increase its flexibility.

A. Proposed NFC

The proposed NFC incorporates fuzzy logic and a learning algorithm with a four-layer ANN structure, as depicted in Fig. 4. The learning algorithm adjusts the NFC to match desired system performance. The detailed discussions on different layers of the NFC are given in the following Input Layer: The input of the proposed NFC is the normalized speed error, which is given by

\[ O_1 = \frac{\omega - \omega^*}{\omega^*} \times 100\% \]  

(1)

Where \( \omega \) is the measured speed, \( \omega^* \) is the command speed, and I denote the first layer. Fuzzification Layer: In order to get fuzzy number from input, three membership functions \( O_{1II}, O_{2II}, \) and \( O_{3II} \) are used, which are shown in Fig 5. The three nodes in Fuzzification layer of NFC shown in Fig 4. Represent these three membership functions. Here, O stands for output, superscript indicates the layer number, and subscripts indicate the node numbers. The linear triangular and trapezoidal functions are chosen as the membership functions so that the computational burden is low as compared to any exponential functions. Where \( x_{II} \) is the input of the second layer, which is the output of the first layer. It is considered that \( a_2 = 0 \) so that the membership ship functions become symmetrical and it also further reduces the computational burden.

![Fig.4. Four layer ANN structure.](image)

![Fig.5. Membership functions for input.](image)

Thus, the membership functions \( O_{1II}, O_{2II}, \) and \( O_{3II} \) represent negative, zero, and positive speed errors, respectively. Rule Layer: No “AND” logic is needed in the rule layer since there is only one input in the input layer.

IV. SIMULATION AND RESULTS

The proposed simplified self-tuned NFC-based vector control of IM drive system has been implemented in real time using the digital-signal-processor (DSP) board DS1104. This board is mainly based on 64-b floating-point MPC8240 processor with PPC603e core. The photograph of the experimental system the actual motor currents are measured by the Hall-effect sensors and fed back to the DSP board through the A/D channels. Rotor position is sensed by an optical incremental encoder of 1000-line resolution and is fed back to the DSP board through the encoder interface. The outputs of the DSP board are PWM logic signals, which are sent to the VSI switches through driver circuitry. The test IM is coupled to a dc generator, which is used as a load to the IM. The NFC and self-tuning algorithm are implemented through developing a real-time Simulink model. Then, the model is compiled and downloaded to the DSP board utilizing Control Desk software and real-time workshop. Since the proposed NFC has a simple structure, the highest sampling frequency can reach up to 14.3 kHz. In this paper, the sampling frequency is set to be 10 kHz so that the experiment becomes closer to practical application. For comparison purposes, a
conventional two input NFC-based system is also developed and experimentally implemented. The sampling frequency for the conventional NFC is found to be 5 kHz. For comparison purposes, a PI controller-based system is also developed and experimentally implemented. After trial and error, the proportional gain $K_p$ and the integral gain $K_i$ are selected as 0.1 and 0.02, respectively, so that there is no steady-state error and the settling time, overshoot, and undershoot can be comparable to those of the NFCs. If the PI controller is made critically damped, it became too sluggish, and the response time is not even comparable to that of the NFCs.

Fig.6. Simulated speed responses of the IM drive at a step increase in load. (a) Proposed NFC. (b) Conventional two-input NFC. (c) PI controller.

Fig.7. Simulated speed responses of the IM drive with doubled rotor resistance. (a) Proposed NFC. (b) Conventional two-input NFC. (c) PI controller.

A. Results and Discussion

1. Simulation Results

The performance of the proposed simplified NFC-based IM drive is investigated in simulation using Matlab/Simulink at different operating conditions. Fig.6. (a)–(c) shows the simulated starting performances of the drive at full load with the proposed NFC, conventional two-input NFC, and PI controllers, respectively. It is clearly seen from these figures that the performance of the proposed simplified low computational NFC is similar to that of the conventional NFC and, at the same time, is superior to that of the conventional PI controller in terms of overshoot and settling time. Fig.6.(a)–(c) shows the zoom-in view of the speed responses of the drive system with a steep increase in the load from zero to rated level for the three controllers. It is found that the proposed simplified NFC can handle the load disturbance with lesser dip in speed as compared to both conventional NFC and PI controller.
Development and Implementation of A Simplified Self-Tuned Neuro–Fuzzy-Based IM Drive

NFC provides superior performance as compared to the conventional PI controller.

V. CONCLUSION

In this paper, a novel and simplified low computational online self-tuning NFC-predicated speed control of IM drive has been developed and experimentally implemented for a laboratory 1/3-hp motor. In the proposed NFC, both weights and membership functions are tuned online predicated on operating conditions. The proposed controller can withal be applied to other types of motors of different sizes only by adjusting the tuning rates. The comparison of the proposed NFC with It is found from the results that the proposed simplified NFC exhibits virtually the same performance of the conventional two-input NFC while reducing the computational burden significantly. The maximum sampling frequencies for the proposed NFC and conventional NFC have been found as 14.3 and 5 kHz, respectively, with the same DSP (DS1104) board. Moreover, the performance of the proposed NFC has been found superior to that of the conventional PI-controller-predicated IM drive. The proposed simplified self-tuned NFC-predicated IM drive system is found robust and could be an opportune candidate for authentic-time implementation of high-performance industrial drives.

VI. REFERENCES

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