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Speed Control of an IPMSM Drive System Using MWNN-PSO Based MRPID Controller

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Abstract: In this paper, a Multi wavelet neural network (MWNN)- Particle Swarm Optimization (PSO) based MRPID controller is proposed for the speed control of an Interior Permanent Magnet Synchronous Motor (IPMSM) drive system.In the proposed controller,the Multi Wavelet Transform is used to decompose the error signal available from the actual speed and command speed signal into different frequency components. The parameters of the proposed controller are optimized by using PSO algorithm. Then the calculated error coefficients are multiplied with their respective gains to generate an overall control signal. The proposed model is implemented in MATLAB/SIMULINK working platform and the speed control performance of a proposed controller is evaluated. The IPMSM motor drive with MWNN-PID controller through simulation results proves a better performance and stability when compared to that of conventional PID and WNN-PID controllers.

Key words: IPMSM · Wavelet Neural Network · PID controller · MRPID controller

INTRODUCTION

Permanent Magnet Synchronous Motors (PMSM) is broadly used in industrial and robotic applications, due to their high competence, low inertia and high torque to volume ratio [1,2]. It has the benefits of higher competence when compared to induction motors due to the lack of rotor losses and no-load current below the rated speed, its decoupling control performance is much less receptive to the parameter deviations of the motor [3]. As a result, PMSM have found open attention in planning machines for several high performance industrial applications and particularly for Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) [4]. In specific, the interior permanent magnet synchronous motors are getting increased attention for high performance drive applications because of their high power density, high competence and flux weakening capability [5]. The magnet of IPMSM is hidden in the rotor core, shows certain good properties such as mechanically robust rotor construction, a rotor physical non saliency and small efficient air gap [6]. However the precise speed control of an drive turns out to be a complex issue owing to nonlinear coupling among its winding currents and the rotor speed and the nonlinearity present in the torque equation [7].

Problem in the PI and PID controller can be accomplished by the fuzzy neural network, in order to develop the speed tracking precision of the conventional controllers, an adaptive and artificial intelligent controllers have been variable. The speed issues of the motors are usually handled by conventional controllers such as Proportional Integral (PI), Proportional Integral Derivative (PID) controllers [8], Fuzzy Neural Network controller, adaptive Neural Network (NN) controller and wavelet based MRPID controller correspondingly [9]. Although they are uncomplicated, these controllers are very sensitive to parameter differences, change in load, changes in command speed and other uncertainties [10]. The design of PI or PID controller is uncomplicated as the computations of the proportional gain, integral gain and derivative gain are prepared using second-order method or Ziegler-Nichols method [11]. The uncertainty proposed [12].

Recently, wavelet neural networks have been employed in power systems for dissimilar goals, because of their benefits such as the Multi-Resolution of Wavelets and the learning of NN [13]. In the proposed system, the MRPID controllers utilize wavelet theory for the disintegration of the tracking error signals, these controllers have two or more parameters and the number of parameters depends on the level of decomposition [14].

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A Multi-Resolution Wavelet (MRW) controller is applied for the speed control of traveling wave ultrasonic motor where the wavelet controller is based on wavelet theory and takes benefit of the advanced filtering capability of the wavelet transform [15]. The wavelet transforms have been applied in the modeling, analysis and control of motor drives for high-performance applications [16]. The wavelet transforms include the capacity to decay wideband signals into time and frequency domains at the same time in order to spotlight on short time intervals for high-frequency components and on long time intervals for low frequency components [17]. The WNN is appropriate for the approximation of unknown nonlinear functions and fast variations [18,19]. As a result, WNN has been demonstrated to be better than the other neural networks in that the structure can present more potential to enhance the mapping relationship between the inputs and outputs [20].

Speed Control Process of Proposed Hybrid Ipmsm Drive System: In this section, MWNN-PSO based speed controller of an IPMSM is described. The motor speed is recognized by monitoring the rotor position using an optical encoder which is mounted on the rotor shaft. by using backward difference interpolation technique, the motor speed and the error value is evaluated. The actual and the command speed difference gives the corresponding speed error values. Then, the error and the change in error values are given as an input to the MWNN. The error signals processed through the multi wavelet transformation, it has three frequency levels low, medium and high, which is to carry out two level decomposition of error signal based on the frequency in terms of low and high frequency error signals. Since there is more information of low and high frequency with multi wavelet decomposition than traditional wavelets, the error gets decomposed to a high level by using the multi wavelet transformation.

The error coefficients gets added along with the gain parameters from the MWNN to produce the efficient control signal u (5) using a self tuning MRPID controller. However, the PSO algorithm is applied to optimize the gain parameters of the Multi-wavelet neural network, the gains K_{d1}, K_{d2} are used for tuning the high and medium frequency components. The gain K_{a2} is used for tuning the low frequency components. Thus, the control signal generated by the MRPID controller will control the speed of an IPMSM drive system effectively. Moreover, the controller based on particle swarm optimization (PSO) is used to control the speed of IPMSM motor in wide range and to provide better performance than the conventional WNN based controller. Figure 1 shows the block diagram of the IPMSM motor with MWNN-MRPID controller based on PSO algorithm. The specified explanation of the proposed MRPID controller is described below.

Description of the Proposed MRPID Controller: A speculation of PID controller based on Multi-Resolution decomposition of error by utilizing small waves is generally known as wavelets. The wavelet decomposition provides much higher resolution than the traditional PID in describing the history and predicting the immediate future of the error. Therefore, this controller is named a Multi Resolution Proportional-Integral-Derivative (MRPID) controller. The basic idea is that if e is decomposed as

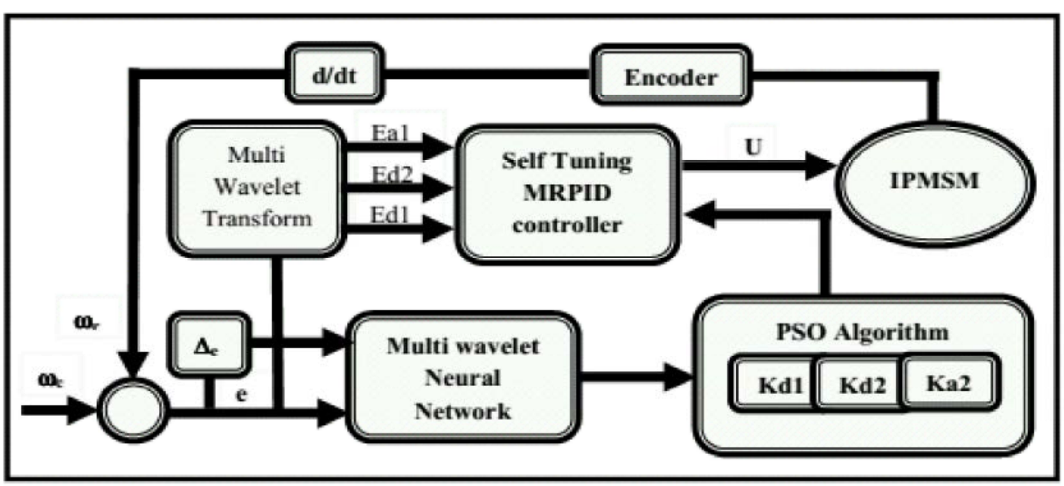

Fig. 1: Proposed Multi-wavelet neural network based MRPID controller

$$e = \sum e_i \quad where,\ i = 1,2,\ldots\ldots n \tag{1}$$

Then a generalized PID controller can be formulated as

$$u = \sum K_i e_i\ Where, i = 1,2,\ldots.n \tag{2}$$

Where K_i are gain parameters to be determined. In general, error and the change in error values are given as an input to the PID controller in order to generate the control output u which is shown in

$$u_{Pid} = K_p e + K_i \int edt + K_d \frac{d}{dt} e \tag{3}$$

The gain values K_p, K_i, K_d are the Proportional Derivative gains used by the system to act on the error respectively. In terms of frequency information the proportional and integral terms are used to capture the low frequency information of the error signal and the derivative term is used to capture the high frequency information of the error signal. If more resolution in frequency is desired, less resolution in time is achieved by using an MRPID controller, in which the computation time and complexity have also been reduced. An MRPID controller decomposes the error signal into its high, low frequency signals, by applying multi wavelet decomposition to the error signal, the error gets decomposed up to the second level of resolution. Each one of these is scaled by its respective gain and then added together to generate the control signal (u)

$$u_{mrpid} = K_{d1} e_{d1} + k_{d2} e_{d2} + K_{a2} e_{a2} \tag{4}$$

Based on the level of decomposition of the error signal the MRPID controller can have two or more parameters. If there is a one level decomposition next the error signal is classified as low and high frequency signal and the controller will be containing only two gain parameters. In order to attain high resolution two level decomposition of the error signal is performed, so that there will be a generation of three gain parameters. Each of these gain parameters are inserted together with the error signals to produce the effective control signal

Simulation Results and Discussions: In the paper, the MWNN based MRPID controller is used for the optimal speed control of an IPMSM drive system. The proposed MWNN has two inputs; the speed error and the change of this error which is given to the input layer. The hidden layer has neurons with multi wavelet function. One output in the output layer and feedback connection from the output for each layer. The translation and dilation factors, weights connection for MWNN and the speed is controlled by tuning the MRPID parameters using PSO algorithm. Figure 4 shows the Simulink model of the proposed speed control strategy. In order to verify the effectiveness of the proposed controller, the performances of the proposed method is evaluated and compared with the existing methods such as, PID and wavelet based MRPID controllers.

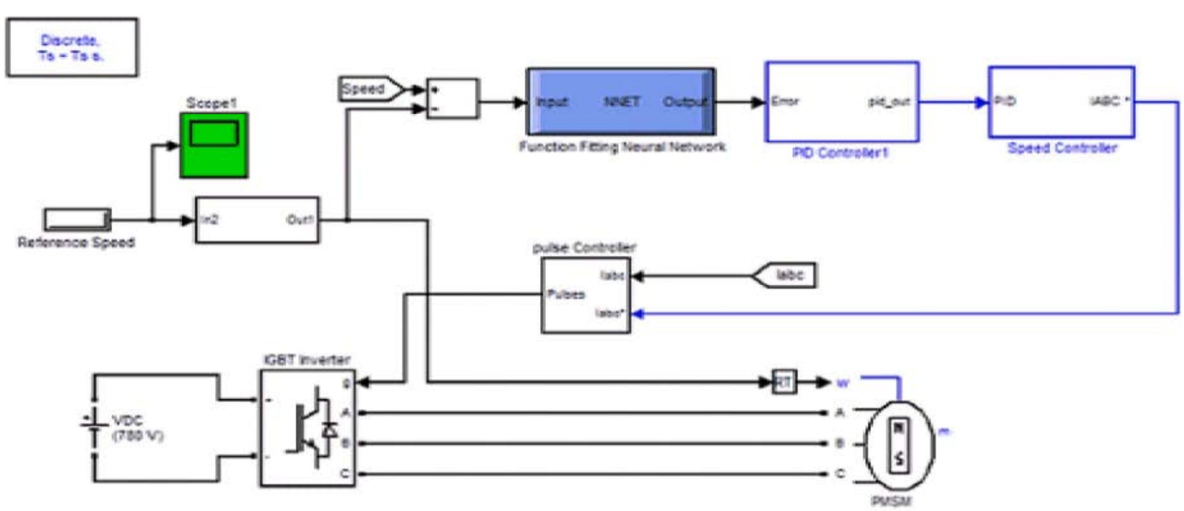

Fig. 2: Simulation circuit diagram of proposed system

Performance Analysis of the Proposed and Existing Controller: The performance of the IPMSM drive system with MWNN-MRPID controller is determined and illustrated in figure 3, 4and 5. It shows the speed response of the IPMSM motor for the conventional and the proposed controllers. The actual speed of the motor varies for different controllers with respect to 100rad/sec as the reference speed for each 0.01sec. In order to show the step response of the proposed controllers, the reference speed is varied between 100and 160rad/sec and its effectiveness is compared with the conventional PID and MRPID controllers. The speed response of the IPMSM drive system with PID controller was shown in figure (3). In which the reference speed is about 100rad/sec and the actual speed of the motor is about 120rad/sec at time of about time t= 0.0053 sec. Then after the fraction of a second again the speed of the motor reduces to 90rad/sec. Then the oscillations in the curve has been reduced and starts to attain the steady state at time t=0.01rad/sec.

In the wavelet based MRPID controller technique, the speed curve is initially raised at time t=0.004sec and attains the speed of about 115 rad/sec. At t=0.005, oscillations in the curve has been reduced and then starts to attain the steady state and the speed is of about 100 rad/sec which is almost equal to the applied command speed. From, the simulated results shown in Fig 4(a) - (b), one can see that the speed responses for the proposed controller is good from the beginning and the differences between the actual speed and the desired command speed is lower than that of the existing PID controller.

The simulated speed response results of the Proposed MWNN-PSO based MRPID controller for a IPMSM drive system is of about 100 rad/sec at time t=0 is shown in Figure 7,. In this the speed curve is initially raised at time t=0 and attains the speed of about 100 rad/sec and then it goes steadily at the same speed. The reference command speed is varied for the step change of 140 rad/sec and 160 rad/sec at time t=0 and t=0.1 respectively. The output speed response of the IPMSM drive system and the error performances are evaluated using the proposed controller and the conventional controllers is shown in figure (6) and (7).

The compared performance analysis of the proposed MWNN-PSO based MRPID controller with other controllers is depicted in figure 8.The output speed response of the controller for the given reference speed of 100 rad/sec is shown. It can be seen that while using the bio-inspired particle swarm optimization technique the overshoots obtained is zero as compared to the case when the PID Controller was tuned by using conventional methods. The settling time is also lesser in case of the PSO Optimization, also the rise time is reduced. The MWNN-PSO based MRPID controller tends to approach the reference speed faster and has, comparatively, a zero overshoot. It can be observed from Fig 5 and 6 that the conventional PID controllers have overshoot from the reference speed and attain a steady state with some larger settling time.

At time t=0 the reference speed of 100v is given as an input, at this situation the speed response of the proposed controller is of about 100 rad/sec and it will constant up to time t= 0.1 sec and at this time the reference speed is of about 160rad/sec is given as an input..Therefore the comparison analysis of the existing and the proposed illustrates that the proposed controller has zero steady state error and shows 86 % of improvement than that of the existing controller.

By observing the results at figure (3-7) difference between the actual and the command speed of various controllers gives the corresponding error values which is illustrated in figure (7) and (8).At time t=0 the error occurred will be of about 50% for the existing controller which is highly reduced by using the proposed controller and it attains the steady state at time t=0.004 sec to that of the other controller.

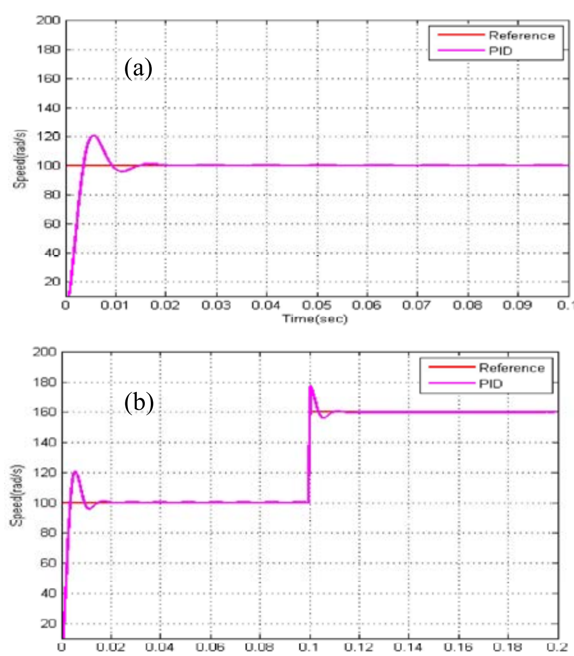

Fig. 3: Speed response of the IPMSM drive system using PID controller

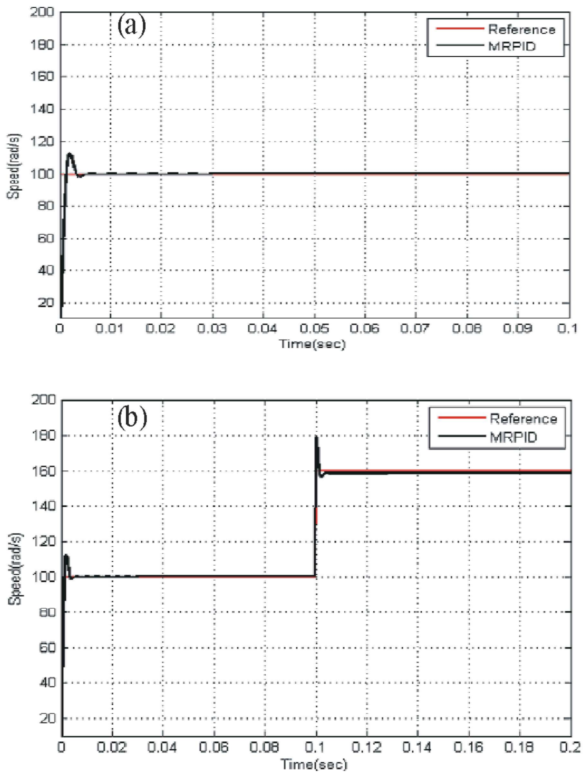

Fig. 4: Performance analysis of speed for the wavelet based MRPID controller

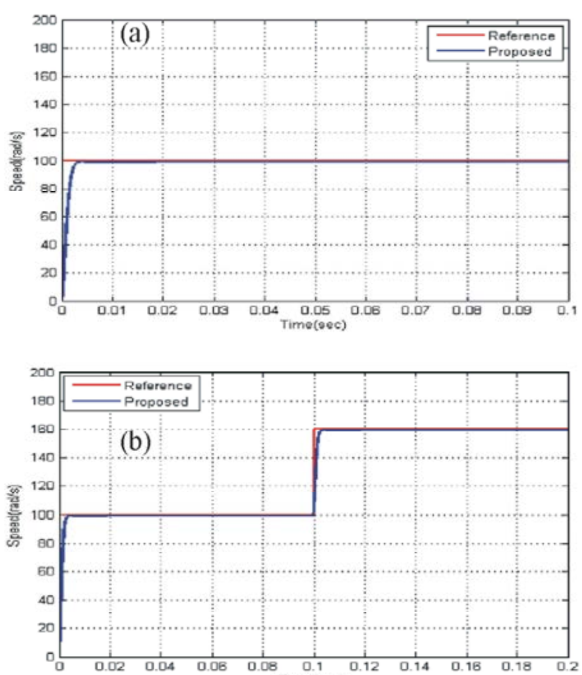

Fig. 5: Performance of the proposed MWNN-PSO based MRPID controller

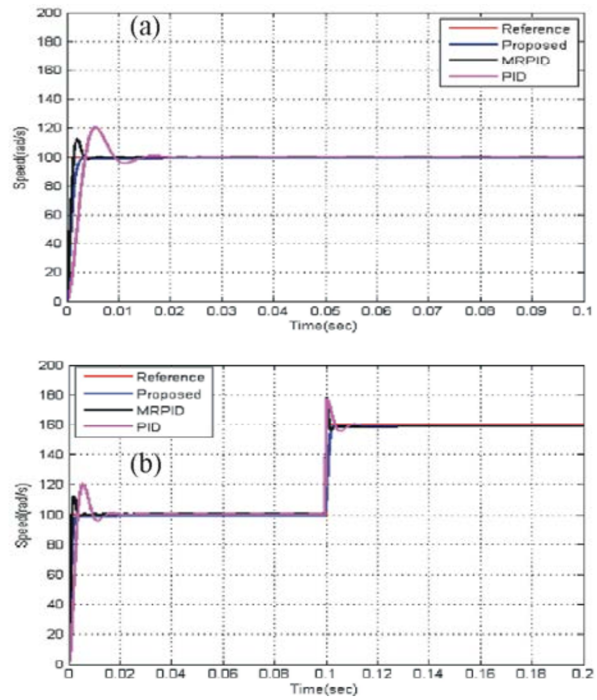

Fig. 6(a-b): Comparison analysis of the IPMSM drive controllers for step change and for the speed of 100 rad/sec

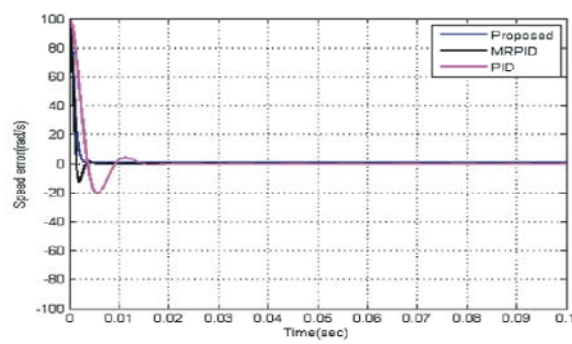

Fig. 7: Comparison of Error performance of various controllers

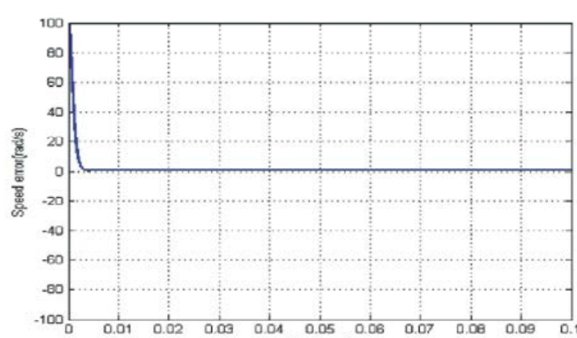

Fig. 8: Performance analysis of error using proposed method

Table 1: Comparison in performance

Performance	PID	MRPID	Proposed
settling time	0.025	0.004	0.003
Rise time	0.0053	0.007	0.004
Overshoot	0.0083	0.005	0.004

Table 1 illustrates a comparison among PID, wavelet based MRPID and the proposed hybrid MRPID speed controller in terms of performance. The comparison includes the calculation of speed rise time, settling time and overshoot. This comparison shows that the proposed method is the best method to overcome the nonlinearity in this drive with high reliability, more robust and good performance than the other methods as can be shown in figure 7.

From the above illustrations, the performances of the proposed method, with PI, PID and the proposed MWNN based MRPID controller is analyzed by using the speed response and the error obtained by the drive system. From the evaluations, the effectiveness of the proposed method is determined. The effectiveness is evaluated based on the overall performances IPMSM drive system. By using the proposed controller, the IPMSM drive system achieves better speed response with lower error when compared to that of other controllers. The actual speed of the proposed MWNN-PSO based MRPID, wavelet based MRPID and PID controller techniques are evaluated which is of about100rad/sec, 110rad/sec and 115rad/sec respectively. From the above analysis the speed control performance of the MWNN based MRPID controller is highly superior

CONCLUSION

In this paper, an optimal MWNN-PSO based MRPID controller is designed for an optimal speed control of an interior permanent magnet synchronous motor. The Multi Wavelet Decomposition, which represents the error signal at different scales, provides higher resolution representation of the error signals than the one used in existing PID and is the basis of the new controller design. A generalized MRPID controller based on the MWNN is proposed is similar to the conventional PID controller, but it is intuitive and effective. The controller gains have an explicit relationship with the characteristics of the error signal, which makes tuning of the controller insightful using PSO algorithm. The Multi wavelet decomposition, which represents the error signal at different scales, provides higher resolution representation of the error signal than the one used in the existing PID and is the basis of the new controller design. Implementation of the Multi wavelet neural network based multi resolution controller in SIMULINK shows promising results, particularly in its ability to provide smooth control effort and better disturbance rejection compared to that of the existing PID controller where analyzed and their results are demonstrated.

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