PARAMETERS ESTIMATION AND AUTO-TUNING OF A DISCRETE-TIME MODEL PREDICTIVE SPEED CONTROLLER OF INDUCTION MOTOR DRIVES BY ANFIS CONTROLLER

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ABSTRACT

This paper proposes a technique that can automatically estimate and fine-tune the parameters that have been considered in an IM drive to provide high performance speed control for a discrete time MPC. The control mechanism here combines the process MRAS with the controller ANFIS. The method of fine tuning the parameters achieves a high performance in time. The integration of MRAS and ANFIS is achieved as predictive control of the Adaptive Discrete Time model. The proposed ADMPC framework optimizes the objective function by state space model which considers the actual and reference speeds along with the acceleration of the IM drive. The high performance of motor drive and effectiveness of proposed ADMPC is validated by selective simulation results by using MATLAB/SIMULINK.

KEYWORDS: Motor Drives, Model Predictive Control(MPC), ADMPC, Control Systems, MRAS Control & ANFIS Control

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1. INTRODUCTION

High performance applications in speed-controlled motions are characterized by the goals of quick rising time, low overshooting, high accuracy and adequate load variance rejection. Although PI controller may have advantages such as simple structure and ease of implementation that ensure the microcontroller's low computational requirements, PI controller cannot provide high performance with constant parameters over a wide range of speed and load torque. Performance enhancement can be observed with the use of adaptive PI controller but this can contribute to the complicated nature[1].

The PI controller's shortcomings could be addressed by the use of MPC technique which has the ability to know the motor's actions beforehand under certain considered operating conditions. It is achieved because at the design stage control goals are included in the controller as the desired control problem. There is therefore no need to change the control system and the drive's output reliability is maintained without increasing the complexity of the controller [2].

MPC is typically a useful technique that can efficiently manage the nonlinearities along with a multivariable system's control objectives. And in many of the applications including power converters, active filters, UPS, high-performance electrical drives, this is adopted. Consequently, MPC has attracted the attention of the research community among all controllers in the last few years due to its comparative advantages and improved

alternative against PI controller [1].

The MPC methodology was originally applied for the sluggish systems. In the most demanding applications such as electric motor drives and power converters, the computational power MPC began to be introduced as there was an increase. Nonetheless, there are open issues such as the need for self-adaptation of the MPC parameters so that the motor drive can be started on its own without any human source requirement and another problem is that the parameters must be fine tuned so that the device model variations can be considered. So these might be faced with the MPC's advantages [1].

MPC is a vast term which has evolved several methodologies based on load, power converter and motor models to predict the motor behavior. An description of the roots of the MPCs and various architectures of the MPC algorithms[10]. Multiple control strategies based on the MPC technique have been proposed for PMSM, such as, a cascade control structure ripple speed minimization, MPC application in VSI(voltage source inverter) and CSI(current source inverter)" have been presented in[3] and[4], generalized configuration controlled speed and location, state controlled feedback scheme with constraints, control scheme compensation MPC, MPC methodology with small horizons for prediction[6]. Various MPC designs have been proposed for IM drives such as predictive algorithm control of speed and rotor flux control[7], predictive torque controlled system based on state-space models, a speed and current cascaded MPC process, predictive direct torque control scheme using fuzzy. In order to increase the sampling rate by properly manipulating the control and prediction horizons an attempt was made and presented in[9], the problem on MPC computational load was analyzed, such as trajectory and finite horizon methods [8].

The electrical system parameters play a significant role for designing high-performance controllers. Many efforts have been made in the last years and recorded in the technical literature to address the above issue [1]. Sensorless control was implemented in PMSM based on observer-based identification, and an adaptive parameter recognition approach was implemented by synchronizing the dynamic response of the drive with the model system respectively, in[13] and[14]. Measurements of the location of the motor drives have been used to measure inertia and friction[15].

ADMPC advantages in enhancing motor drive efficiency and the versatile organized architecture of MPC controllers [11]. An adaptive predictive controller has been developed by studying the dynamic characteristics of the converter output present. Therefore the controller parameters need an auto adaptive device, so there is no need for human effort to start a motor operation. Drive gets the function from the auto adaptive system. There must therefore be a technique in which parameters are automatically measured and finely tuned, taking into account all the operating conditions and also where there are differences in the motor model. The iterative method must be a modern technique, such that there is no need to know the parameters of the motor drive, except the parameters that are already required for the application of the space vector control. And it can be used easily in a motor drive [1] and [2].

The purpose of this paper is to implement ADMPC system to determine and fine-tune the parameters of the predictive controller by using ANFIS controller without any human intervention. Therefore, knowledge of the IM drive model is not necessary and drive operation is initiated without user according to the operating conditions. Improved output of the IM drive is achieved as the MPC parameters are fine-tuned by considering potential device mode variations. This is introduced without any additional hardware or drive topology modifications but hardware is replaced by the system firmware [1].

Through combining the MRA technique[12] and the ANFIS control scheme, the ADMPC program is introduced. Implementing the MPC involves IM model parameters that are experimentally defined, then those fine-tuned parameters in each control stage. The MRA methodology determines those parameters. Weighing factor is required that provides a balance between the goals of rapidly rising time and desired overshoot, and this is controlled by the ANFIS controller. ADMPC strategy for IM drives is suggested in this paper but this can also be implemented for PMSM drives by modifying the mathematical methodology [1].

The ADMPC strategy for Induction Motor drive is applied by taking into account the control constraints a variety of control and prediction horizons to evaluate the right reference q-axis current that provides high output in IM Drive the speed of the rotor, the acceleration or deceleration response of the motor drive [1]. MATLAB / SIMULINK, selective simulation tests support the high performance of the motor drive and efficiency of the proposed ADMPC.

II. DYNAMIC MODEL OF IM

The dynamic mechanical model is expressed as follows,

$$J_m \frac{d\omega_r}{dt} + F_d \omega_r = T_e - T_L \quad (1)$$

Where, J_m - inertia,

ω_r - rotor mechanical speed

T_L - load torque

F_d - friction coefficient

T_e - IM electromechanical torque

and T_e , electromechanical torque of induction motor

$$T_e = \frac{3}{2} p \frac{L_m}{L_r} (i_{qs} \psi_{dr} - i_{ds} \psi_{qr}) \quad (2)$$

For decoupling control, $\psi_{qr} = 0$

So equation (2) becomes,

$$T_e = \frac{3}{2} p \frac{L_m}{L_r} (i_{qs} \psi_{dr}) \quad (3)$$

Here, P is the pole pair, L_m and L_r are the magnetizing and rotor inductance respectively. i_{qs} and ψ_{dr} are the q -axis stator current and d -axis rotor flux linkage respectively.

Combining (1) and (3) yields,

$$\frac{d\omega_r}{dt} = \frac{3}{2} p \frac{L_m}{L_r J_m} (i_{qs} \psi_{dr}) - \left[\frac{F_d}{J_m} \omega_r + \frac{T_L}{J_m} \right] \quad (4)$$

Using first-order Taylor series expansion, $i_{qs} \psi_{dr}$ can be represented with the steady state operating condition as follows,

$$i_{qs}(t) \psi_{dr}(t) \approx \psi_{dr}^0 i_{qs}^0 + \psi_{dr}^0 (i_{qs}(t) - i_{qs}^0) + i_{qs}^0 (\psi_{dr}(t) - \psi_{dr}^0) \quad (5)$$

Results to,

$$i_{qs}(t)\psi_{dr}(t) \approx i_{qs}^0(\psi_{dr}(t)) + i_{qs}(t)\psi_{dr}^0 - i_{qs}^0(\psi_{dr}^0) \quad (6)$$

Where ψ_{dr}^0 and $i_{qs}(t)$ are the d-axis steady state rotor flux linkage and q-axis stator current respectively.

The magnetic flux of IM is kept constant at the steady state operation. So,

$$\frac{d(i_{qs}^0(\psi_{dr}^0))}{dt} = 0 \quad (7)$$

$$i_{qs}^0 \frac{d(\psi_{dr}(t))}{dt} = 0 \quad (8)$$

For a given T_L , the second order derivative of the ω_r could be obtained from (4) and by using (7), (6) and (8) and is given by

$$\frac{d^2\omega_r}{dt^2} = \frac{3}{2}p \frac{L_m\psi_{dr}^0}{L_r J_m} \frac{di_{qs}}{dt} - \frac{F_d}{J_m} \frac{d\omega_r}{dt} \quad (9)$$

III. DISCRETE MPC SPEED CONTROLLER FOR AN INDUCTION MOTOR DRIVE

The state-space model for an IM can be given as,

$$\begin{aligned} \dot{\mathbf{x}}_m &= \mathbf{A}_s \mathbf{x}_m + \mathbf{B}_s u_m \\ \mathbf{y}_m &= \mathbf{C}_s \mathbf{x}_m \end{aligned} \quad (10)$$

Where, $\mathbf{x}_m$ – state space vector,

u_m and y_m - input and output respectively,

$\mathbf{A}_s, \mathbf{B}_s, \mathbf{C}_s$ are appropriate dimension matrices.

$$\begin{bmatrix} \ddot{\omega}_r(t) \\ \dot{\omega}_r(t) \end{bmatrix} = \begin{bmatrix} -\frac{F_d}{J_m} & 0 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \dot{\omega}_r(t) \\ \omega_r(t) \end{bmatrix} + \begin{bmatrix} \frac{3}{2}p \frac{L_m\psi_{dr}^0}{L_r J_m} \\ 0 \end{bmatrix} \frac{di_{qs}(t)}{dt} \quad (11)$$

And

$$\omega_r(t) = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{\omega}_r(t) \\ \omega_r(t) \end{bmatrix} \quad (12)$$

Now considering sampling time T_s and sampling instant k , the above considered state space model could be discretized by,

$$\begin{aligned} \mathbf{x}_m(k+1) &= \mathbf{A}_d \mathbf{x}_m(k) + \mathbf{B}_d u_m(k) \\ \mathbf{y}_m(k+1) &= \mathbf{C}_d \mathbf{x}_m(k+1) \end{aligned} \quad (13)$$

Where, discrete forms of matrices $\mathbf{A}_s, \mathbf{B}_s, \mathbf{C}_s$ are $\mathbf{A}_d, \mathbf{B}_d, \mathbf{C}_d$ respectively. These are determined by the second order Taylor series expansion of the exponential matrix[1].

$$\begin{aligned} \mathbf{A}_d &= e^{\mathbf{A}_s T_s} \approx \mathbf{I} + \mathbf{A}_s T_s + \frac{\mathbf{A}_s^2 T_s^2}{2} \\ \mathbf{B}_d &= \int_0^{T_s} e^{\mathbf{A}_s \tau} \mathbf{B}_s d\tau \approx \mathbf{B}_s T_s + \frac{\mathbf{A}_s \mathbf{B}_s T_s^2}{2} \\ \mathbf{C}_d &= \mathbf{C}_s \end{aligned} \quad (14)$$

The methodology implemented here is DMPC. This is done by considering two elements that are mutually coupled. The IM drive and optimizer control system model decides the potential control behavior by means of sufficient feedback and predictive horizons. In particular, for a given set point signal $r(k)$ at sampling instant k , the DMPC goal is to evaluate the future behavior of the device model-based IM drive, and to obey a control law established by cost function optimization. Therefore a reasonable balance between the computational load and error between the real and predictive performance value is achieved. The optimization of cost function is always sought in each sampling. Particularly for a given sampling time k , the predictive control output procedure is derived from state space model [1] which is given by,

$$Y = Hx(k) + F \Delta U \quad (15)$$

Where,

$$Y = [y(k+1) \ y(k+2) \ y(k+3) \ \dots \ y(k+N_p)]^T$$

$$H = [C_d A_d \ C_d A_d^2 \ C_d A_d^3 \ \dots \ C_d A_d^{N_p}]^T$$

$$F = \begin{bmatrix} C_d B_d & 0 & 0 & \dots & 0 \\ C_d A_d B_d & C_d B_d & 0 & \dots & 0 \\ C_d A_d^2 B_d & C_d A_d B_d & C_d B_d & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ C_d A_d^{N_p-1} B_d & C_d A_d^{N_p-2} B_d & C_d A_d^{N_p-3} B_d & \dots & C_d A_d^{N_p-N_c} B_d \end{bmatrix}$$

$$\Delta U = [u(k) \ u(k+1) \ u(k+2) \ \dots \ u(k+N_p-1)]^T \quad (16)$$

N_c and N_p are the control and prediction horizons respectively. In (15) the first term $H x(k)$ to the minimum error objective between the prediction output and the set-point input signal, where as the second term $F \Delta U$ depends on the ΔU size which deals the effectiveness of the objective law. The control law is given by the cost function minimization as follows,

$$G = (R_s - Y)^T (R_s - Y) + \Delta U^T R \Delta U \quad (17)$$

Where, R_s - data vector of the set-point signal $r(k)$ for sample time k , R is a diagonal matrix form. r_w is a weighting factor which affects the close loop performance of IM drive and is an identity matrix with dimensions $N_c \times N_c$. [1]. R_s is given by as follows,

$$R_s^T = [1^1 \ 1^2 \ \dots \ 1^{N_p}] r(k) \quad (18)$$

Substituting (15) in (17) which results to

$$G = [R_s - Hx(k)]^T [R_s - Hx(k)] - 2\Delta U^T F^T [R_s - Hx(k)] + \Delta U^T (F^T F + R) \Delta U \quad (19)$$

The cost function minimization is done by

$$\frac{\partial G}{\partial \Delta U} = 0 \quad (20)$$

and optimal condition is obtained as follows,

$$\Delta U = [(F^T F + R)^{-1} F^T] [R_s r(k) - Hx(k)] \quad (21)$$

The equation(21) governs the DMPC control law.

IV. PROPOSED ADMPC STRATEGY IMPLEMENTATION FOR AN IM

Fig.1 shows the IM structure with DMPC. Technique directed to the area of the DMPC space vector is adopted in illustrating. The predictive controller is realized by equation(21), which manipulates the horizons of prediction and control and takes the actual direct and quadrature stator currents, rotor speed, and acceleration of IM for getting a proper reference q-axis current [1] given by i_{qs}^* .

Considering (21), (11), (16) and (18), in order to implement DMPC system and following parameters knowledge is required

$$B_s(1) = \frac{3}{2} p \frac{L_m^2}{L_r J_m} = P_1 \quad (22)$$

$$A_s(1,1) = -\frac{F_d}{J_m} = P_2 \quad (23)$$

The weighing factor r_w , control horizon(N_c) and prediction horizon(N_p) are also required.

The value for P_1 and P_2 parameters are calculated from IM drive model. Mostly, experiments with high cost are done to determine inertia J_m , friction constant F_d . So, for most of the applications this is not allowed to be conducted. There would be degradation of DMPC accuracy and performance of drive as variation occurs in J_m and F_d due to aging of the mechanical parts of the drive and also variation of inductances L_m and L_r due to variation in magnetic saturation. Therefore there is a need for an auto adaptive technique which can automatically calculate P_1 and P_2 parameters of DMPC system without requirement of knowledge of model.

Fine tuning of P_1 and P_2 parameters is done when there are variations that are caused due to aging of the mechanical parts of the drive and also variation in magnetic saturation. By considering all variations including speed and load conditions ADMPC operates without the need for any presetting process for parameter adjustment and high IM drive efficiency. The weighing factor may affect the close loop performance of the IM drive, so a simple experimental procedure is required to determine the weighing factor, taking into account all the variations listed as the load torque, reference speed as well as P_1 and P_2 parameters variations that are caused due to aging and magnetic saturation in an IM drive. The weighing factor r_w which is also a parameter is determined in order to ensure a correct balance between the objective of fast rising time and low overshoot [1] and [2].

The performance of MPC could be improved by increase in N_c and N_p horizons but this may result in an increase in the computational burden which leads to the confinement of the sampling frequency of the speed predictive controller

which would degrade the motor drive output. Therefore, an appropriate balance must be struck between the computational capabilities of the controller, the motor drive performance specifications and also the necessary sampling frequency. The objectives listed above depend on the system's hardware capabilities and also on the specific requirements of a particular application with respect to the output of the motor drive. So the user manually selects the control and prediction horizons and also the sampling frequency [2]. Preferably, N_C and N_P horizons are considered as $N_C=N_P$.

Figure 1: The speed controlled IM drive layout with the proposed ADMPC system.

A. MRA ALGORITHM FOR DETERMINING AND FINE TUNING OF P_1 AND P_2 PARAMETERS:

The MRA principle consists of creating an adjustable predictor to get the output of the device by considering a sequence of inputs[12]. The machine parameters are modified by means of an iteration process so that the prediction performance error with the measured output of each sampling instant is minimized. Therefore, an approximate model is obtained that provides exact description of the real system asymptotically. MRA control technique has been used in PI controlled IM drives to establish sensorless speed and predictive torque controllers by estimating the rotor time constant [1].

Considering the equations (22) and (23), (4) can be written as,

$$\frac{d\omega_r}{dt} = P_1 i_{ds} i_{qs} + P_2 \omega_r - \frac{T_L}{J_m} \quad (24)$$

At a sampling time k, the discretized form is given by,

$$\omega_r(k) = T_s \left[P_1 i_{ds} i_{qs}(k-1) + P_2 \omega_r(k-1) - \frac{T_L(k-1)}{J_m} \right] + \omega_r(k-1) \quad (25)$$

The disparity between two consecutive instants is minimal and is therefore considered constant. Consideration now of the rotor speed for instant sampling k-1,

$$\omega_r(k-1) = T_s \left[P_1 i_{ds} i_{qs}(k-2) + P_2 \omega_r(k-2) - \frac{T_L(k-2)}{J_m} \right] + \omega_r(k-2) \quad (26)$$

Sub (25) and (26),

$$\begin{aligned}\omega_r(k) = T_s \left[P_1 i_{ds} \Delta i_{qs}(k-1) + P_2 \Delta \omega_r(k-1) \right] \\ + 2\omega_r(k-1) - \omega_r(k-2)\end{aligned}\quad (27)$$

Where,

$$\Delta i_{qs}(k-1) = i_{qs}(k-1) - i_{qs}(k-2) \quad (28)$$

$$\Delta \omega_r(k-1) = \omega_r(k-1) - \omega_r(k-2) \quad (29)$$

The estimated rotor speed at given sampling time k,

$$\hat{\omega}_r(k) = 2\omega_r(k-1) - \omega_r(k-2) + \phi^T(k-1) \hat{h}(k-1) \quad (30)$$

Where,

$$\phi^T(k-1) = \begin{bmatrix} i_{ds} \Delta i_{qs}(k-1) & \Delta \omega_r(k-1) \end{bmatrix} \quad (31)$$

$$\hat{h}^T(k-1) = T_s \begin{bmatrix} \hat{P}_1 & \hat{P}_2 \end{bmatrix} \quad (32)$$

The recursive parameter identification algorithm is obtained as follows,

a) Initially h matrix is roughly estimated at k=1 instant in (32). The initial values of P_1 and P_2 parameters are calculated by (22) and (23) respectively. The inertia and friction constant are considered according to the application conditions, magnetizing inductance is obtained by the space vector control of IM drive.

b) The error between the estimated and measured rotor speed is determined by,

$$e(k) = \omega_r(k) - \hat{\omega}_r(k) \quad (33)$$

c) The adaptive gain matrix is calculated from (3.31) and (3.33),

$$\Gamma(k-1) = \Gamma(k-2) - \frac{\Gamma(k-2)\phi(k-1)\phi^T(k-1)\Gamma(k-2)}{1 + \phi^T(k-1)\Gamma(k-2)\phi(k-1)} \quad (34)$$

Where,

$$\Gamma(k) = \begin{bmatrix} \Gamma_1(k) & 0 \\ 0 & \Gamma_2(k) \end{bmatrix}.$$

d) The new h matrix is calculated from (31), (33), and (34) which gives the new estimation of parameters,

$$\hat{h}(k) = \hat{h}(k-1) + \frac{\Gamma(k-1)\phi(k)e(k)}{1 + \phi^T(k)\Gamma(k-1)\phi(k)} \quad (35)$$

Then, it goes to step b). From step b) to d), during IM drive operation the flow iterates continuously.

It could be proved that the stability of the MPC parameter is such that the calculated parameter vector is always pushed toward some value, so that the error converges to zero [1]. This will only be true if we prove the

$$\lim_{k_1 \rightarrow \infty} \sum_{k=0}^{k_1} e^2(k+1) < \infty \quad (36)$$

By considering (27) and (30) the error at k+1 instant is given by,

$$e(k+1) = -\phi^T(k) \tilde{h}(k+1) \quad (37)$$

From (35),

$$\phi(k)e(k+1) = [1 + \phi^T(k)\Gamma(k)\phi(k)]\Gamma^{-1}(k)[\tilde{h}(k+1) - \tilde{h}(k)] \quad (38)$$

From (37),

$$\sum_{k=0}^{k_1} e^2(k+1) = \sum_{k=0}^{k_1} -\phi^T(k) \tilde{h}(k+1) e(k+1) \quad (39)$$

Since,

$$\phi^T(k) \tilde{h}(k+1) = \tilde{h}^T(k+1) \phi(k)$$

$$\sum_{k=0}^{k_1} e^2(k+1) = \sum_{k=0}^{k_1} -\tilde{h}^T(k+1) \phi(k) e(k+1) \quad (40)$$

Substituting (38) in (40) results (41),

$$\sum_{k=0}^{k_1} e^2(k+1) = \sum_{k=0}^{k_1} [1 + \phi^T(k)\Gamma(k)\phi(k)] [-\tilde{h}^T(k+1)\Gamma^{-1}(k)\tilde{h}(k+1) + \tilde{h}^T(k+1)\Gamma^{-1}(k)\tilde{h}(k)] \quad (41)$$

Figure 2: MRA method for parameters estimation.

Fig.2 shows the block diagram of a MRA method for parameter estimation.

Thus, following expression would be positive

$$\left[\tilde{h}(k+1) - \tilde{h}(k) \right]^T \Gamma^{-1}(k) \left[\tilde{h}(k+1) - \tilde{h}(k) \right] \geq 0 \quad (42)$$

We have,

$$\begin{aligned} & \tilde{h}^T(k+1) \Gamma^{-1}(k) \tilde{h}(k+1) + \tilde{h}^T(k) \Gamma^{-1}(k) \tilde{h}(k) \\ & - 2\tilde{h}^T(k+1) \Gamma^{-1}(k) \tilde{h}(k) \geq 0 \end{aligned} \quad (43)$$

and finally,

$$\begin{aligned} & \tilde{h}^T(k+1) \Gamma^{-1}(k) \tilde{h}(k) \leq \frac{1}{2} \tilde{h}^T(k+1) \Gamma^{-1}(k) \tilde{h}(k+1) \\ & + \frac{1}{2} \tilde{h}^T(k) \Gamma^{-1}(k) \tilde{h}(k) \end{aligned} \quad (44)$$

Then, on substituting (44) in (41), we get (45)

$$\begin{aligned} & \sum_{k=0}^{k_1} e^2(k+1) \leq \sum_{k=0}^{k_1} \left[1 + \phi^T(k) \Gamma(k) \phi(k) \right] \left[-\frac{1}{2} \tilde{h}^T(k+1) \Gamma^{-1}(k) \tilde{h}(k+1) + \frac{1}{2} \tilde{h}^T(k) \Gamma^{-1}(k) \tilde{h}(k) \right] \\ & = \left[1 + \phi^T(k_1) \Gamma(k_1) \phi(k_1) \right] \left[-\frac{1}{2} \tilde{h}^T(k_1+1) \Gamma^{-1}(k_1) \tilde{h}(k_1+1) \right] + \left[1 + \phi^T(0) \Gamma(0) \phi(0) \right] \left[\frac{1}{2} \tilde{h}^T(0) \Gamma^{-1}(0) \tilde{h}(0) \right] \\ & \leq \left[1 + \phi^T(0) \Gamma(0) \phi(0) \right] \frac{1}{2} \tilde{h}^T(0) \Gamma^{-1}(0) \tilde{h}(0) < \infty \end{aligned} \quad (45)$$

From (45), shows stable MPC system parameter estimation technique.

B. ANFIS SYSTEM FOR DETERMINING AND FINE TUNING THE r_w PARAMETER:

If we observe equation (21), we can say matrix R is a tuning term for both the $r(k)$ and the $x(k)$ input signal set points. Therefore, the r_w parameter is a weighing factor that affects the IM drive's over-shooting OS and upward time r_t . Thus an ANFIS system is considered to change the r_w parameter to provide a correct balance between the goals of fast rising time and desired overshooting.

If we observe in fig.3, ANFIS considers the difference in incremental time between two consecutive rotor speed changes as

$$\Delta r_t = r_t(z) - r_t(z^{-1})$$

And the difference between the current and the

$$\Delta OS(z) = OS(z) - OS^*$$

Normally the desired overshoot OS^* is considered as zero. The ANFIS output gives the proper correction factor Δr_w and the estimated parameter is obtained by

$$\hat{r}_w(z) = \hat{r}_w(z^{-1}) + \Delta r_w(z).$$

The ANFIS rules are designed on the basis of following considerations. The rules are, if there is increase of overshoot or decrease of the rising time leads to the increase of r_w parameter and also the increase of r_w by the overshoot increase is higher compared to the increase of r_w by the rising time decrease [1]. Therefore, ANFIS at first satisfies the objective of minimization of ΔOS and then, r_w parameter is fine tuned by reducing the rising time.

Table 1: Parameter ΔR_w Adapter ANFIS Rules

$\Delta r_t \backslash OS$	A	B	C	D	E	F	G
A ₁	P	P	S	S	S	S	S
B ₁	P	P	S	S	S	S	S
C ₁	P	P	S	S	S	S	S
D ₁	N	N	S	S	S	S	S
E ₁	N	N	S	S	S	S	S
F ₁	N	N	N	N	P	P	P
G ₁	N	N	N	P	P	P	P

The ANFIS rules and membership functions of the ANFIS are given in Table 1 and Fig.4, respectively. The ANFIS sets are defined as A,A₁=Negative High; B,B₁=Negative Medium; C,C₁=Negative Low; D,D₁=Zero; E,E₁=Positive Low; F,F₁=Positive Medium; G,G₁=Positive High. S, N, P are Small, Negative, Positive respectively.

Figure 3: ANFIS block diagram for estimation of r_w parameter.

(a) Δr_t

(b) OS

(c) Δr_w

Figure 4: Membership functions of ANFIS

(a) Difference in rising time, (b) Overshoot, OS, (c) Correcting factor Δr_w of r_w parameter which is an output.

Table 2: 3-Phase, 4-Pole Im Drive Parameter with Control Parameters

Nominal power	2.5kW	Nominal stat. voltage	400V
Rated current	10.6 A	Rated frequency	50Hz
Stator resistance	2.5 Ω	Rotor resistance	2.5 Ω
Magnetizing inductance	0.48 H	Stator leak. inductance	0.03 H
Rotor leak. inductance	0.03 H		
Inertia	0.025 Kg m^2	Friction factor	$7 \cdot 10^{-3}$ Nms
SVM sample time	50us	DMPC sampe time	2ms

C. PROPOSED ADMPC ALGORITHM FOR IM DRIVE USING ANFIS

The proposed IM drive with ADMPC system flow chart has been illustrated in Fig. 5.

Figure 5: Flow chart for the IM drive with ADMPC strategy.

V. SIMULATION RESULTS

To encourage comparison, multiple simulation results on the same IM drive endorsed the above theoretical considerations. Table II lists the motor drive parameters and control system parameters.

From Fig. 6 to Fig. 8, each figure illustrates the simulation results of proposed ADMPC technique with step change in reference speed. The simulation analysis has been done using MATLAB/SIMULINK program.

In Fig. 6 Load torque, friction, and inertia are taken as constant, with values of 8Nm, 0.007Nms, 0.025Kgm. The parameters of P_1 and P_2 are computed by (22) and (23), respectively. The r_w parameter is the optimal value from which ANFIS predetermines of Fig. 3. Via Fig. 6, It has been noted that while the pace varies with phase impulses, the ADMPC goals have been achieved with almost zero over-shooting and increasingly increasing time.

Fig. 7, shows simulation results validating the efficacy of the MRA method of Fig.2. For accurate estimation of parameters P_1 and P_2 when the load changes linearly throughout the operation, the friction and inertia changes steeply at the beginning of the second speed. The r_w parameter is the optimum value that ANFIS of Fig3 predetermines. The speed switches with phase pulses of 1000rpm. Changes in friction and inertia during drive operation are usually uncommon, but here we looked for the worst case.

The accuracy of P_1 and P_2 parameters which are estimated by MRAS is validated by calculation of (22) and (23) respectively. It must be noted that though there is variation in the load torque the accuracy of MRAS is not affected. The objective of fast rising time and almost zero overshoot has been met.

Figure 6: simulation result of IM drive ADMPC technique for constant torque, friction and inertia. Where P_1 , P_2 , r_w are ADMPC parameters.

Figure 7: simulation result of MRA System of IM drive with ADMPC for variable torque, friction and inertia.

Where P_1 , P_2 , r_w are ADMPC parameters.

Figure 8: Simulation results of the ANFIS in Fig. 3 which determines r_w parameter with ADMPC for the cases (a) small and (b) large discrepancies of initial and correct r_w values. Where P_1 , P_2 , r_w are ADMPC parameters.

Lastly, Fig. 8 Shows the effectiveness of ANFIS of fig. 3, to evaluate r_w to provide the proposed ADMPC technique with high performance for an IM drive using ANFIS; In fig. 8.a. we have considered variable load torque while in the case of fig. 8.b. constant torque load, friction and inertia are constant in both the cases of Fig. 8.

The ANFIS r_w estimator will determine the optimal value at any inertial value in the cycle of iteration. It should be remembered that the r_w parameter must always be positive[9], and ranges from 1 to 50. At Fig. 8 The first case refers to the r_w parameter fine tuning process during ADMPC drive operation, while (b) case refers to ADMPC first operation. With a fast growing time of less than 0.13sec and an overshoot of less than 0.1rpm, ADMPC 's target was achieved.

VII CONCLUSIONS

This paper introduces an ADMPC strategy using ANFIS controller that provides high-performance speed control in an IM drive by automatically changing the MPC parameter to the drive 's configuration and operational conditions. Implementation of ADMPC is easier as it is auto adapting the parameters without requirement of knowledge of the motor drive model and also without intervention of the user. so, here there is no requirement of the additional hardware but it is being replaced by the firmware of the motor drive. The proposed ADMPC strategy is the integration of MRA and ANFIS controller. Here, ADMPC is implemented for IM drive but this can also be implemented for PMSM drives by some mathematical methodology changes. Several simulation results have been validated using MATLAB/SIMULINK at various operating conditions.

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