Model Prediction Speed Control In PMSM

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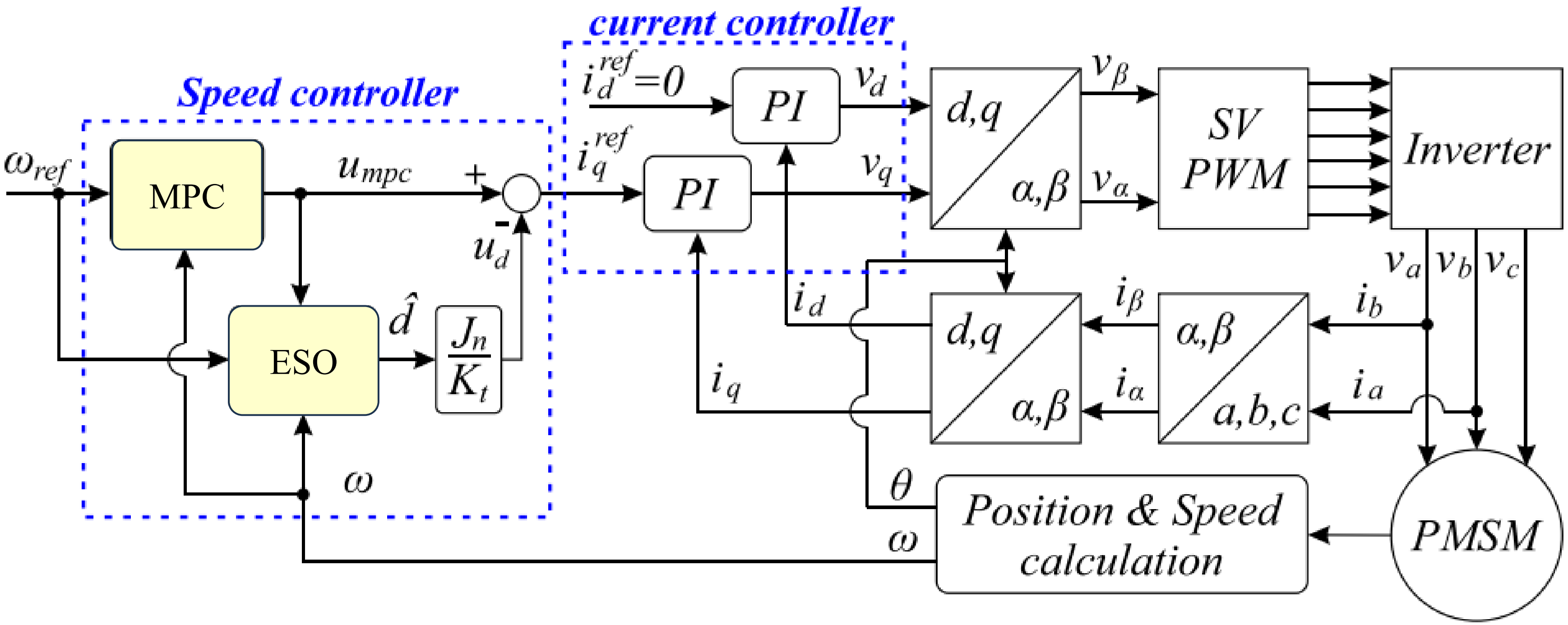
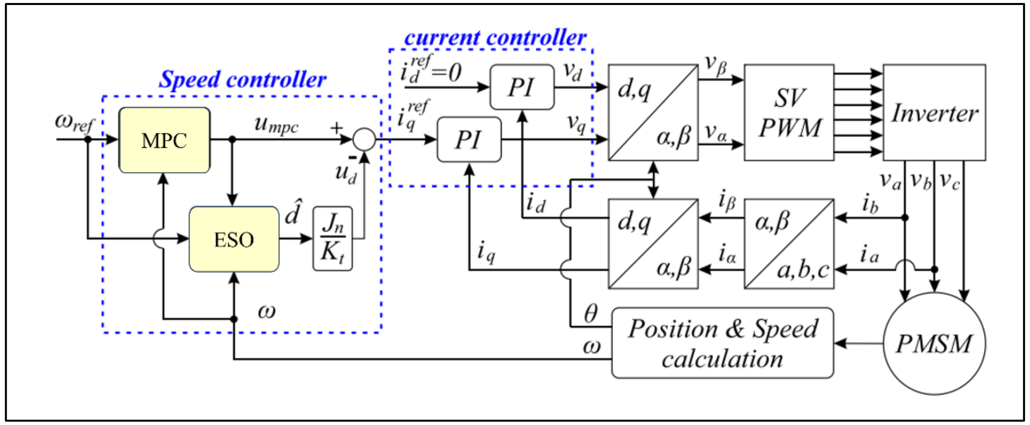
0 목차


current controller
Speed controller
ω_{ref}
MPC
u_{mpc}
+
-
u_d
ESO
$\hat{d}$
$\frac{J_n}{K_t}$
ω
$i_d^{ref}=0$
i_q^{ref}
PI
PI
v_d
v_q
d,q
α,β
v_β
v_α
SV PWM
Inverter
v_a v_b v_c
i_d
i_q
i_β
i_α
α,β
a,b,c
i_b
i_a
θ
ω
Position & Speed calculation
PMSM

1 Model Predictive Speed Control

❖ **1.1**

❖ **Introduction**



<Fig 1>

Fig 1은 PMSM system에 FOC method를 적용한 Cascade 제어 시스템.

$$\dot{\theta} = \omega$$

$$\dot{\omega} = \frac{1}{J_r}[K_m i_q - B_r\omega - \tau_l]$$

$$\dot{i}_q = \frac{1}{L_r}[u_q - R_r i_q - P_r\omega L_r i_d - P_r\Phi_r\omega]$$

$$\dot{i}_d = \frac{1}{L_r}[u_d - R_r i_d + P_r\omega L_r i_q]$$

θ: rotor position
ω: rotor velocity
B_r: viscous friction coefficient
τ_l: load torque
J_r: inertia of motor
L_r: inductance
Φ_r: magnetic flux
P: pole pairs

$$u = i_q$$

$$a_n = \frac{B_r}{J_r}$$

$$b_n = \frac{K_m}{J_r}$$

d: disturbance $(\tau_l, \Delta B\ etc..)$

1 Model Predictive Speed Control

- 1.1
  - **Design of Model predictive speed controller**
    - Dynamic equation of PMSM angular velocity

$$\dot{\omega} = \frac{1}{J_r}[K_m i_q - B_r \omega - \tau_l]$$

$$\dot{x}_m = -a_n x_m + b_n u + d$$

$$a_n = \frac{B_r}{J_r}$$

$$b_n = \frac{K_m}{J_r}$$

$$u = i_q$$

$d:\ disturbance\ (\tau_l, \Delta B\ etc..)$

$T_s: sampling\ time$

- Converted to discrete model using the Euler discretization method

$$x_m(k+1) = (1 - a_n T_s) x_m(k) + b_n T_s u(k) + T_s d(k)$$

$$x_m(k+1) = A_n x_m(k) + B_n u(k) + B_d d(k)$$

$$y_m(k) = x_m(k)$$

$$A_n = 1 - a_n T_s$$
$$B_n = b_n T_s$$
$$B_d = T_s$$

- Employed incremental model to reduce disturbance

$$\Delta x_m(k+1) = A_n \Delta x_m(k) + B_n \Delta u(k) + B_d \Delta d(k)$$

$$\Delta x_m(k+1) = A_n \Delta x_m(k) + B_n \Delta u(k)$$

T_s, $\Delta d(k)$ is very small value

1 Model Predictive Speed Control

- **1.1**
  - **Design of Model predictive speed controller**
    - Define new state vector

$$x(k) = \begin{bmatrix} \Delta x_m(k) & x_m(k) \end{bmatrix}^T$$

    - augmented state-space model

$$\begin{bmatrix} \Delta x_m(k+1) \\ x(k+1) \end{bmatrix} = \begin{bmatrix} A_n & 0 \\ A_n & 1 \end{bmatrix} \begin{bmatrix} \Delta x_m(k) \\ x_m(k) \end{bmatrix} + \begin{bmatrix} B_n \\ B_n \end{bmatrix} \Delta u(k)$$

$$y(k) = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} \Delta x_m(k) \\ x(k) \end{bmatrix}$$

$$\longrightarrow \begin{cases} x(k+1) = Ax(k) + B\Delta u(k) \\ y(k) = Cx(k) \end{cases}$$

    - Define future control trajectory

1 Model Predictive Speed Control

- **1.1**
  - **Design of Model predictive speed controller**
    - Define future control trajectory

$$\Delta U = \begin{bmatrix} u(k+1) & u(k+2) & \dots & u(k+N_c-1) \end{bmatrix}^T$$
$$Y = \begin{bmatrix} y(k+1) & y(k+2) & \dots & y(k+N_p) \end{bmatrix}^T$$

N_p: Prediction horizon
N_c: Control horizon
$N_p > N_c$

$$Y = Fx(k_i) + \Phi \Delta U,$$

$$F = \begin{bmatrix} CA \\ CA^2 \\ CA^3 \\ \vdots \\ CA^{N_p} \end{bmatrix}; \Phi = \begin{bmatrix} CB & 0 & 0 & \dots & 0 \\ CAB & CB & 0 & \dots & 0 \\ CA^2B & CAB & CB & \dots & 0 \\ \vdots & & & & \\ CA^{N_p-1}B & CA^{N_p-2}B & CA^{N_p-3}B & \dots & CA^{N_p-N_c}B \end{bmatrix}$$

- Define Cost function

$$J = (Y_{ref} - Y)^T (Y_{ref} - Y) + \Delta U^T Q \Delta U,$$

Y_{ref} is constant

$Q = \lambda I_{N_c}$

- Calculation globally optimal solution

$$\Delta U^* = [\Phi^T \Phi + Q]^{-1} \Phi^T [Y_{ref} - Fx(k)]$$

1 Model Predictive Speed Control

- 1.1
  - **Design of Model predictive speed controller**
    - Define future control trajectory

$$\Delta U^* = [\Phi^T\Phi + Q]^{-1}\Phi^T[Y_{ref} - Fx(k)]$$

$$\begin{aligned}\Delta u(k) &= [1\ 0\ \ldots\ 0]\Delta U^* \\ &= K_y r(k) - K_{mpc}x(k) \\ u(k) &= u(k-1) + \Delta u(k)\end{aligned}$$

- Exceeding physical constraints,

$$u_{mpc} = \begin{cases} I_{min} & if \ \ u(k) < I_{min} \\ u(k) & if \ \ I_{min} < u(k) < I_{max} \\ I_{max} & if \ \ u(k) > I_{min} \end{cases}$$

- Calculation globally optimal solution

2 Simulation

❖ **2.1**

❖ **Parameter Setting**

❖ PMSM Model

$$\dot{\theta} = \omega$$

$$\dot{\omega} = \frac{1}{J_r}[K_m i_q - B_r \omega - \tau_l]$$

$$\dot{i}_q = \frac{1}{L_r}[u_q - R_r i_q - P_r \omega L_r i_d - P_r \Phi_r \omega]$$

$$\dot{i}_d = \frac{1}{L_r}[u_d - R_r i_d + P_r \omega L_r i_q]$$

- parameter

  B_r: $2 \cdot 10^{-3}$ $[N \cdot m \cdot s/rad]$
  J_r: $3.24 \cdot 10^{-5}$ $[kg \cdot m^2]$
  L_r: 0.66 $[mH]$
  Φ_r: $16.8 \cdot 10^{-3}$ $[Wb]$
  P_r: 4

- PI gain

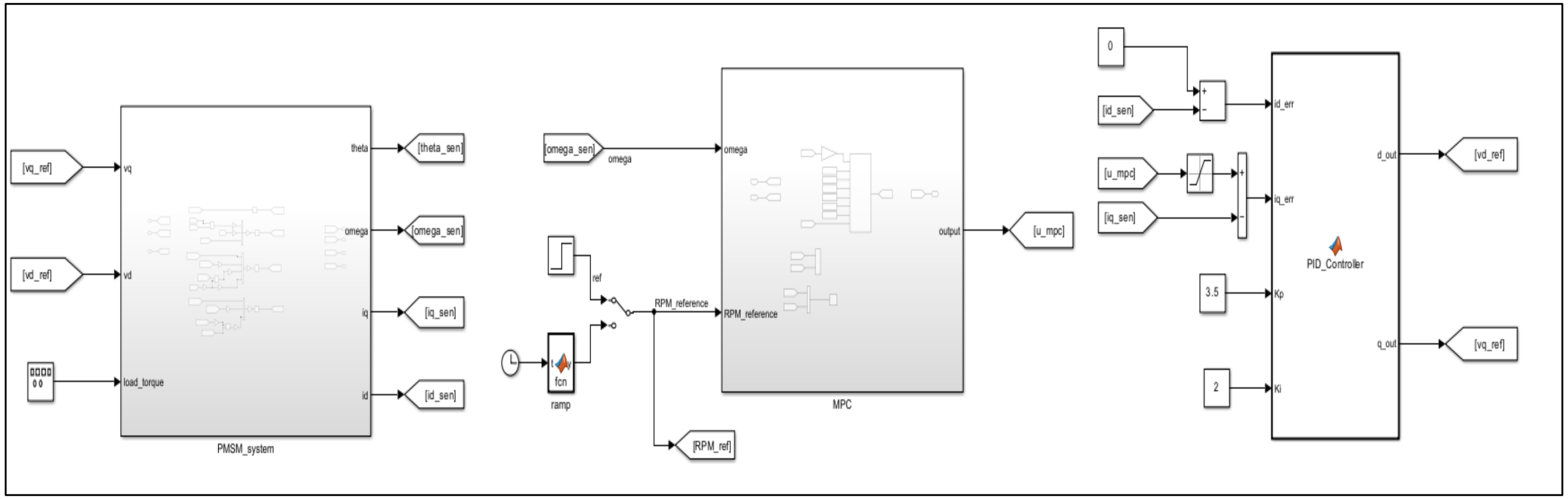
  K_p: 3.5
  K_I: 2

- Sampling time

  Ts, Current controller (PI): 0.05ms
  Ts, Speed controller (MPC): 0.5ms

2 Simulation

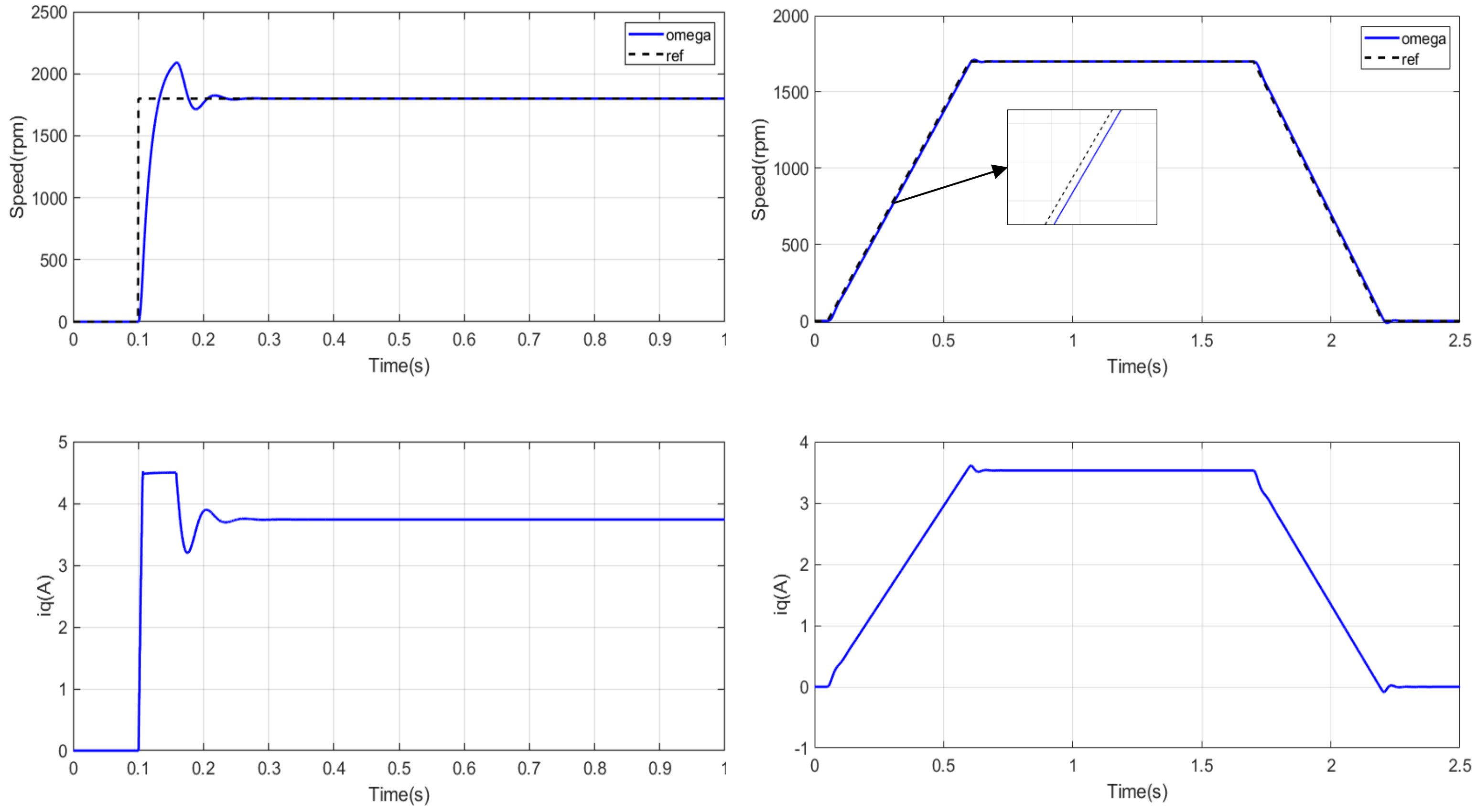
- ❖ 2.1
  - ❖ Implement Simulink




```
function output = MPC(Y_ref,Phi_Phi,Phi_R,Phi_F ,Q, Ad,Bd,y)
persistent Ui SpeedLoopCount SpeedLoopPrescaler u
% PI=3.141592653574;

% 초기화 (Simulink 상에서 첫 실행 시)
if isempty(Ui)
    Ui = 0;

    u = 0;

end
if isempty(SpeedLoopCount)
    SpeedLoopCount = 0;
end
if isempty(SpeedLoopPrescaler)
    SpeedLoopPrescaler = 50;
end


if SpeedLoopCount == SpeedLoopPrescaler
    SpeedLoopCount=0;
    xm=Ad*y+Bd*u;
    xf=[xm-y;y];
    %Y_ref=Y_ref*(2*PI/60);
    delta_U = (Phi_Phi + Q)\(Phi_R*Y_ref-Phi_F*xf);
    delta_u=delta_U(1,1);
    output=u+delta_u;
    u=output;
else
    SpeedLoopCount = SpeedLoopCount + 1;
    output=u;
end


end
```

2 Simulation

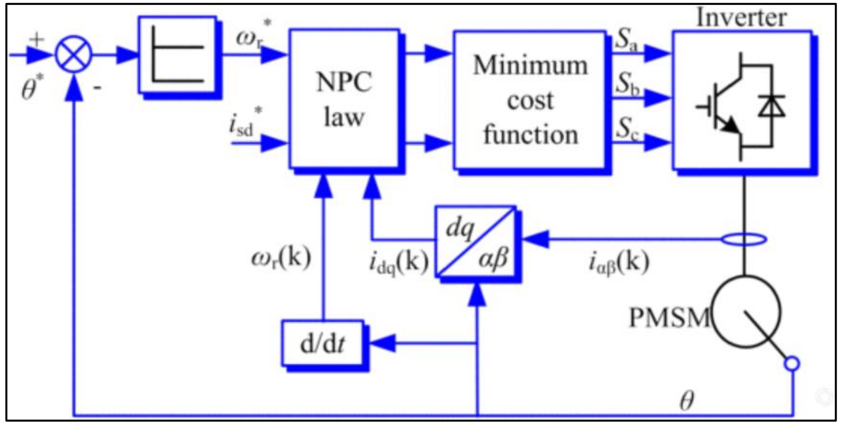
- Simulation Result
  - 느린 응답 성능, delay 발생



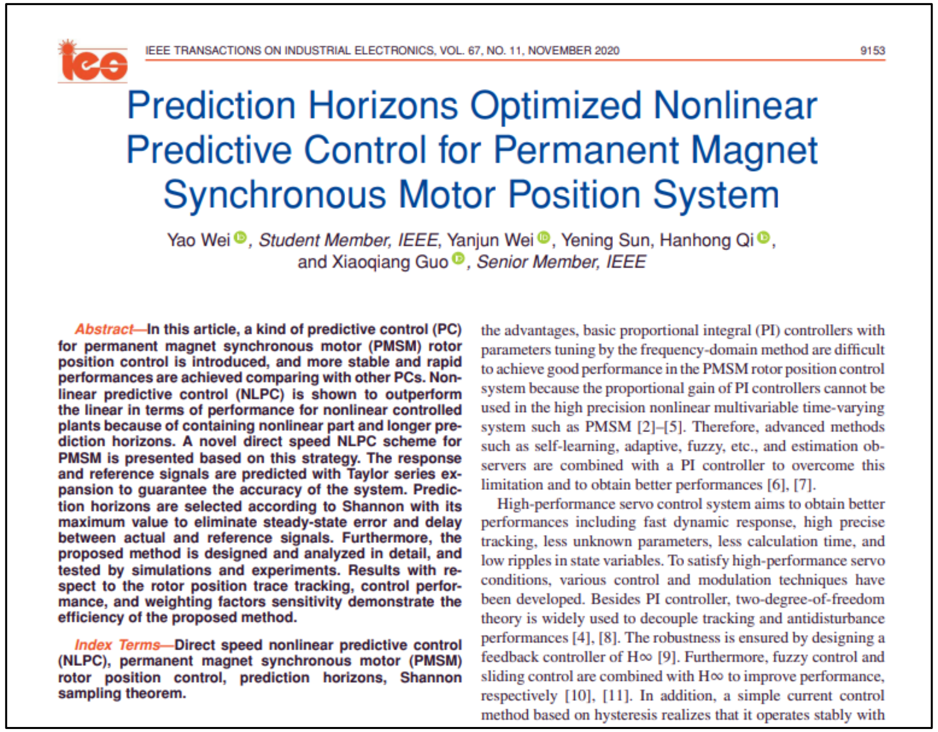
3 차후 계획

❖ **Nonlinear Predictive Control**

❖ Cascade 구조가 아닌 $x = [\omega_e \; i_q \; i_d]^T, u = [v_q \; v_d]^T$ 로 구현된 통합 제어기 구조



<Fig 1>



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Prediction Horizons Optimized Nonlinear Predictive Control for Permanent Magnet Synchronous Motor Position System

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***Abstract*—In this article, a kind of predictive control (PC) for permanent magnet synchronous motor (PMSM) rotor position control is introduced, and more stable and rapid performances are achieved comparing with other PCs. Nonlinear predictive control (NLPC) is shown to outperform the linear in terms of performance for nonlinear controlled plants because of containing nonlinear part and longer prediction horizons. A novel direct speed NLPC scheme for PMSM is presented based on this strategy. The response and reference signals are predicted with Taylor series expansion to guarantee the accuracy of the system. Prediction horizons are selected according to Shannon with its maximum value to eliminate steady-state error and delay between actual and reference signals. Furthermore, the proposed method is designed and analyzed in detail, and tested by simulations and experiments. Results with respect to the rotor position trace tracking, control performance, and weighting factors sensitivity demonstrate the efficiency of the proposed method.**

***Index Terms*—Direct speed nonlinear predictive control (NLPC), permanent magnet synchronous motor (PMSM) rotor position control, prediction horizons, Shannon sampling theorem.**

the advantages, basic proportional integral (PI) controllers with parameters tuning by the frequency-domain method are difficult to achieve good performance in the PMSM rotor position control system because the proportional gain of PI controllers cannot be used in the high precision nonlinear multivariable time-varying system such as PMSM [2]–[5]. Therefore, advanced methods such as self-learning, adaptive, fuzzy, etc., and estimation observers are combined with a PI controller to overcome this limitation and to obtain better performances [6], [7].

High-performance servo control system aims to obtain better performances including fast dynamic response, high precise tracking, less unknown parameters, less calculation time, and low ripples in state variables. To satisfy high-performance servo conditions, various control and modulation techniques have been developed. Besides PI controller, two-degree-of-freedom theory is widely used to decouple tracking and antidisturbance performances [4], [8]. The robustness is ensured by designing a feedback controller of H∞ [9]. Furthermore, fuzzy control and sliding control are combined with H∞ to improve performance, respectively [10], [11]. In addition, a simple current control method based on hysteresis realizes that it operates stably with

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