A NOVEL FLC BASED PMSM WITH PTC CONTROLLER

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ABSTRACT: The main component that guarantees the torque control performance of the permanent-magnet synchronous motor (PMSM) is the fast and steady current inner loop in the control device. Rapid dynamic responsiveness can be achieved with the deadbeat model predictive control technique, however it is dependent on the motor's mathematical model. Static error or oscillations will occur inside the usual state when the predictive controller's model parameter is not in line with the actual device. Consequently, this work proposes a single current predictive control that is entirely based on the fuzzy algorithm. A fuzzy controller, a magnetic flux observer, a proportional-integral (PI) compensation link, and a predictive controller were all included in the new manipulating technique. The fuzzy algorithm can adjust the effect of the compensating hyperlink in real time through the weight coefficient based on the motor's operating condition and the controller's version parameter mismatch. Comparing the suggested method to the conventional deadbeat predictive current control based on gap vector pulse width modulation (SVPWM), the dynamic performance is assured. When there is a controller model parameter mismatch, the PI compensation hyperlink's load is higher, and the motor machine's oscillation or static errors may be eliminated.

KEYWORDS: SVPWM, PI control, Fuzzy logic controller, permanent-magnet synchronous motor (PMSM).

I.INTRODUCTION: IN THE permanent-magnet synchronous motor (PMSM) system, current loop control methods are mainly proportional–integral (PI) control, hysteresis control, and predictive control. The PI controller has advantages of simple structure, good stability, and reliability. Therefore, it is widely used in the PMSM control system [1]–[3]. The hysteresis control has good rapidity, but also has many defects such as large ripple and unfixed switching frequency. It is often difficult to meet the requirements of high-performance control [4]. According to different action modes of voltage vector, the current predictive control of PMSM system can be divided into two categories: direct predictive current control and pulse width modulation (PWM) predictive current control. The PWM predictive current control is also known as the deadbeat predictive current control [5], [6]. The d–q axis voltage vector of deadbeat predictive current controller's output is calculated by the current reference value, stator current sample value, rotor position angle, and prediction model of the motor. Then, the voltage vector is applied to motor precisely through space vector PWM (SVPWM) modulation of the inverter. After several control periods, the motor current could trace the reference current by the voltage vector of controller's output. The deadbeat predictive current control makes the current loop of the motor control system to achieve good dynamic and steady performance. However, there are still some problems need to be solved. Because the deadbeat predictive current control is based on the motor system model, and this algorithm requires high accuracy of the model. However, accurate values of some key parameters are not easy to be captured, and some parameters are changed with the operating state of the motor, such as stator inductance and resistance. The parameter inaccuracy of the motor model will cause oscillation and static error of the current control [7]–[9]. The current oscillation will cause mechanical vibration and inverter damage by over current. The static error of the current control can lead to the inaccuracy output torque of the motor.

To deal with the above problems, many researchers have proposed several solutions. The influence of inductance on system stability is analyzed by establishing the transfer function of current loop with accurate and inaccurate parameters in [10] and [11]. The robust controller is added in the control system to eliminate the oscillation caused by larger inductance value deviation, but the influence of the inductance and flux value deviation on the static error of current loop is not considered in [12] and [13]. [14] Applied PI controller in the d-axis control and introduce static error integration in the q-axis control. Although the current static error can be eliminated, the performance of the PWM predictive control was weakened severely in the dynamic process. The error integration link was added to the d-axis current control, and the flux linkage parameter was adjusted by the q-axis current error in [15] and [16]. However, the current static error integration link still affects the dynamic performance of the predictive control, and the identification of the flux parameter cannot work in the dynamic process. The fuzzy logic controller is the easiest to implement for high-performance control of motor system among many intelligent algorithms [17]. In [18], a simplified fuzzy logic controller is proposed, but it does not consider the influence of inductance parameters on the system performance. In order to ensure that the motor maintains good operating characteristics in a wide speed range, the fuzzy algorithm is used to improve the robustness of the whole system [24]–[27]. From the results shown in the above reference, the fuzzy algorithm is very suitable to solve the parameter robustness and large load variation problems. In order to restrain the parameters sensitivity of the PWM predictive control and guarantee the dynamic performance of the current loop, a novel model predictive control based on the fuzzy control algorithm is proposed in this paper. Combined with the fuzzy algorithm, the PWM predictive control method and the PI method are adopted to make the dynamic and steady characteristics of the whole controller to adjust with the variation of operating conditions. Then, the adaptability of the controller is improved.

The intelligent control algorithm is introduced to judge the dynamic process and steady state of the motor system and analyze the parameters mismatch of controller. The model predictive controller is compensated by PI link with the weight coefficient that is adjusted by the fuzzy controller. In the dynamic process, the effect of PI compensation link is weakened to reduce the influence of integral link on the dynamic performance of model predictive control, but also reduce the excessive system oscillation caused by parameters mismatch of the control model. In the steady-state process, the role of PI compensation link is enhanced, so as to eliminate the oscillation and static error caused by the parameters mismatch of control model. Meanwhile, a novel flux observer is designed based on the fuzzy algorithm. The novel flux observer eliminated the influence of flux deviation on the control performance. In general, the proposed method in this paper not only eliminated the influence of the parameters mismatch of control model on the steady-state performance but also guaranteed the dynamic performance of the whole motor system.

II.PROPOSED SYSTEM:

The intelligent control algorithm is introduced to judge the dynamic process and steady state of the motor system and analyze the parameters mismatch of controller. The model predictive controller is compensated by PI link with the weight coefficient that is adjusted by the fuzzy controller. In the dynamic process, the effect of PI compensation link is weakened to reduce the influence of integral link on the dynamic performance of model predictive control, but also reduce the excessive system oscillation caused by parameters mismatch of the control model. In the steady-state process, the role of PI compensation link is enhanced, so as to eliminate the oscillation and static error caused by the parameters mismatch of control model. Meanwhile, a novel flux observer is designed based on the fuzzy algorithm. The novel flux observer eliminated the influence of flux deviation on the control performance. In general, the proposed method in this paper not only eliminated the influence of the parameters mismatch of control model on the steady-state performance but also guaranteed the dynamic performance of the whole motor system.

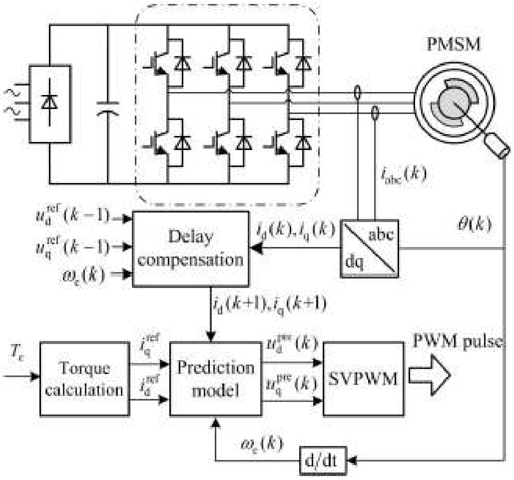


Fig. 3.1. Control block diagram of PMSM based on the traditional deadbeat predictive current control algorithm.

3.1 PREDICTIVE CURRENT CONTROL

The traditional deadbeat predictive current control algorithm is described in this section. The block diagram of the control algorithm is shown in Fig. 1. The voltage equation of PMSM in the d–q axis is shown as follows:

$$\begin{cases} u_d = Ri_d + L_d\dfrac{di_d}{dt} - \omega_e L_q i_q \\ u_q = Ri_q + L_q\dfrac{di_q}{dt} + \omega_e L_d i_d + \omega_e \psi_f \end{cases} \quad (1)$$

Where R is the stator resistance, Ld is the stator d-axis inductance, and Lq is the stator q-axis inductance. For the surface-mounted PMSM stator inductance Ld = Lq = Le is the electrical μ_E angular velocity. μ_f is the magnetic flux linkage. id and iq are the d–q axis stator currents, ud and uq are the d–q axis stator voltages. For the discrete-time system, if the sampling period T is small enough, in a sampling period, the angular velocity of the rotor can be seen as constant. By using the Euler approximation, the discrete-time expression of the stator voltage under the d–q axis can be obtained from (1)

$$\begin{cases} u_d(k) = Ri_d(k) + (L/T)\left[i_d(k+1) - i_d(k)\right] \\ \qquad - \omega_e L i_q(k) \\ u_q(k) = Ri_q(k) + (L/T)\left[i_q(k+1) - i_q(k)\right] \\ \qquad + \omega_e L i_d(k) + \omega_e \psi_f \end{cases} \tag{2}$$

Where (k) represents the kth control period. According to (2), the stator current of the next control period iq(k+1), id (k+1) can be predicted accurately, if the motor parameters are accurate and the voltage that acted in this control period ud (k), uq (k), stator current id (k), and iq(k) are known. Substituting reference current i ref d (k), i ref q (k) as predictive current iq(k+1), id (k+1) into (2), the formula for predicting the value of voltage can be obtained

$$\begin{cases} u_d^{\mathrm{pre}}(k) = Ri_d(k) + (L_d/T)\left[i_d^{\mathrm{ref}}(k) - i_d(k)\right] \\ \qquad - \omega_e L_q i_q(k) \\ u_q^{\mathrm{pre}}(k) = Ri_q(k) + (L_q/T)\left[i_q^{\mathrm{ref}}(k) - i_q(k)\right] \\ \qquad + \omega_e L_d i_d(k) + \omega_e \psi_f . \end{cases} \tag{3}$$

The predictive voltages u^{pre}d (k) and u^{pre}q (k) are modulated by SVPWM, so that the stator current can accurately trace the reference current in the next control period. When the digital control is used, the typical current sampling and PWM duty cycle update time series are shown in Fig. 2. In the initial time of the k control period, the current values of the stator id (k) and iq (k) are obtained by current sampling. In the k control period, the predictive control algorithm is performed. The predictive voltages u^{pre}d (k) and u^{pre}q (k) and its duty cycle value are calculated within the k control period. Restricted by hardware conditions, up to the initial time of the k+1 control period, the duty cycle value can only be updated by microprocessor. Then, the predictive voltages u^{pre}d (k) and u^{pre}q (k) can act on the motor by SVPWM. However, the actual current of the motor has been changed to id (k+1) and iq (k+1) by the previous period predictive voltages u^{pre}d (k − 1) and u^{pre}q (k−1) at this time. It will lead to the result that the effect of predictive voltages u^{pre}d (k) and u^{pre}q (k) action is inaccurate. Therefore, it is necessary to predict the current values id (k+1) and iq (k+1) as delay compensation for predictive model. The delay compensation equation is as follows:

$$\begin{cases} i_d^{\mathrm{com}}(k+1) = (1 - RT/L)i_d(k) + T\omega_e i_q(k) \\ \qquad + u_d^{\mathrm{pre}}(k-1)T/L \\ i_q^{\mathrm{com}}(k+1) = (1 - RT/L)i_q(k) - T\omega_e i_d(k) \\ \qquad + u_q^{\mathrm{pre}}(k-1)T/L \end{cases} \tag{4}$$

$$\begin{cases} u_d^{\mathrm{pre}}(k) = Ri_d^{\mathrm{com}}(k+1) + (L_d/T)\left[i_d^{\mathrm{ref}}(k) - i_d^{\mathrm{com}}(k+1)\right] \\ \qquad - \omega_e L_q i_q(k) \\ u_q^{\mathrm{pre}}(k) = Ri_q^{\mathrm{com}}(k+1) + (L_q/T)\left[i_q^{\mathrm{ref}}(k) - i_q^{\mathrm{com}}(k+1)\right] \\ \qquad + \omega_e L_d i_d^{\mathrm{com}}(k+1) + \omega_e \psi_f . \end{cases} \tag{5}$$

With the delay compensation, the current will be able to track the reference currents $i^{ref}d$ (k) and $i^{ref}q$ (k) until the end of the next control period. Based on this analysis, Nasiri [21] points out that the delay of tracking the reference current is two control period, including the voltage calculation period and the actual action period. The PWM predictive current control has good dynamic performance. According to the (4), there is a close relationship between the output of the controller and the parameters of the motor model. Therefore, whether the parameter in the predictive controller is accurate has a great impact on the control performance, the inductance and flux parameters of the motor are more significant to controller. If the inductance parameter of the controller is equal to two times the actual inductance, the system will oscillate [22]. When the system has flux error, it will lead to the static error [23].

3.2 NOVEL CURRENT PREDICTIVE CONTROL BASED ON FUZZY ALGORITHM

To solve the parameter sensitivity issues of traditional PWM predictive control and enhance the robustness of the model predictive control, the novel predictive current control based on the fuzzy algorithm is proposed in this paper. On the basis of the model predictive control, a compensation link based on the PI algorithm is added. The fuzzy control algorithm is introduced to judge the dynamic process, the steady process, and parameter mismatch of the control system. The fuzzy control algorithm output weight coefficient to adjust the compensation effect of the PI link to the model predictive controller. In the dynamic process, the weight and effect of the compensation link both are reduced, so that the dynamic performance of the model predictive control do not get affected by the compensation link. In the steady-state process or parameter mismatch, the weight of the compensation link is enhanced; meanwhile, the weight of the model predictive control is reduced, so as to eliminate the oscillation and static error caused by the parameters mismatch of the control model. The effect of the system delay on the weight coefficient is considered. In addition, a novel flux observer is designed based on the fuzzy algorithm. The introduction of flux observer fundamentally solved the influence of flux error on the control performance. The fuzzy algorithm is used to control the flux observation only worked in the steady state, and the problem of the inaccurate observation of the flux in the dynamic process is avoided. The structural diagram of the novel control algorithm proposed in this paper is shown in Fig. 3.2 mainly include: compensation with weight, fuzzy controller (including delay algorithm), novel flux observer, and other parts.

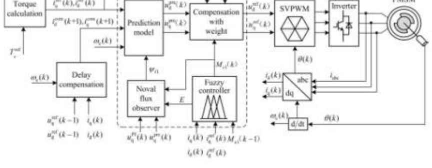


Fig. 2.2. Structural diagram of the novel predictive current control based on the fuzzy algorithm.

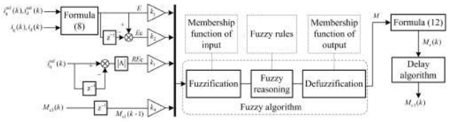
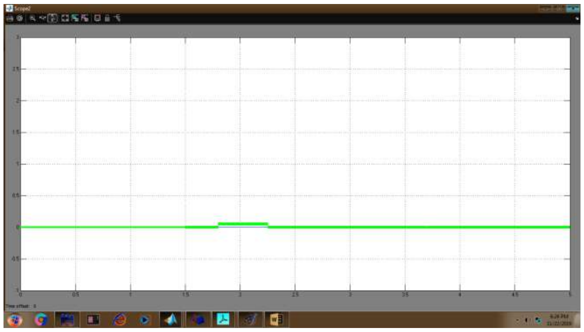


Fig. 2.3. Block diagram of the fuzzy control subsystem.

In this section, the principle of determining the weight coefficient Mc1(k) is described in detail. In order to enable the fuzzy algorithm to judge the steady state, the dynamic process and parameter mismatch of the system, a four input and one output fuzzy control system is designed. The absolute value of the current error E, the change rate of the absolute value of the current error Ec, the absolute value of the change rate of reference current REc, and the weight coefficient Mc1(k − 1) which obtained from the previous period calculation are set as inputs. The weight coefficient Mc1(k) is set as output. The triangle membership function is selected for all membership functions, and the fuzzy rules and membership functions are designed according to the logical reasoning and engineering experience. The fuzzy control subsystem block diagram is shown in Fig. 4, where k1, k2, k3, and k4 are the ratio coefficients of the input variable. The symbol |A| is the absolute value operator, and the symbol z−1 represents the one control period of delay.

III.SIMULATION RESULTS

Current and Mc1 waveforms with rated model parameters under different step load variation



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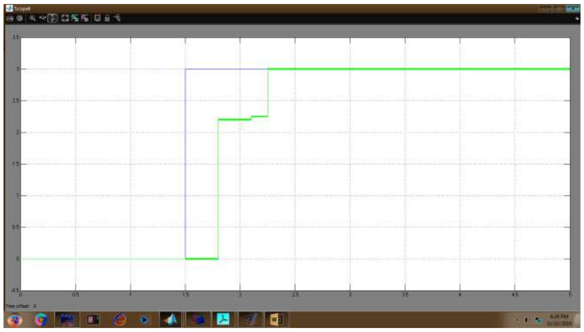

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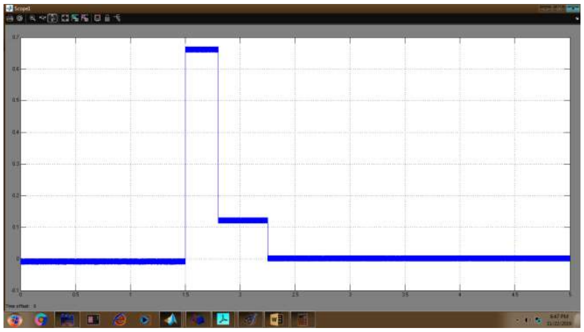
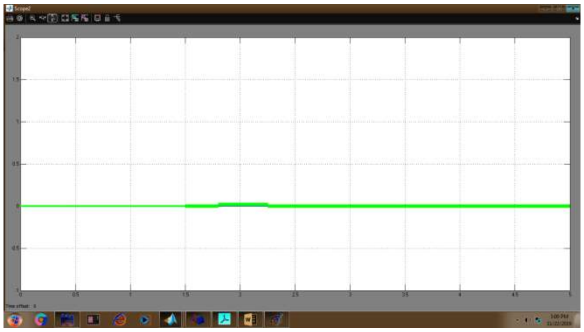


Mc1(k)



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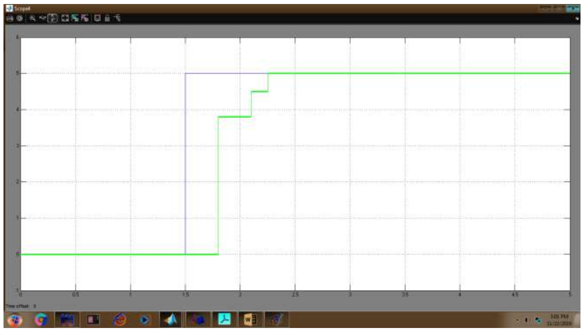

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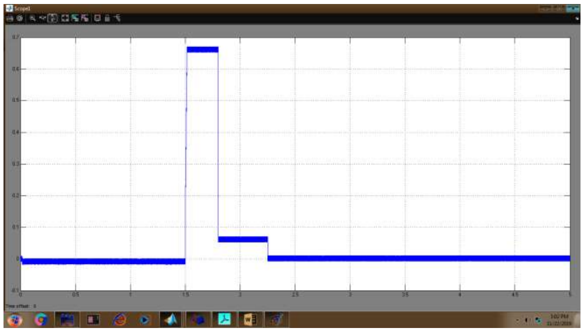
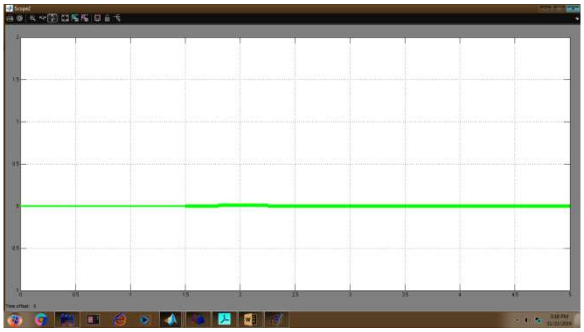


Mc1(k)

11(b)



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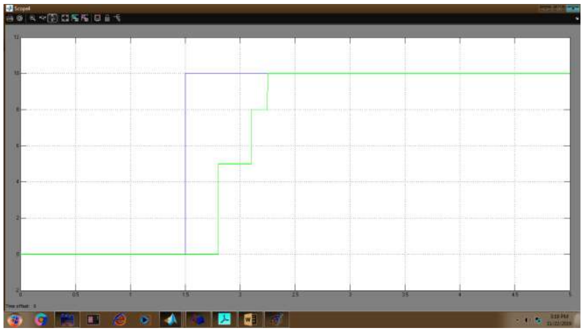

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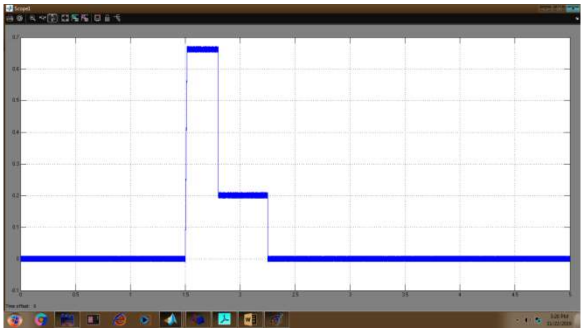
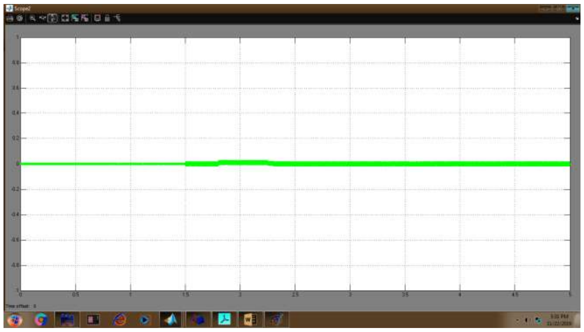


Mc1(k)

Fig11(c)



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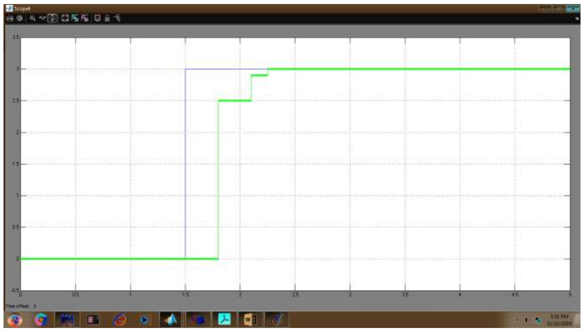

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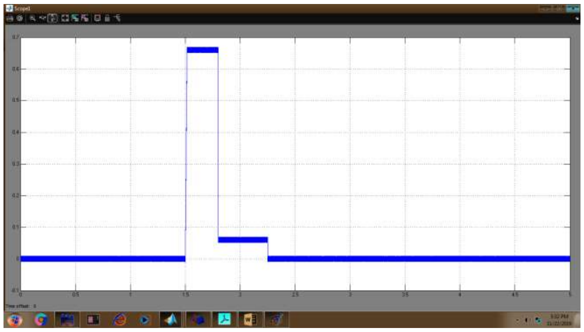
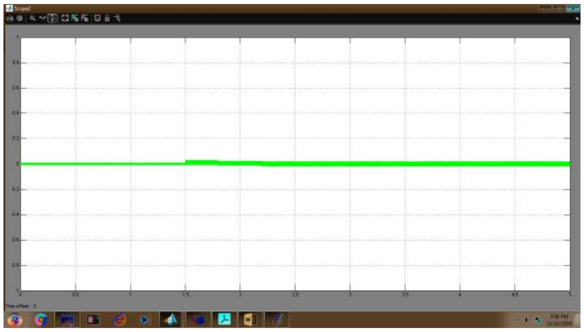


Mc1(k)
Fig11(d)



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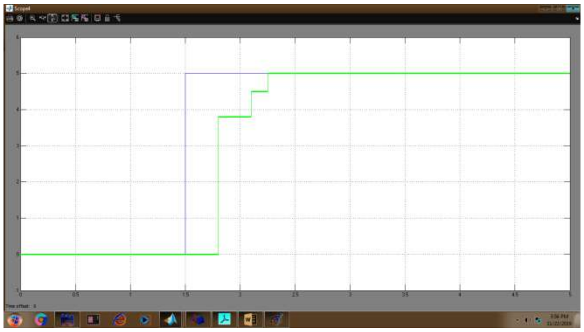

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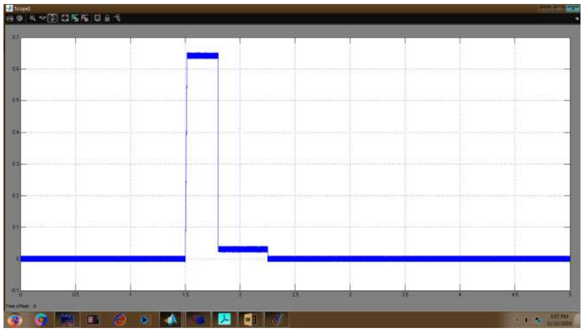
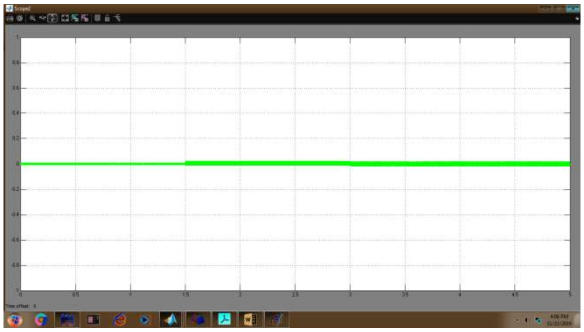


Mc1(k)
Fig11e&12c



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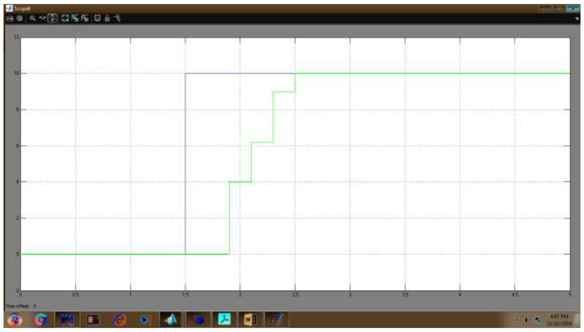

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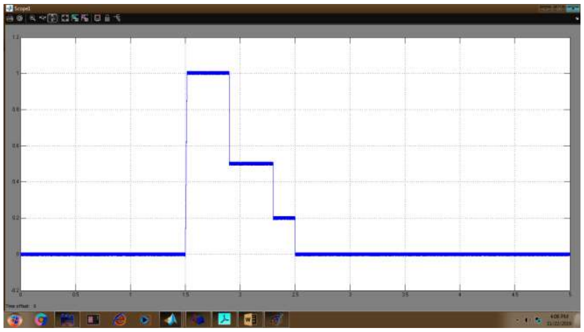
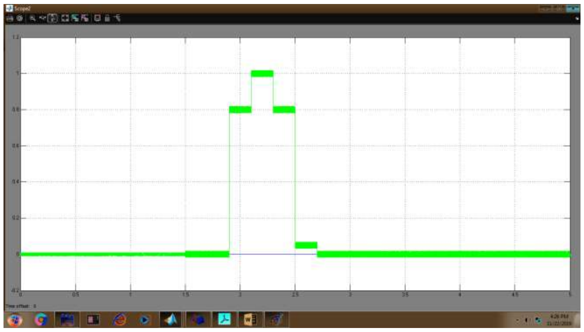


Mc1(k)

11(f)



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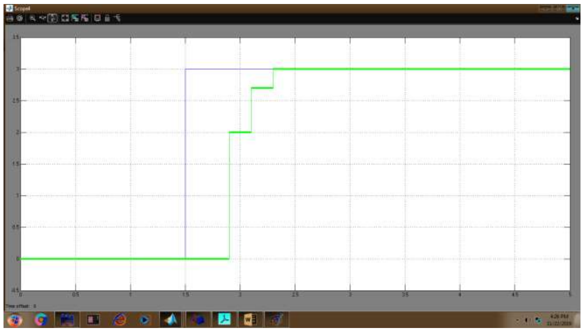

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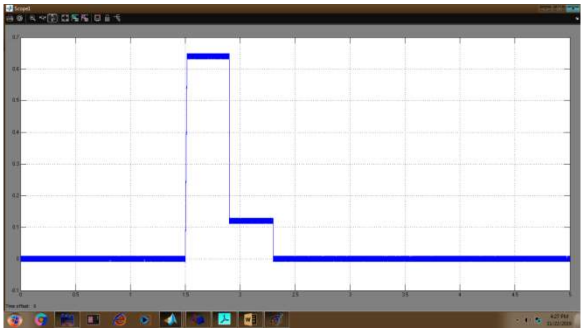
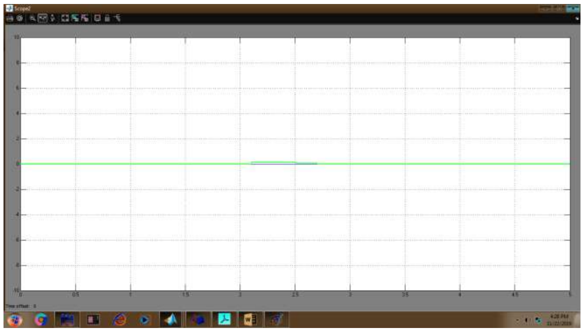


Mc1(k)

11(g)



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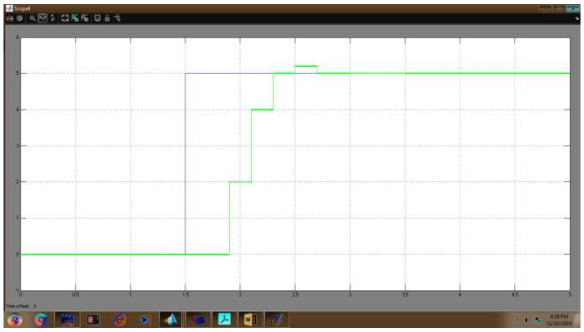

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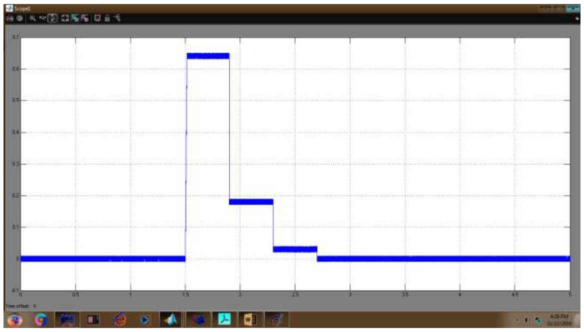
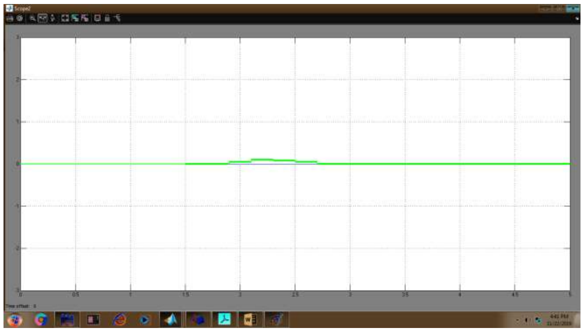


Mc1(k)

Fig11h



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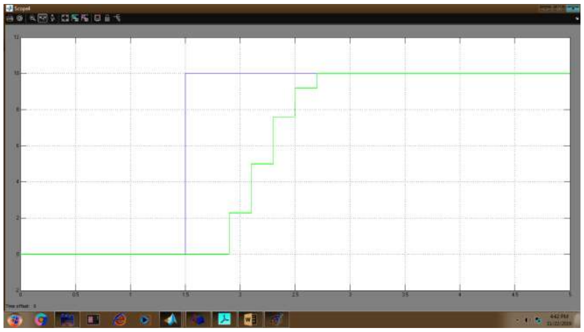

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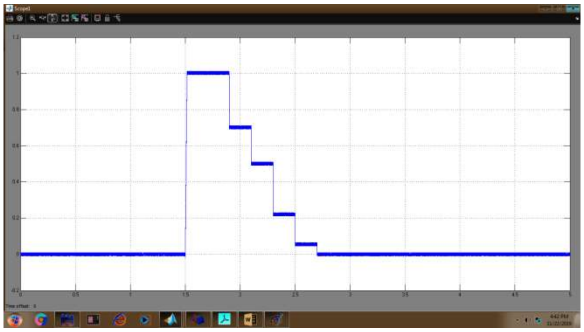

Mc1(k)

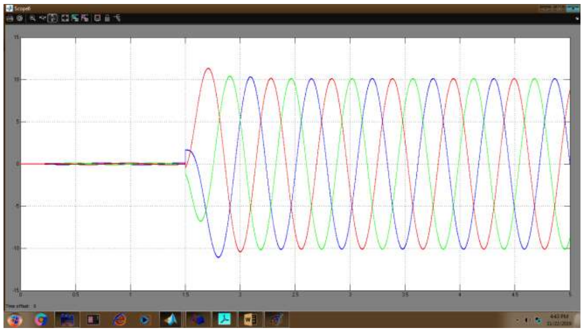

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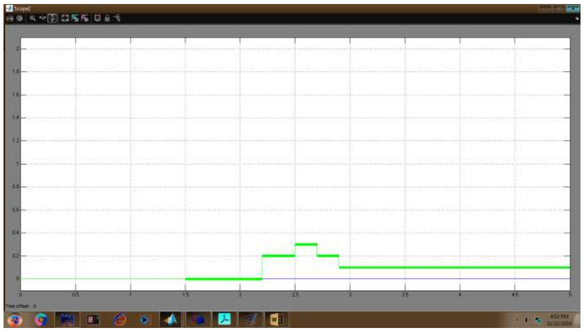
Fig11i

Fig.12 The current waveform with different method under the different operating condition



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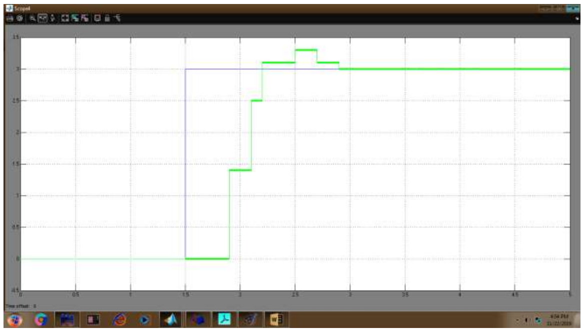

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IV.CONCLUSION

The PMSM control system's rapid and steady current inner loop is essential to guaranteeing the motor's torque control performance. This work proposes a unique fuzzy algorithm-based current predictive control based on the model predictive control. The following findings are drawn from this paper on the suggested algorithm. The fuzzy controller is intended to modify the model predictive controller's weight and the compensating impact of the PI compensation link. Synthetic consideration is given to the system delay. The new flux observer, which is based on the controller's output voltage reference value, is constructed using fuzzy controllers. The innovative flux observer essentially eliminates the impact of flux inaccuracy on the control performance. By employing the novel control strategy, the static error and oscillation brought on by the parameter mismatch are compensated for and eliminated, and the dynamic performance is also guaranteed under the model parameters mismatch condition, in contrast to the conventional current predictive control and PI control.

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