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Electric Vehicle Control using PMSM

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Abstract: Considering model parameter imbalance and one-step lag, an revised Deadbeat Predictive Current Control (DPCC) is proposed in this work. It improves the performance of current control of Permanent Magnet Synchronous Motor (PMSM). By improving the current control, losses in the machine can be reduced and machine performance can be improved. For doing this, traditional predictive current control performance is analyzed. Based on sliding mode exponential reaching law, a stator current and disturbance observer (SCDO) is being proposed. SCDO can concurrently forecast future value of stator value of stator current and track system disturbance caused by parameter imbalance. For compensating the voltage reference calculated by deadbeat predictive current controller, a feed forward value is considered. This feed forward value is the prediction currents based on SCDO. These are used for replacing the fragmented current in DPCC. By connecting the DPCC part and current forecasting and feed forward rectification part based on SCDO, a compound control method is developed in this work. This paper focuses an adaptive SCDO based on novel adaptive sliding mode reaching law which can increase the control performance of the existing method. This method can be used for Electric Vehicle (EV) control.

Keywords: Observer, Parameter mismatch, Permanent Magnet Synchronous Motor (PMSM), Predictive Control, Deadbeat Predictive Control.

I. INTRODUCTION

For smooth torque control in PMSM drives, high performance current control is necessary. For this, a novel discrete time robust predictive current controller is proposed for PMSM drives. Deadbeat structure is mainly used to design controller and current prediction schemes. This deadbeat control has good transient response but it contains parametric uncertainties and unmodelled dynamics. In order to provide good condition, a discrete time integral term is added to the deadbeat current prediction. The controller is easy to apply and suitable for achieving high performance in PMSM applications. Digital control systems of PMSM are now frequently used in industrial applications. For a realistic PMSM system, current control performance affects the performance of the system. So to achieve high steady state precision and fast dynamic torque response, many current control methods have been studied and the most common current control methods are hysteresis control [2], proportional – integral control[3] and predictive control[4]. For enhancing the control performance and compensate the effects of system disturbances, the combination of predictive control and disturbance observer has been studied. The value of voltage input into the inverter is variable depending on the battery performance conditions because the battery is directly coupled to the inverter, and this influences motor control. The inverter is a power converter consisting of semiconductor switching elements and performs switching at a high frequency of several kilohertz to convert DC voltage to AC voltage synchronous with motor rotation. Sensors necessary for motor control are angle sensors, current sensors, and voltage sensors. A resolver that can detect absolute angles is used as the angle sensor. The basics of Permanent Magnet motor control are current amplitude and phase control. An upper-level torque command is transformed to a current command, and a feedback control is done to make the current sensor value agree with the current command value. The current sensor value is converted from three-phase to direct and quadrature axis coordinates to wipe out the phase delay caused by the feedback control.

II. MODELLING OF THE MACHINE

The following equations have been applied for modelling o PMSM[9]. The direct and quadrature-axis voltages are given as.

$$V_q = R_q i_q + P\lambda_q + \omega_r \lambda_d \qquad (1)$$

$$V_d = R_d i_d + P\lambda_d - \omega_r \lambda_q \qquad (2)$$

The d- and q-axis fluxes are,

$$\lambda_q = Li_q \tag{3}$$

$$\lambda_d = L_d i_d + \lambda_f \tag{4}$$

The d- and q-axis currents are given as,

$$i_d = \int \frac{1}{L_d}(V_d - i_d R_d + \omega_r L_q i_q) \tag{5}$$

$$i_q = \int \frac{1}{L_q}(V_q - i_q R_q - \omega_r (L_d i_d + L_m i_{dr}) \tag{6}$$

The torque produces is given by,

$$T_e = \frac{3P}{4}(\lambda_d i_q - \lambda_q i_d) \tag{7}$$

Mechanical torque developed is given by,

$$T_e = T_L + B\omega_m + J\frac{d\omega_m}{dt} \tag{8}$$

The rotor mechanical speed of the motor is given by,

$$\omega_m = \int \frac{1}{J}(T_e - T_L - B\omega_m)dt \tag{9}$$

And

$$\omega_e = \frac{P}{2}\omega_m \tag{10}$$

The modeling of Permanent Magnet Synchronous Motor is executed using the above equations[10]. Fig.1 shows the modeling of PMSM. Table I shows the parameters of the machine.

Table I: Machine Parameters

Rated Power	4 kW
Rated Voltage	400 V
Rated Speed	1500 rpm
Flux Linkage	0.175 Wb
Number of poles	4
d- axis inductance	8.5 mH
q- axis inductance	8.5 mH
Stator Resistance	2.875 Ω
Rated Current	10 A

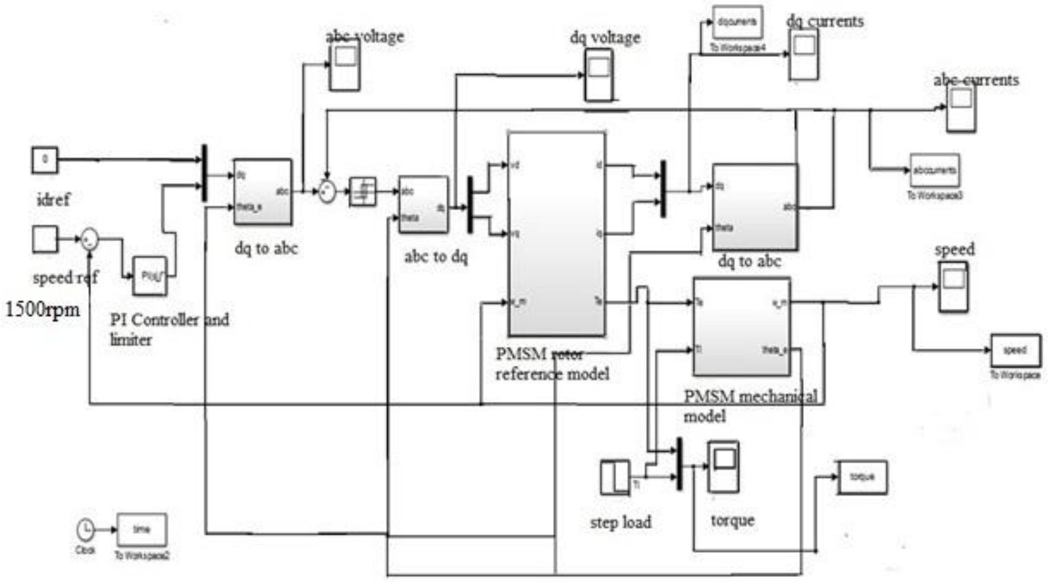

Fig.1. Modeling of PMSM

The output of electrical model is the d-axis and q-axis currents and the electromagnetic torque[11]. Speed of the machine is the output of mechanical speed.

III.PREDICTIVE CURRENT CONTROL

Hysteresis control has been used for the current control of PMSM [5]. This has much influence such as quick current responses, good robustness, and easy algorithm application. The main problems of this method are large current ripple and fluctuating switching frequency. The Proportional Integral (PI) based current control has such advantages as high steady-state control precision and fixed switching frequency[6].This advantages have made possible for improving the static tracking performance of the control system in many applications. PMSM control system consists of unavoidable disturbances as well as parameter variations. This makes it impossible for PI control algorithms to obtain a satisfying dynamic performance in the entire operating range for this kind of nonlinear systems. Discrete-model-based predictive current control show better steady-state and dynamic performance as compared to hysteresis control and classical PI control [7]. The main aim of this control method is to direct motor currents with high accuracy in a fleeting interval that is as short as possible. Predictive current control is broadly classified into two: model predictive control[8] and deadbeat predictive current control[9].

IV. MODEL PREDICTIVE CURRENT CONTROL OF PMSM

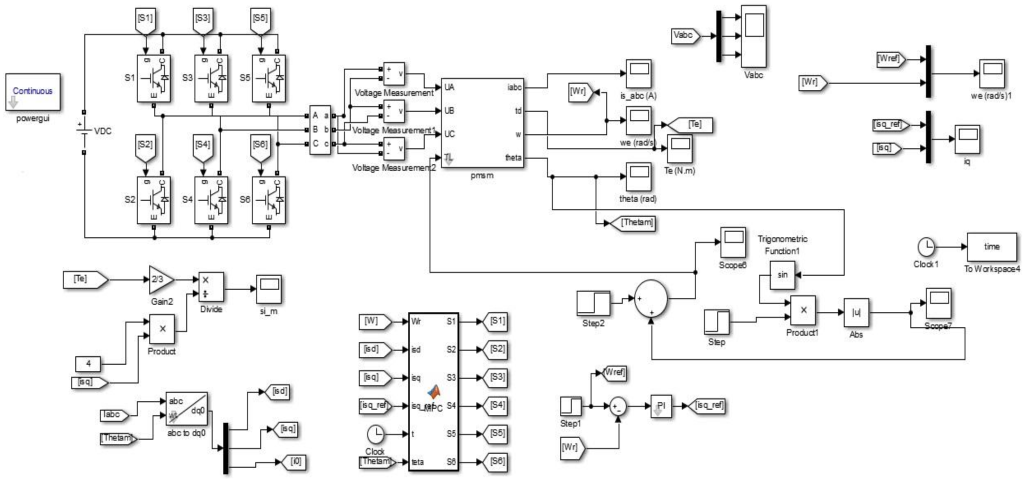

Fig.3. MPCC of PMSM

Model Predictive Current Control utilizes system discrete model and inherent distinct nature of motor inverter to estimate the prospective behavior of states and persuades the future voltage vector according to optimization of an operating cost function. The selected voltage vector, which is one of the seven basic vectors and can minimize the cost function, is used for the output of the control system. Fig. 3 shows the Model Predictive Current Control of Permanent Magnet Synchronous Motor. The voltage signal for the motor is generated from an inverter. The inverter consists of six switches. The switching signal for the switches is generated by Space Vector Pulse Width Modulation (SVPWM). SVPWM signals are generated from Model Predictive Current Control. The currents from the motor are controlled by MPCC and the switching sequences are generated accordingly.

V. DEADBEAT PREDICTIVE CURRENT CONTROL

The block diagram of the proposed system is shown in Fig.4[1]. First, we have to measure stator current, speed of motor and angular displacement. Then we have to predict the future values of d-axis and q-axis currents which is performed by adaptive stator current and disturbance observer (ASCDO). Predictive values of d- and q-axis currents, the reference values of currents and speed of motor are the inputs to DPCC. DPCC calculates the voltage vectors. ASCDO also estimates the predicted parameter disturbances. Both these become the inputs to the sum block. The voltage output of the controller becomes the input of the Space Vector Pulse Width Modulation (SVPWM) block and these modulation schemes makes the switching sequences to inverter and inverter is connected to PMSM.

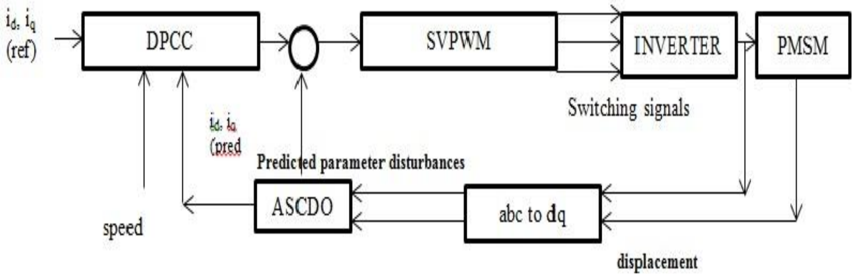

Fig.4: Deadbeat Predictive Current Control of PMSM

VI. SIMULATION RESULTS AND DISCUSSIONS

A. Modelling of PMSM

The following graph shows the simulation results of PMSM modelling in MATLAB. Fig.5 shows the voltage waveforms of PMSM. The peak value of PMSM is 325V.

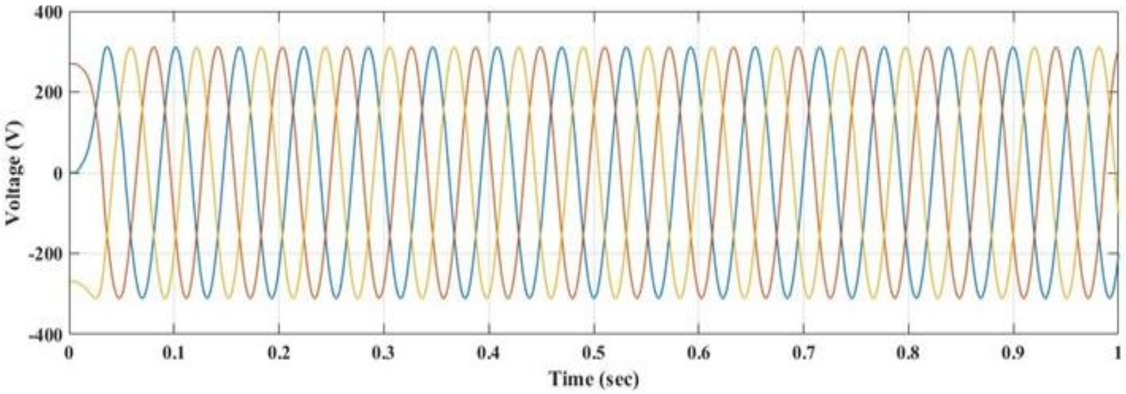

Fig.5. Voltage vs time characteristics

Fig.6 shows the current waveforms of PMSM. The peak value of current is 10A.

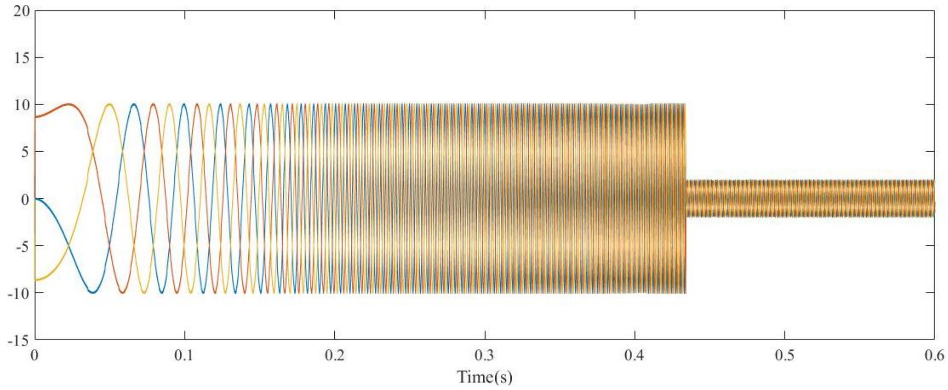

Fig.6. Current vs time characteristics

Fig.7 shows the change of speed with time. Speed increases from 0 to 1500 rpm and remains steady after 0.2sec. The steady state speed is the same as that of the commanded reference speed which validates the simulation result.

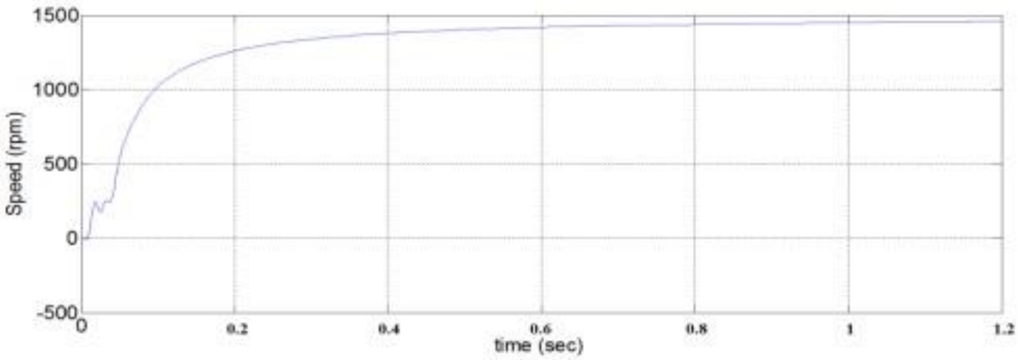

Fig.7. Speed vs time characteristics

Fig.8 shows the developed torque of the motor. During initial time i.e. from 0 to 0.05sec, starting torque is twice the steady state value. After 0.1sec torque will remain steady and the value of this steady torque.

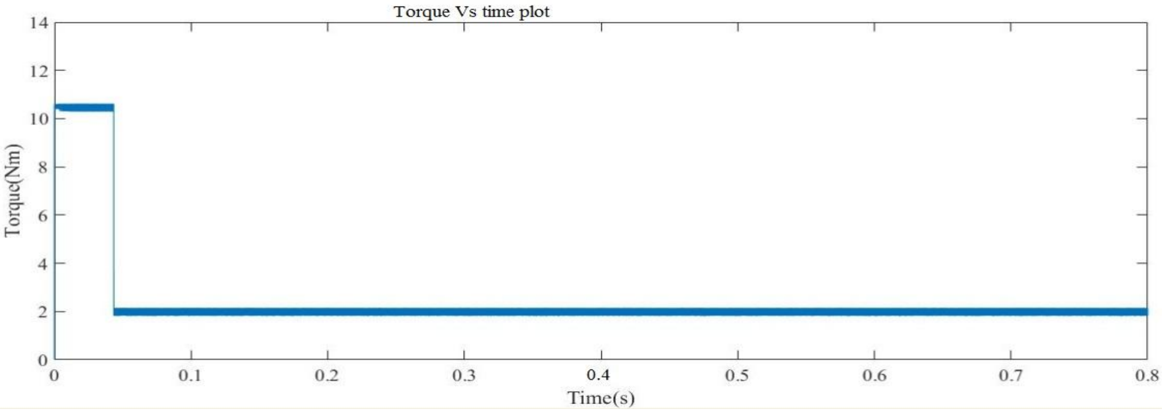

Fig.8. Torque vs time characteristics

B. MPCC of PMSM

Fig.9 shows the current waveform of Model Predictive Current Control of PMSM. The rms value of current is 14.14A.

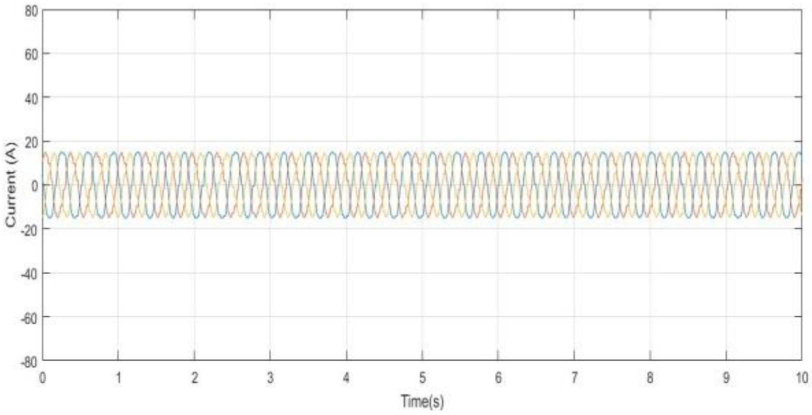

Fig.9. Current characteristics of MPCC

Fig.10 shows the speed waveforms of MPCC of PMSM. The value of speed is varying from 0 to 1500 rpm.

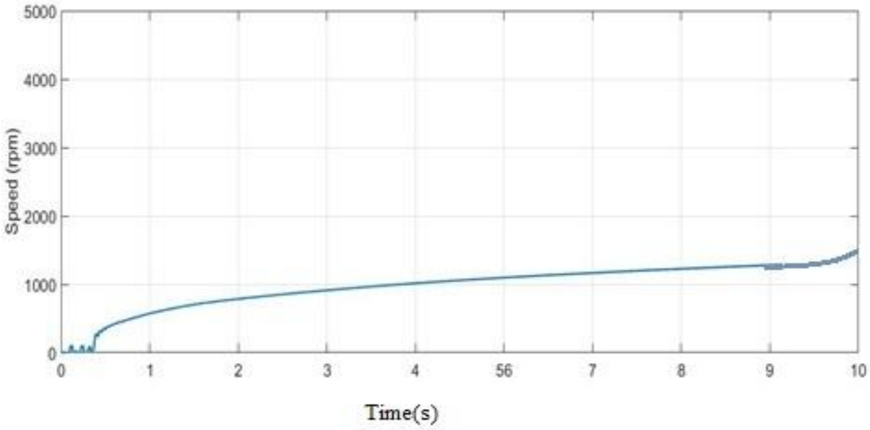

Fig.10. Speed characteristics of MPCC

Fig.11 shows the torque waveform of MPCC of PMSM. The value of torque is 10Nm.

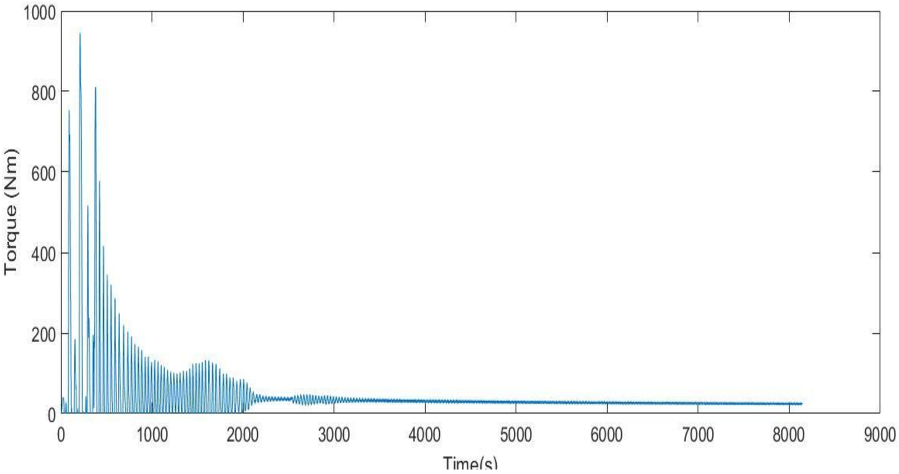

Fig.11. Torque characteristics of MPCC

VII. CONCLUSION

The modelling of PMSM is completed and waveforms are obtained successfully. Model Predictive Current Control of PMSM is done. The predictive current control algorithm of Permanent Magnet Synchronous Motor (PMSM) drives has clear cut current tracking, consistent switching frequency and is relevant for digital implementation. The proposed algorithm is very simple and can be effectively implemented. This deadbeat predictive current control with adaptive SCDO (ASCDO) can be applied for Electric Vehicle (EV) control. A composite control algorithm combining Deadbeat Predictive Current Controller (DPCC) and Stator Current and Disturbance Observer (SCDO) is developed to improve the control performance of PMSM system. A novel sliding mode exponential reaching law is introduced to suppress the sliding mode chattering of SCDO. A DPCC+ASCDO method is developed to further improve the performance of DPCC+SCDO method. The novelty of this paper is that deadbeat predictive current control with adaptive SCDO can be applied for Electric Vehicle (EV) control. The motor drives have beneficial characteristics that are absent in internal combustion engines including high responsivity, ease of control, and low noise. By utilizing these advantages, we have the ability to give vehicles Improved stable maneuverability, safety and marketability. Additionally, lowering costs is essential to popularizing hybrid vehicles, and further technological development is necessary with motor hardware control and electrical systems. In the future, the importance of motor driving technology in the automotive field will steadily grow.

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