Current Sensorless Model Free Control Applied on PMSM Drive System

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ABSTRACT - In control of electric machines, removing the current sensors from the electric powertrains has a great importance owing to saving on manufacturing and maintenance costs. This paper addresses the Model-Free-Controller (MFC) as a current sensor-less controller that do the control task for a Permanent-Magnet-Synchronism-Machine (PMSM) without using neither sensor nor estimator for stator current. As this controller is model free, it doesn't require any information about parameters. MFC tries to control the drive system just with measuring the rotor speed and dc bus voltage. Simulation study has been done to show the MFC's robustness under ideal and parametric error condition.

Key Words—Model free Control, Sensorless Control, Synchronous machin Control.

1. Introduction

Nowadays, the hybrid and full electric vehicles plays a lead role in car industry and they will be dominant in conventional vehicles in the coming years. Despite of the large demand, the electric vehicles meets some restrictions related to the manufacturing and maintenance cost, optimal design of powertrain for high reliability. Sensor-less control is an impressive way to reduce the measurement noises and improve the reliability of system [2].

The mechanical sensor-less control has been used broadly in the literature and got good results too [3] [4], but the electric machines used in hybrid vehicles are commonly working in low voltage and high current condition, consequently this requires some sensitive and more expensive current sensors and more probes connection on stator side. All these constraints lead technology to remove the current sensors for a better optimization in weight, volume and cost. This paper will focus on current sensor-less (on stator side) control composition.

In this paper, the Model-Free-Control (MFC) [10], is presented for control of PMSM drive system just by measuring the rotor mechanical speed and input filter voltage. As this controller is model free, it doesn't need more information about system model and removes the effects of parametric errors.

2. Studied PMSM Drive System

The studied Permanent-Magnet-Synchronous-Machin (PMSM) drive system is illustrated in Fig 1. In this nonlinear system, a 12V battery acts as DC power source, an input filter with big capacitor is located between battery and inverter to cover battery from dangerous voltage peaks and a 3-legs inverter as power electronic interface to drive the mentioned PMSM. As explained in introduction, this paper tries to remove the current sensors in stator side and introduce a sensor-less control method. For this, during control task, the dc bus voltage and rotor speed $[v_s, \Omega]$ will be measured and the stator phase currents will stay unmeasured. The $[v_d, v_q]$ paire will be considered as control inputs.

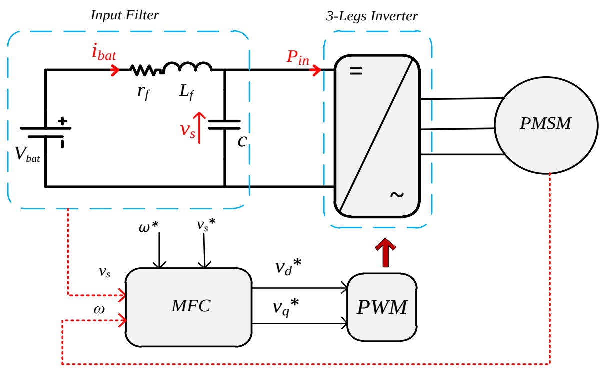

Fig. 1. Studied system and sensorless control scheme

3. Control Methoed

The fundamental concept of the MFC architecture is carried out by creating an equivalent dynamic linearization data model of nonlinear system at every operation point then estimating the system's PPD online by using I/O data of the controlled plant. Finally, the controller will be designed based on some weighted one-step-ahead cost function [9].

Considering a Multi-Input-Multi-Output (MIMO) nonlinear discrete time system as:

$$y(k+1) = f\left(y(k), \dots, y(k-n_y), u(k), \dots, u(k-n_u)\right) \tag{1}$$

In which $y(k) = [y_1(k)\ \ y_2(k)\ \dots\ y_m(k)]^T \epsilon R^{m\times 1}$ is control output vector and $u(k) = [u_1(k)\ \ u_2(k)\ \dots\ u_m(k)]^T \epsilon R^{m\times 1}$ is the control input vectors, n_y and n_u are the unknown integers and $f(\dots) = [f_1(\dots), \dots, f_m(\dots)]^T$ is an unknown non-linear vector-valued function. By applying compact form dynamic linearization data model on the mentioned system (1), the general model of this system can be described as:

$$\Delta y(k+1) = \varphi_c(k)\Delta u(k) \tag{2}$$

Where the $\varphi_c(k) = [\varphi_{i,j}(k)]$, $i, j\epsilon[1, \dots, m]$ is a time varying matrix called pseudo partial derivative (PPD) is diagonally dominant.

For designing the control input, strong cost function has been used to insure the minimum error between measured and reference outputs, by this way, control law will be achieved as:

$$u(k) = u(k-1) + \frac{\rho\varphi_c(k)^T}{\lambda+\|\varphi_c(k)\|^2}(y^*(k+1) - y(k+1)) \quad (3)$$

Where $\rho\epsilon(0, 1]$ is step length and $\lambda > 0$ is weight factor.

4. Simulation Results

In this approach, the controller creates control signals, u= [v_d, v_q], just by using the y= [v_s, ω] and y^*= [v_s^*, ω^*] as measured system outputs and desired outputs respectively. In order to validate the accuracy and robustness of MFC on described nonlinear system the simulation is carried out under starting performance, rotor speed variation and load torque disturbance conditions. Since any parameter have not been used in controller, the simulation satisfies the parametric error condition too. The desired stator d-axis current is supposed to be zero ($i_{dref} = 0A$).

The speed variation in this simulation study is extracted according to the new European urban driving cycle. At the first step of simulation ($t = 0.1s$), the operating point corresponds to a rotor speed of 160 rpm then it rises to 380 rpm and 530 rpm at the $t = 3s$ and $t = 6s$ respectively. Finally, the rotor speed decreases to 380 rpm again at fourth simulation step ($t = 11s$). The simulation results (without load torque disturbance) for measured (v_s and ω) and unmeasured variables ($dq - axis$ currents) are shown in Fig. 2.

The simulation results represent a good performance of MFC to track the expected trajectories for both measured and unmeasured variables. Since the MFC works with measured and reference trajectories and doesn't use system parameters, applying any error on parameters doesn't affect the system performance and gives the same results with Fig.2.

5. Conclusions

This paper addressed MFC as a new sensor-less control method applied on PMSM drive system. Firstly, the dq mathematical model of studied system is illustrated. At the next step, the theory and function of MFC has been analyzed shortly. The achievable controller performance with and without sensors in different operation conditions has been analyzed by simulation study. The achieved results represent a good control performance of MFC applied on PMSM drive system specially in steady state.

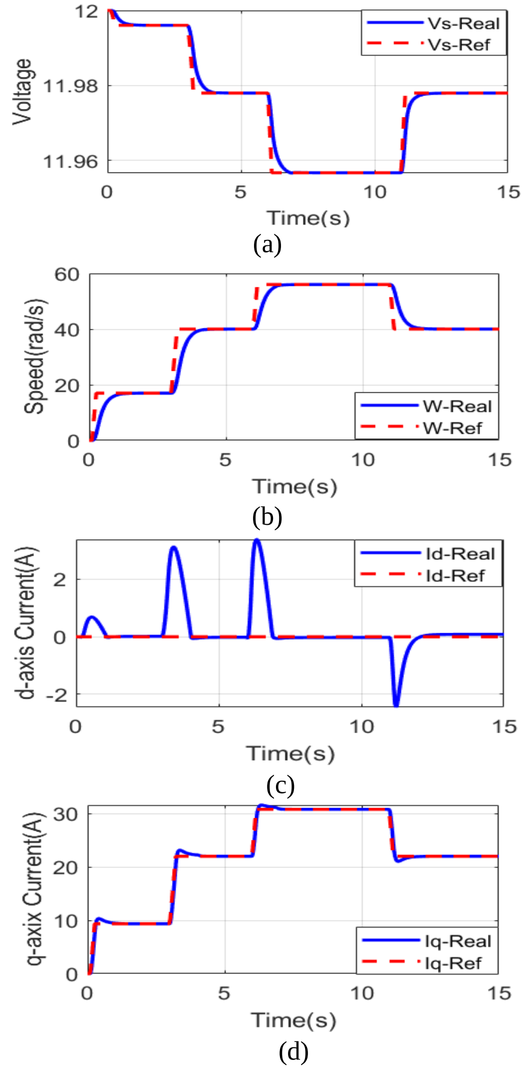

Fig. 2. The simulation results. (a) rotor speed (b) dc bus voltage (c) d-axis stator current i_d (d) q-axis stator current i_q

6. References

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