Annual PhD Students Conference IAEM Lorraine 2019

Current Sensorless Model-Free Control Applied on PMSM Drive System

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1. Context

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.

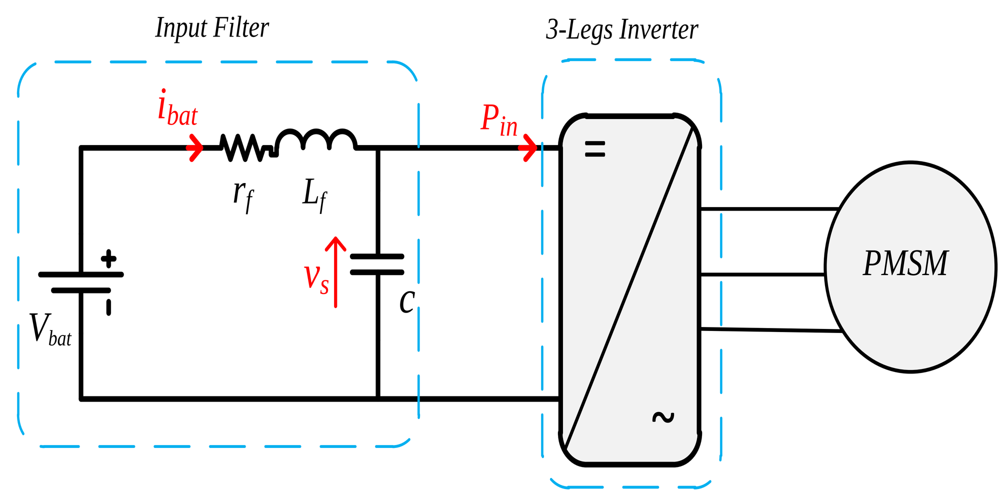
This study addresses the Model-Free-Controller (MFC) as a nonlinear controller which do the control task for Permanent Magnet Synchronous Machine (PMSM) without using current sensors on stator side. In this method, just the rotor speed sensor and dc bus voltage sensors are being used.

The simulation study under different condition has been done to illustrate the effectiveness of proposed method.

- Doesn't require estimation for stator currents.
- Doesn't require information about parameters.

2. Studied PMSM Structure

The studied system is consists of a 12V battery, an input filter, dc/ac inverter and a PMS-Machine.



$$\begin{cases} \frac{di_d}{dt} = \frac{1}{L_d}\left[v_d - R_s.i_d + p.w.L_q.i_q\right] \\ \frac{di_q}{dt} = \frac{1}{L_q}\left[v_q - R_s.i_q - p.wL_d.i_d - w.p.P_{sif}\right] \\ \frac{dw}{dt} = \frac{1}{J}\left[p.i_q i_d(L_d - L_q) + p.P_{sif}.i_q - \Gamma_{load}\right] \\ \frac{di_{bat}}{dt} = \frac{1}{L_f}\left[V_{bat} - r_f i_{bat} - v_s\right] \\ \frac{dv_s}{dt} = \frac{1}{c}\left[i_{bat} - \frac{P_{in}}{v_s}\right] \end{cases}$$

- System is illustrated in dq model.
- v_{dq}, i_{dq} are the dq axis voltages and currents of stator.
- $\Gamma_{load} = f.\Omega - \Gamma_0$ considered as load torque.
- v_s: dc bus voltage.
- w: Rotor speed.
- f: Friction coefficient.

3. MFC

Fundamental concept:

I. Creation an equivalent dynamic linearization data model at every operating points.
II. Online estimation of system's PPD.
III. Designing controller based on a weighted one-step-ahead cost function.

A discrete time MIMO system: $y(k+1) = f\left(y(k), \dots, y(k-n_y), u(k), \dots, u(k-n_u)\right)$,

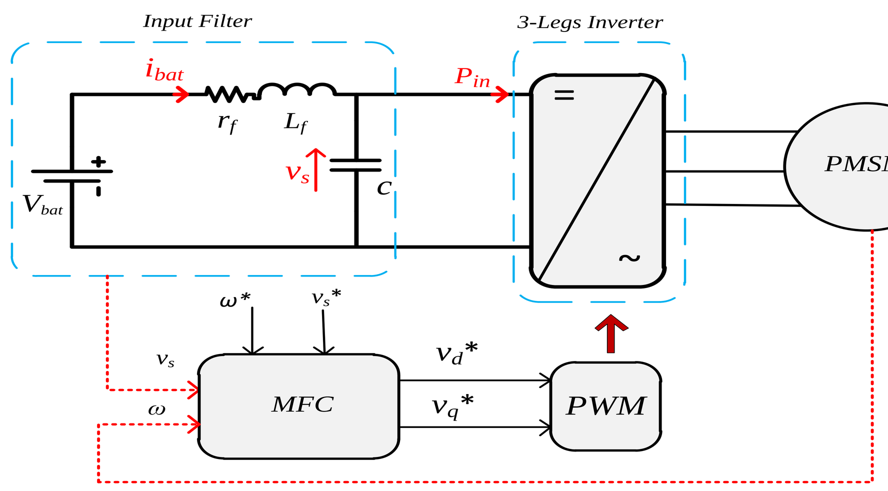
Can be described with compact form dynamic linearization data model: $\Delta \boldsymbol{y}(\boldsymbol{k}+\mathbf{1}) = \boldsymbol{\varphi_c}(\boldsymbol{k})\Delta \boldsymbol{u}(\boldsymbol{k})$

- $y(k) = [y_1(k) \dots\ y_m(k)]^T, u(k) = [u_1(k) \dots\ u_m(k)]^T \epsilon R^{m\times 1}$ system output and inputs.
- $\varphi_c(k) = [\varphi_{i,j}(k)],\ i,j\epsilon[1,\dots,m]$ time varying matrix (PPD), diagonally leading: $|\varphi_{i,j}(k)| \le b_1$, $b_2 \le |\varphi_{i,i}(k)| \le ab_2$, $a \ge 1$, $b_2 > b_1(2a+1)(m-1)$, $i = 1, \dots, m$, $j = 1, \dots, m$, $j \ne i$ and the sign of all the $\varphi_{i,j}(k)$ should be unchanged.

- **Control Law**: $u(k) = u(k-1) + \frac{\rho\varphi_c(k)^T}{\lambda + \|\varphi_c(k)\|^2}(y^*(k+1) - y(k+1))$
- **PPD Estimation:** $\varphi_c(k) = \varphi_c(k-1) + \frac{\eta\Delta u^T(k-1)}{\mu + \|\Delta u(k-1)\|^2}(\Delta y(k) - \varphi_c(k-1)\Delta u(k-1))$
- $\rho\epsilon(0,1]$ is step length, $\lambda, \mu > 0$, $\eta\epsilon(0,2]$ are weight factor.

4. Current Sensor-less MFC

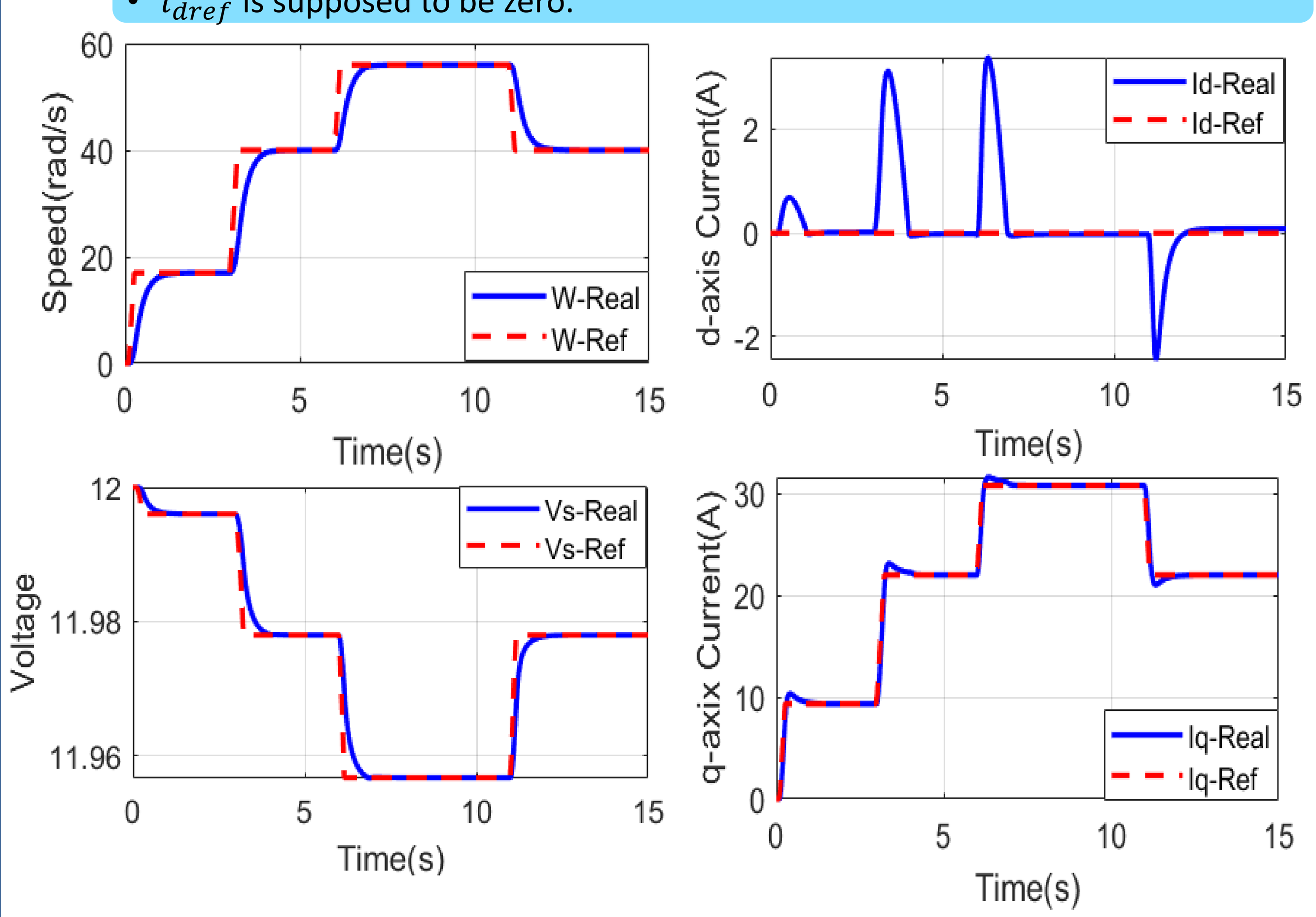
- The simulation study has been done under starting performance, rotor speed and parameters variations (parametric error is included).



- Outputs: w, Vs
- Control Inputs: Vd, Vq

- Control scheme

- Operating points corresponding to rotor speed: w=160, 380, 530 and 380 rpm.
- i_{dref} is supposed to be zero.



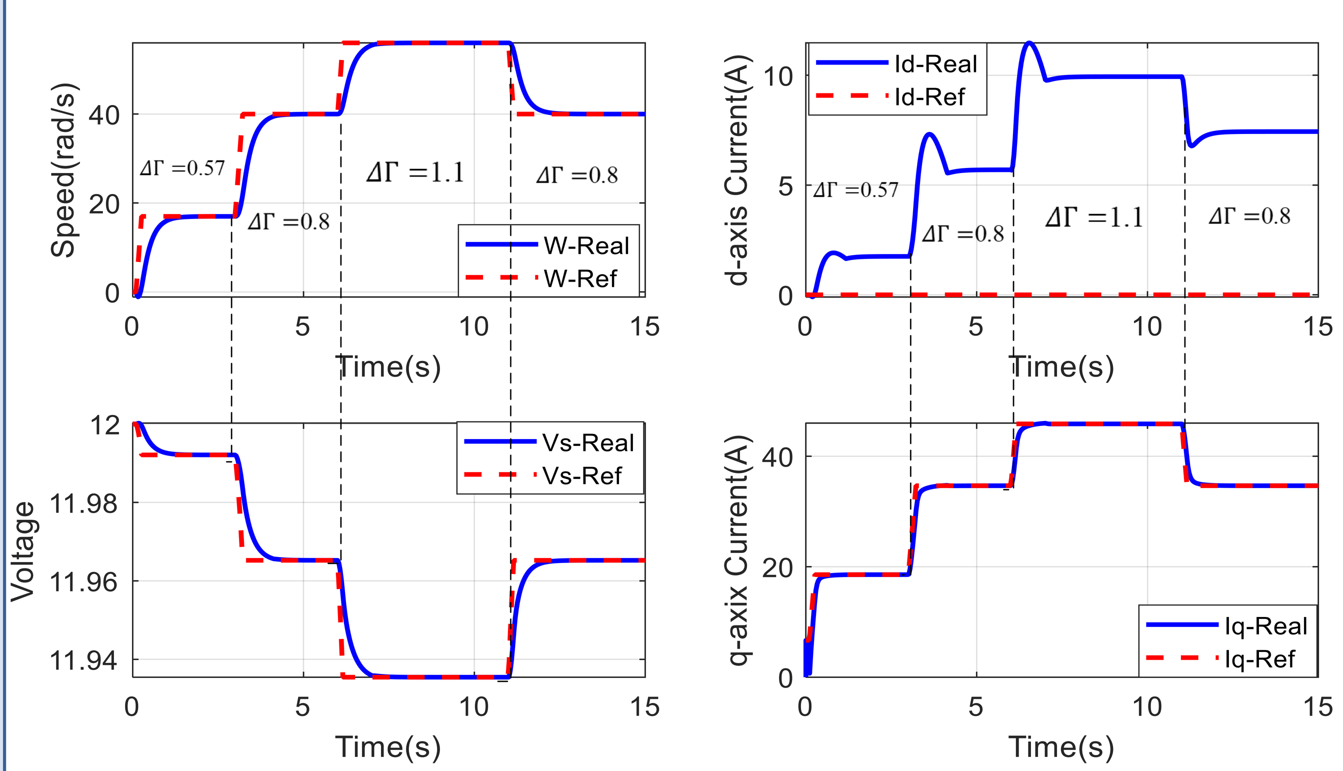
- Good performance in both steady-state and transient.
- There is negligible effects from parameter changes and parametric error.

5. Load Torque Disturbance

Generally the load torque equation, Γ_{load}, is unknown or har to predict. In this study, the $\Gamma_{load} = f.\Omega - \Gamma_0$ is used as load torque.

- MFC's performance could be effected under unexpected load torque changes.
  - The simulation study has been repeated under different load torque changes.

- $\Delta\Gamma$: difference between new and old ($\Gamma_{load} = f.\Omega - \Gamma_0$) load torque.

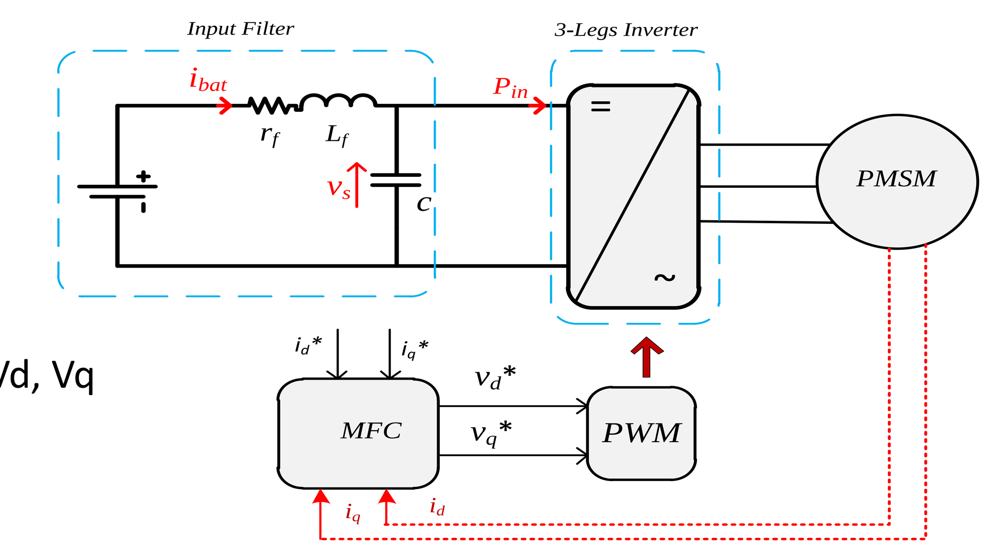


- Simulation results

- Under unexpected torque changes:
  - id has some error at steady-state and doesn't exactly to expected value.

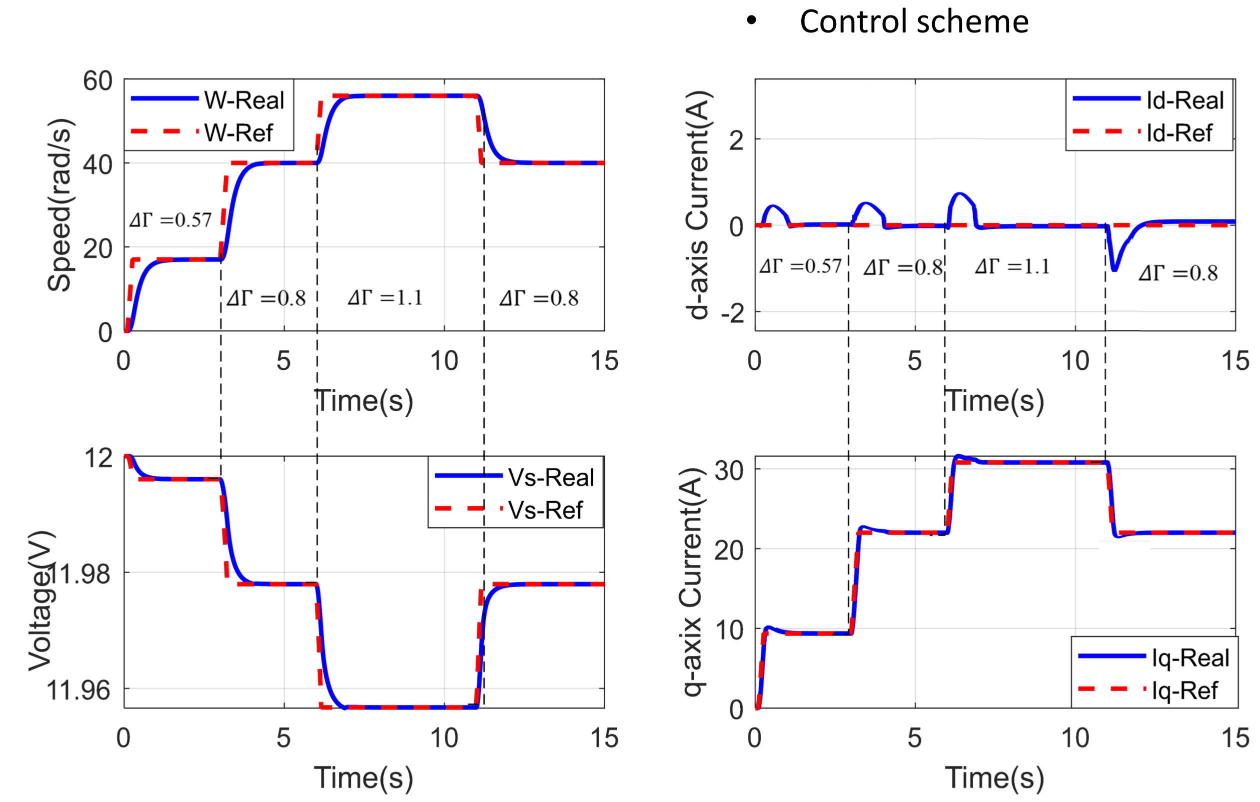
6. MFC With Current Sensors

For better understanding the advantages of MFC, a comparison of the achievable controller performance with current sensors has been analyzed under all uncertainties and unexpected torque changes.



- Outputs: id, iq
- Control Inputs: Vd, Vq

- Control scheme



- Simulation results shows good robustness of MFC.
- There is negligible error on steady-state of state variables.

Conclusions & Perspectives

- In this study, the MFC has been addressed as a new sensor-less control method. The achievable control performance with and without current sensors has been analyzed with simulation study.
- The achieved results represent a good control performance of MFC applied on PMSM drive system specially in steady state, the just considerable problem is related with unexpected load torque change's effect on d-axis stator current.
- For the future, this work will be continued to improve the load torque change's effect and to improve transient performance.
- The main objective of this work is reaching to a controller which work just by measuring the rotor speed.
- This proposed controller will be expanded also for WRSM machine.
- By preparing the test bench in near future, we will try to confirm all these work by experimental results.