Nonlinear Sensorless Control including Zero Speed of Permanent Magnet Synchronous Motor Drives

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Background

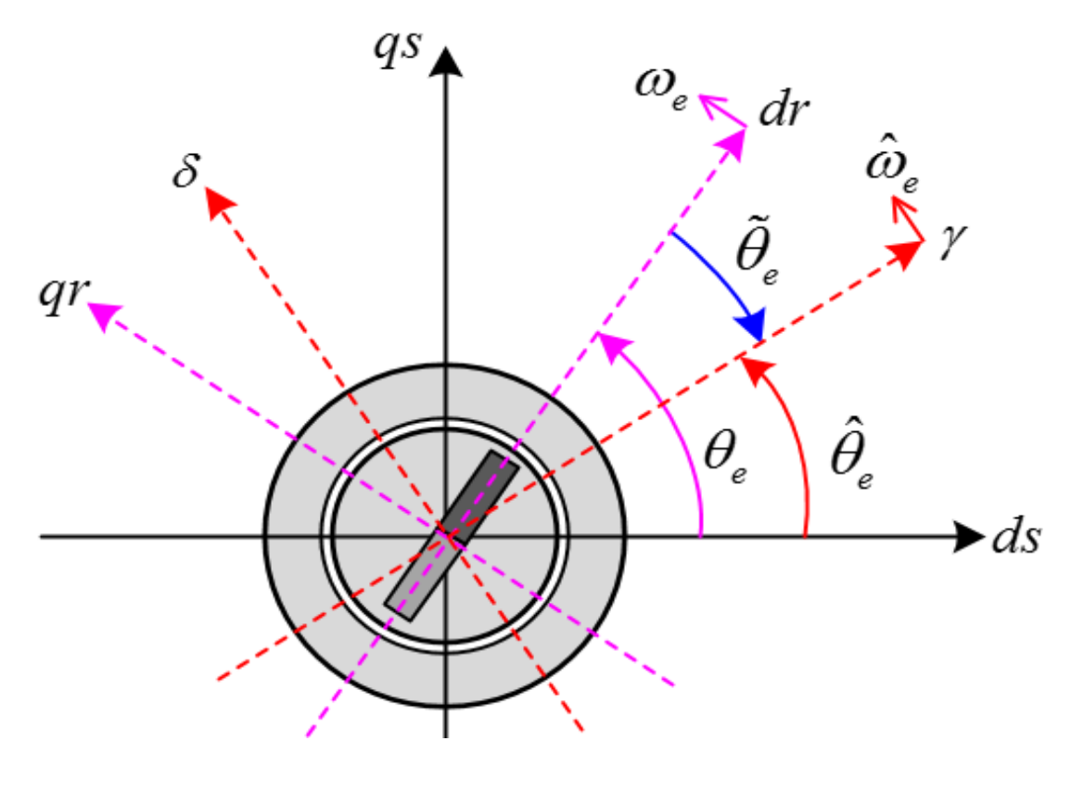
In order to drive an interior permanent magnet synchronous motor (IPMSM) with high efficiency, precise information on the rotor position at all operating sections is very important. In this paper, an estimation method of the rotor position based on a sensorless extended electromotive force (EEMF) algorithm is introduced. Additionally, maximum torque per ampere (MTPA) control is applied to control the maximum output of the IPMSM. However, MTPA control is very influenced by motor parameters, and therefore, leads to a highly complex, greatly nonlinear, and inaccurate current control. To overcome the disadvantages of the IPMSM, this paper proposes a new method that implements a speed controller using the EEMF sensorless method and pre-compensates the MTPA angle to control the motor linearly. The approach is validated via simulations and experiments.

Conclusion

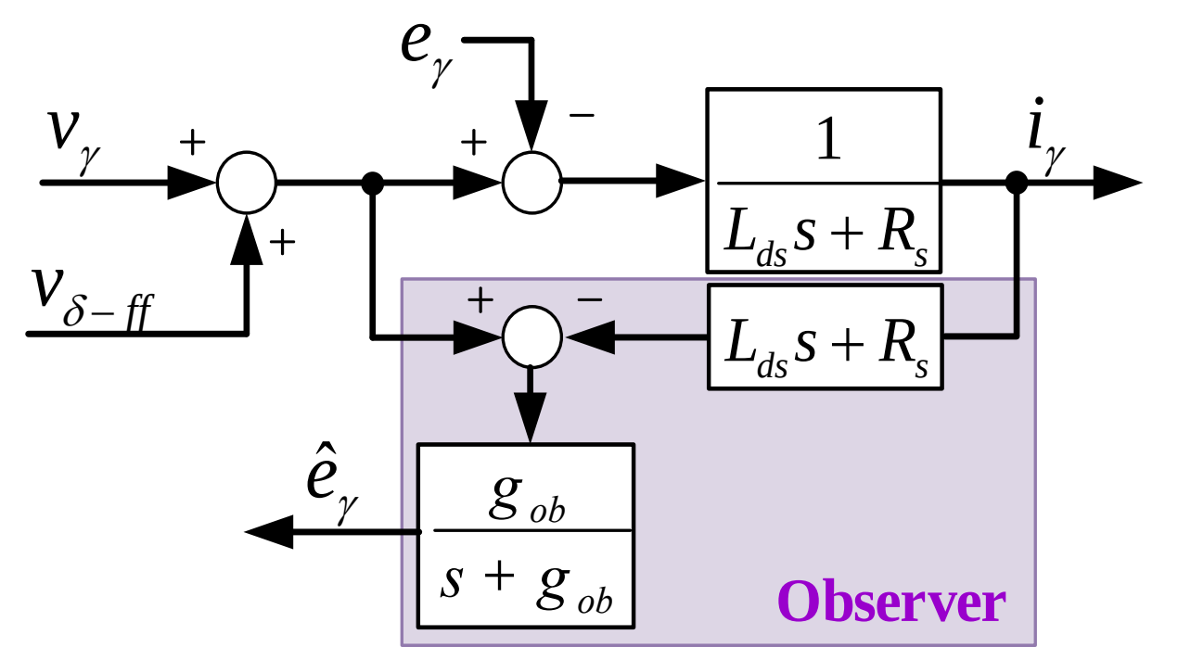
This paper proposes a new concept of a sensorless control algorithm that conducts a pre-compensation of the MTPA angle based on the sensorless EEMF control. Applying this new concept not only overcomes the nonlinear disadvantages of the IPMSM, but implements excellent control performance even under rated states. Consequently, this advanced algorithm has been confirmed to make motor control more reliable and linear.

However, it is necessary to further verify the control stability in the extreme low-to-zero-speed range while using BEMF. In addition, mechanism-adaptation tests referring to the behaviour of β in the field-weakening region will be further investigated in a future study

EEMF Sensorless Control



The estimated rotor position is defined as θ^e and its coordinate system can be obtained using γδ-axes. The relationship between the dqr- and γδ-axes is shown.



The EEMF terms contain the position-estimation error information, which can be obtained using an observer. To eliminate the decoupling terms V_{ff}, it is forward compensated.

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} R+pL_d & \omega_r(L_d-L_q) \\ -\omega_r(L_d-L_q) & R+pL_d \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} + \underline{\{(L_d-L_q)(\omega_r i_d - p i_q)+\omega_r K_E\}\begin{bmatrix} -\sin\theta_r \\ \cos\theta_r \end{bmatrix}}$$

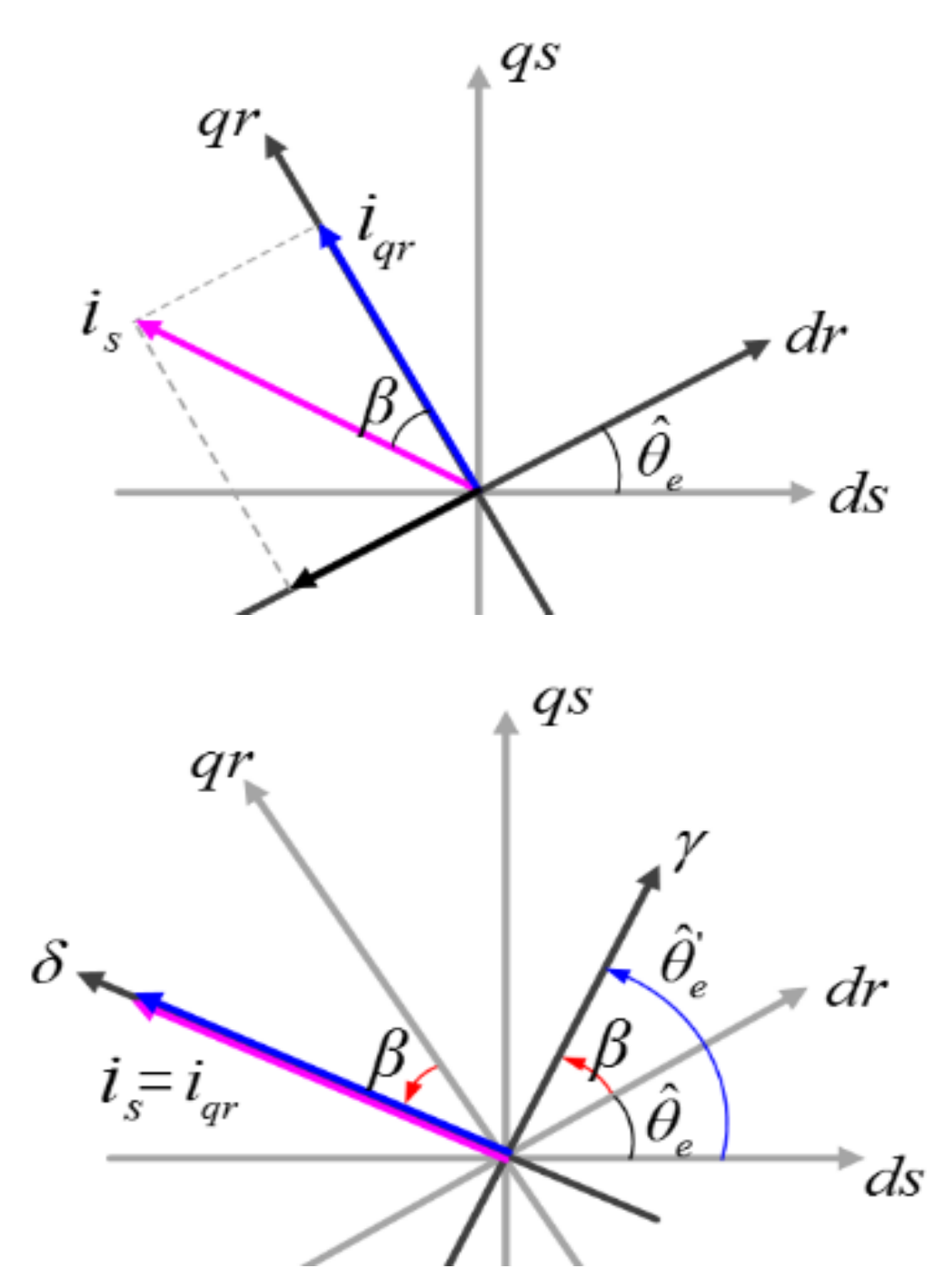
$\mathbf{E_{ex}}$

$$E_{ex} = \begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = \omega_r K_E \begin{bmatrix} -\sin\theta_r \\ \cos\theta_r \end{bmatrix} \qquad E_{ex} = \begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = (L_d-L_q)(\omega_r i_d - p i_q)\begin{bmatrix} -\sin\theta_r \\ \cos\theta_r \end{bmatrix}$$

$$\begin{bmatrix} e_\gamma \\ e_\delta \end{bmatrix} = E_{ex}\begin{bmatrix} -\sin\tilde{\theta}_r \\ \cos\tilde{\theta}_r \end{bmatrix} + (\hat{\omega}_r - \omega_r)L_d\begin{bmatrix} -i_\delta \\ i_\gamma \end{bmatrix}$$

$$\begin{bmatrix} \hat{e}_\gamma \\ \hat{e}_\delta \end{bmatrix} \cong E_{ex}\begin{bmatrix} -\sin\tilde{\theta}_r \\ \cos\tilde{\theta}_r \end{bmatrix}$$

MTPA angle Compensation

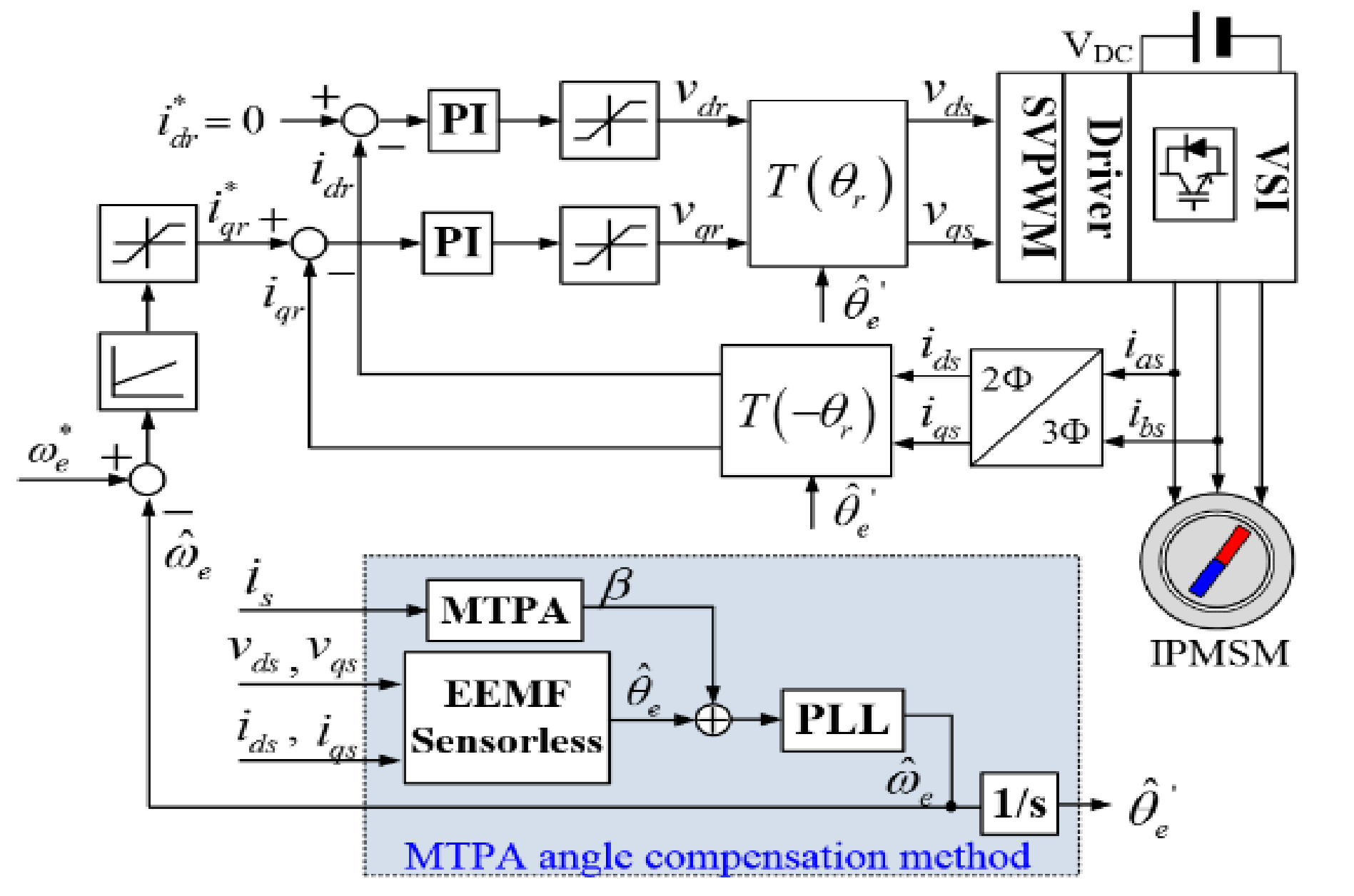


This shows the general IPMSM vector diagram that conducts the MTPA control on the dq-axis current pair for the output phase current.

$$\begin{bmatrix} i_{dr}' \\ i_{qr}' \end{bmatrix} = \begin{bmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{bmatrix}\begin{bmatrix} \cos\theta_e & \sin\theta_e \\ -\sin\theta_e & \cos\theta_e \end{bmatrix}\begin{bmatrix} i_{dr} \\ i_{qr} \end{bmatrix}$$

The transformation further rotates θ^_e by β for the consonances of the phase of the qr-axis current iqr, with the phase of the output current.

$$\begin{bmatrix} i_{dr}' \\ i_{qr}' \end{bmatrix} = \begin{bmatrix} \cos(\theta_e+\beta) & \sin(\theta_e+\beta) \\ -\sin(\theta_e+\beta) & \cos(\theta_e+\beta) \end{bmatrix}\begin{bmatrix} i_{dr} \\ i_{qr} \end{bmatrix}$$



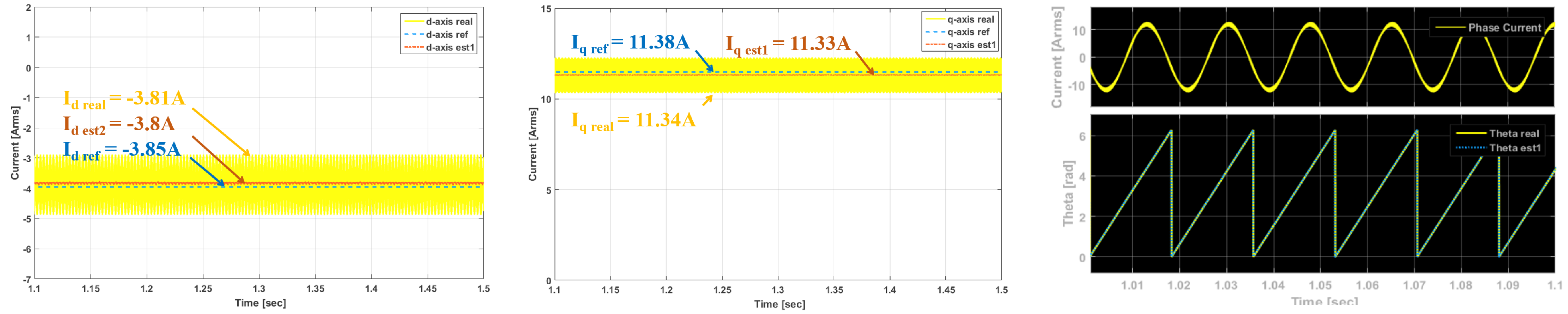
[Overall sensorless control block diagram]

Results

Simulation

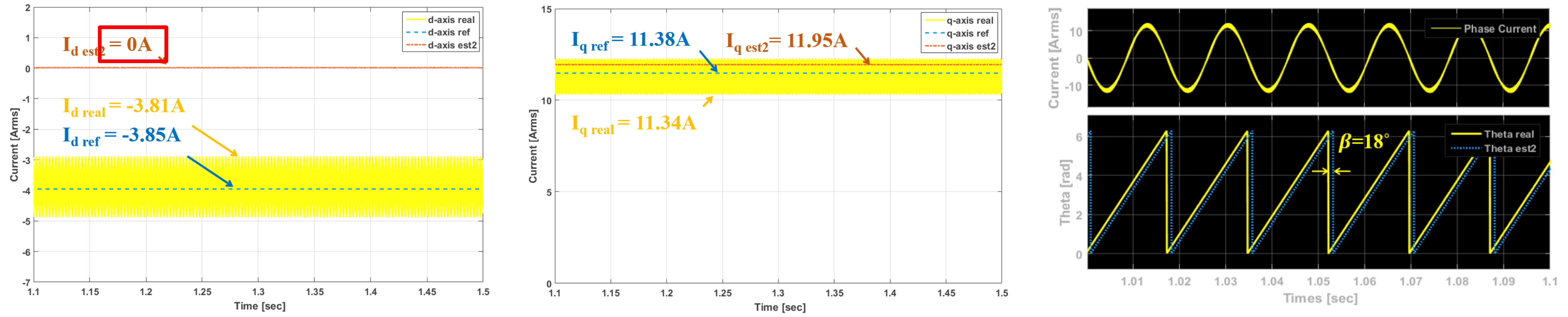
Concept I

EEMF sensorless control



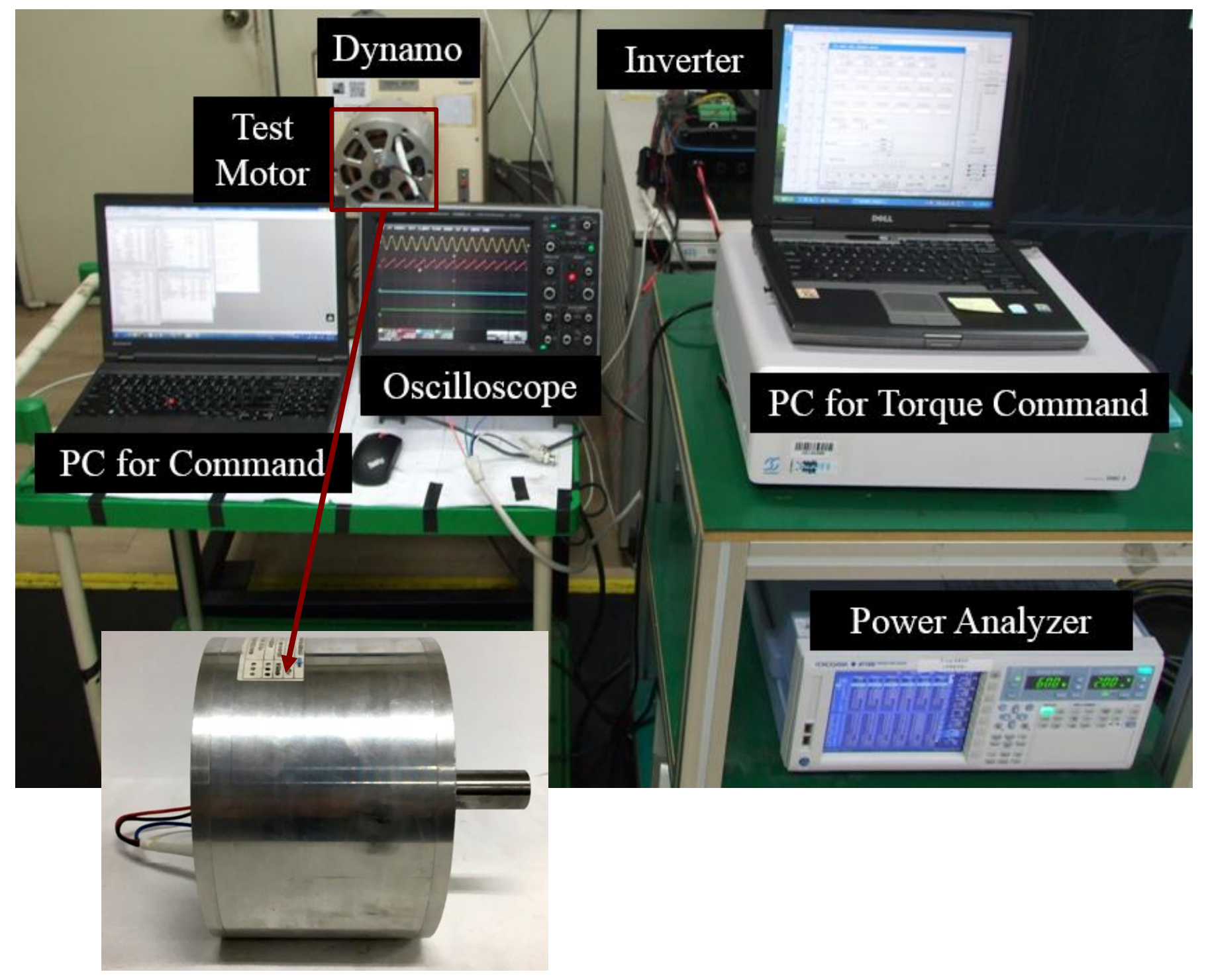
Concept II

EEMF + MTPA compensation

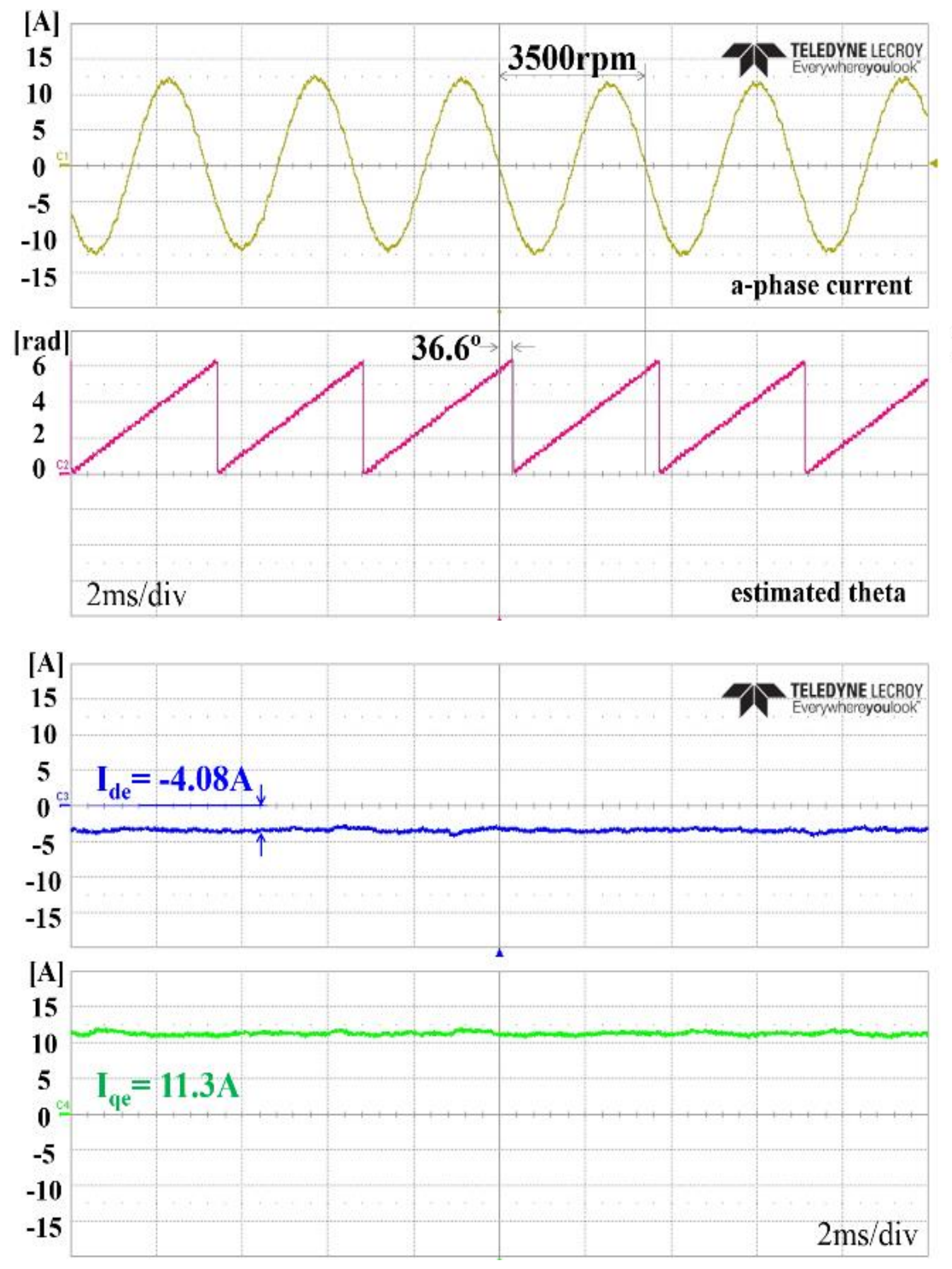


▶ The d-axis command current has negative values, whereas it can be confirmed that the estimated d-axis current of the concept II method with the applied MTPA compensation algorithm converges to 0A. the output current's magnitude of the two concepts is verified to possess an error within ±0.1A.

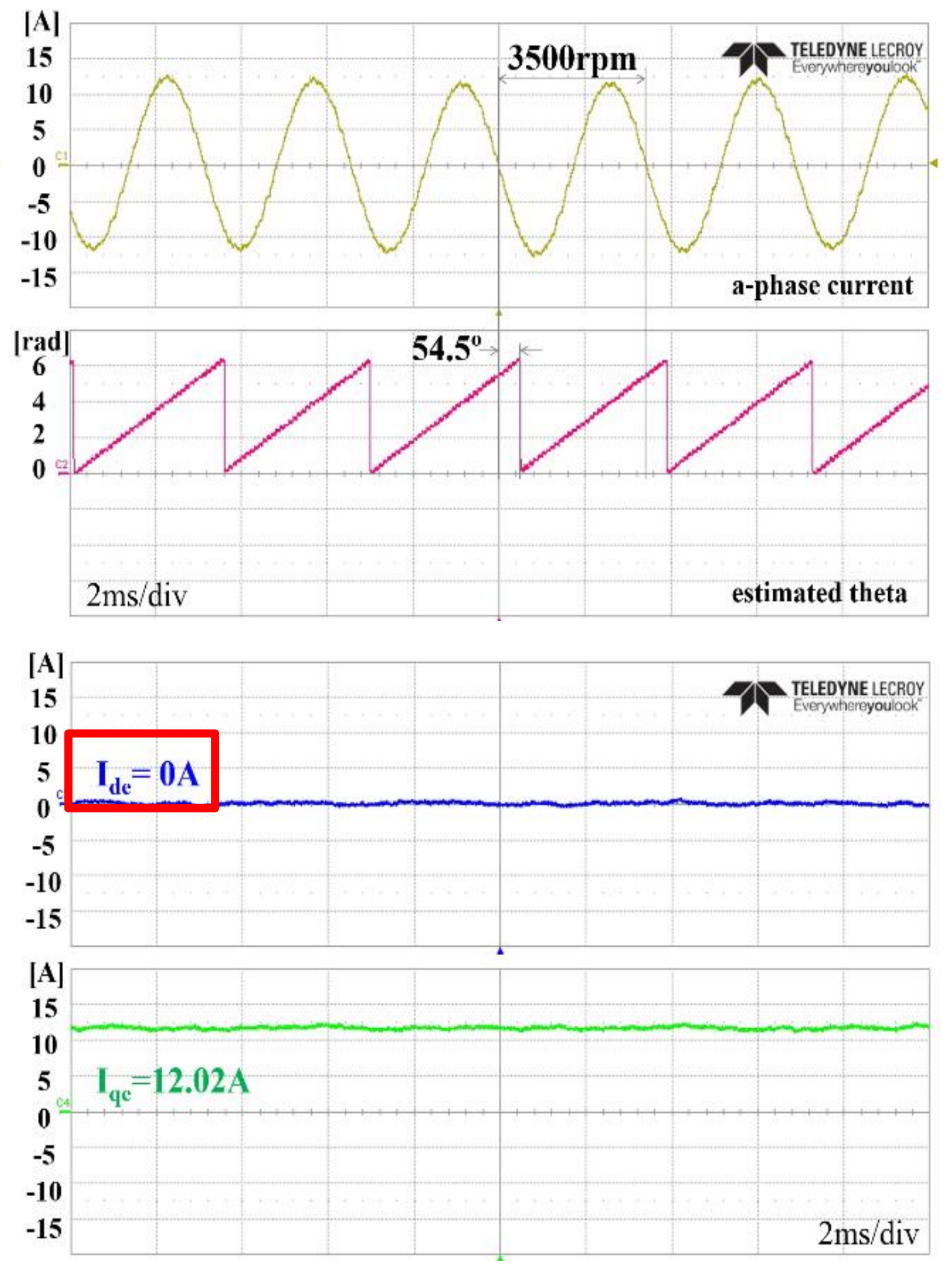
Experimental



Parameters	Values	Parameters	Values
Pole pairs	10	Ld [mH]	7.095
Rated speed [rpm]	3500	Lq [mH]	11.027
Rated current [Arms]	11.3	Rs [Ω]	0.33
Rated torque [Nm]	11	Φ [Vrms]	53.1



Concept I



Concept II

▶ The results indicate that the d-axis current converges to 0 A. And the phase currents measure 12 A with a deviation of 0.01 A due to calculation errors.