Global Summit on Electronics and Electrical Engineering

Acoustic Noise Reduction in DTC-based Induction-Motor Drives using a Unified Flux and Torque Control

Joonhyoung RYU



KRRI 한국철도기술연구원
Korea Railroad Research Institute

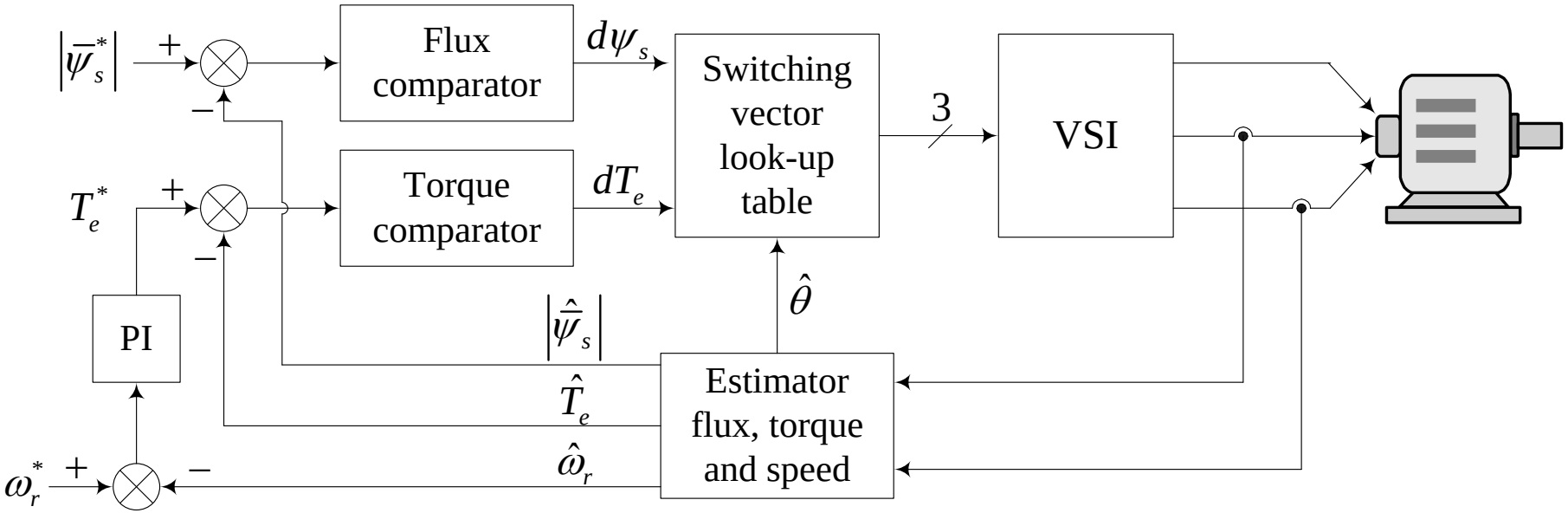
Introduction: Unified flux control (UFC)

- Flux and torque control is performed in unified fashion by the unified flux error control.
- Compensate for the rotational back-emf that conventional DTC ignore.
- Voltage space vector is determined for deadbeat control.
- Minimum-distance vector selection(MDVS) scheme replaces the switching vector look-up table.
- Calculation algorithm is simplified like conventional DTC.

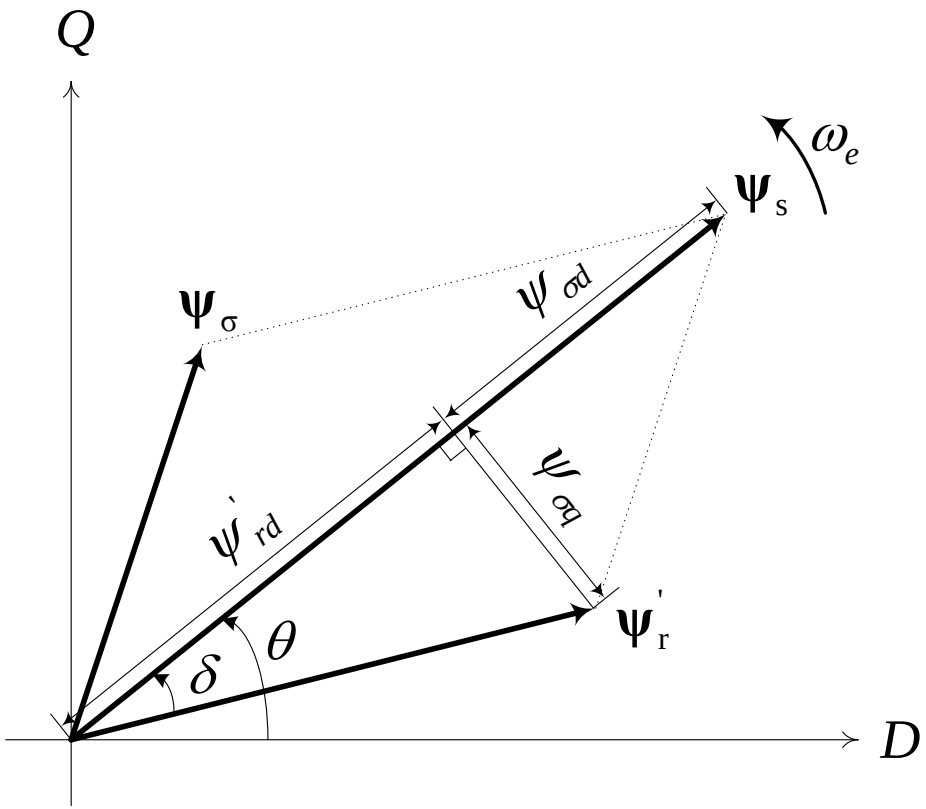
Direct torque control(DTC)

- Advantages of DTC
  - less dependence on machine parameters
  - fast dynamic performance
  - absence of coordinate transformation
  - absence of separate voltage modulation block
  - absence of voltage decoupling circuit
  - absence of current controller
- Disadvantage of DTC
  - high ripples in flux and torque
  - possible problem during start and low speed operation

DTC: Block diagram



UFC: Electromagnetic Torque

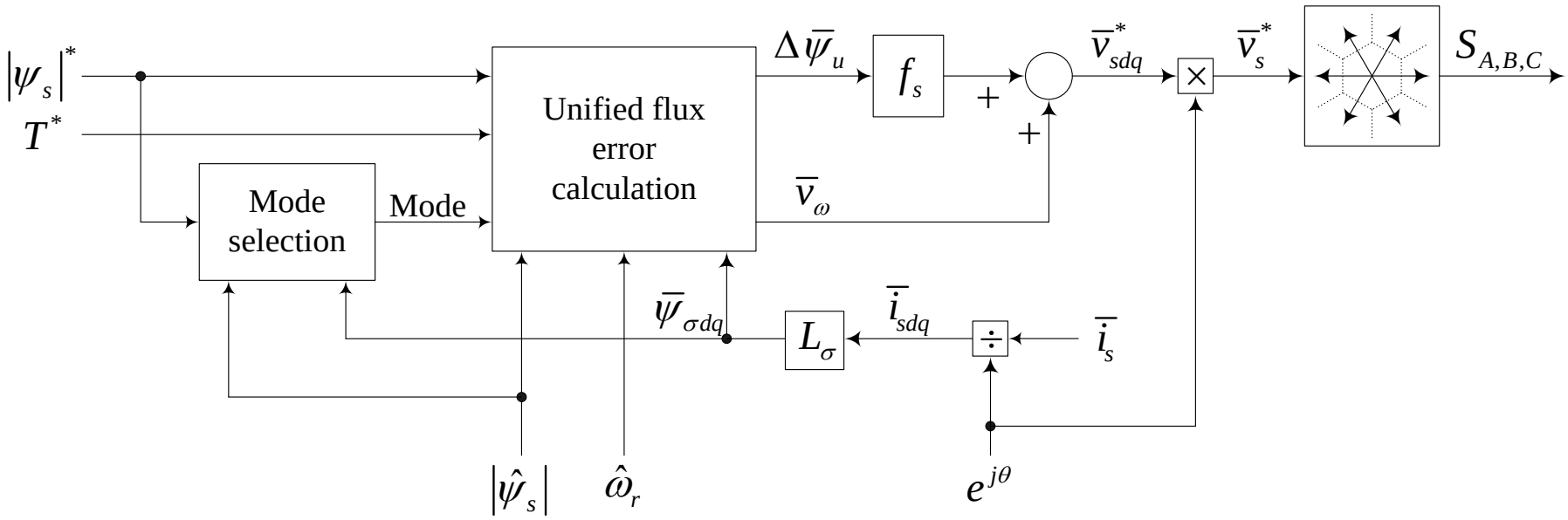


Flux-linkage Space Vectors

$$T_e = \frac{3}{2} p |\psi_s| |\psi_r'| \sin\delta / L_\sigma$$

$$= \frac{3}{2} p |\psi_s| \psi_{\sigma q} / L_\sigma$$

UFC: Control Block Diagram



UFC: Control Modes

	Rotor Flux Magnitude	Control Action
Mode 1	$\psi_{rd}^{'} < \left\|\psi_s\right\|^{*} - \psi_{\lim}$	Direct-axis current control for flux build-up
Mode 2	$\psi_{rd}^{'} \geq \left\|\psi_s\right\|^{*} - \psi_{\lim}$	Unified flux and torque control

Mode 1 : $$\frac{d\psi_{\sigma d}}{dt} = v_{sd}$$

Mode 2 : $$\frac{d}{dt}\begin{bmatrix} \left|\psi_s\right| \\ L_\sigma T_e \Big/ \left(\frac{3}{2} p \left|\psi_s\right|^{*}\right) \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \psi_{\sigma q} \Big/ \left|\psi_s\right|^{*} & \psi_{rd}^{'} \Big/ \left|\psi_s\right|^{*} \end{bmatrix} \begin{bmatrix} v_{sd} \\ v_{sq} - \omega_r \left|\psi_s\right| \end{bmatrix}$$

UFC: Deadbeat Control

- $\left(\left. \frac{dx}{dt} \right|_{\bar{v}_{sdq}^*} \right) T_s = x^* - x(t_k)$

- Stator voltage for a deadbeat control $\quad \bar{v}_{sdq}^* = f_s \Delta\bar{\psi}_u + \bar{v}_\omega$

Mode 1 : $\quad \Delta\bar{\psi}_u = \psi_{\lim} - \psi_{\sigma d}$

$\bar{v}_\omega = 0$

Mode 2 : $\quad \Delta\bar{\psi}_u = |\psi_s|^* - |\psi_s| + j(|\psi_s|^* / \psi'_{rd})(\psi_{\sigma q}^* - \psi_{\sigma q})$

$\bar{v}_\omega = j\omega_r |\psi_s|$

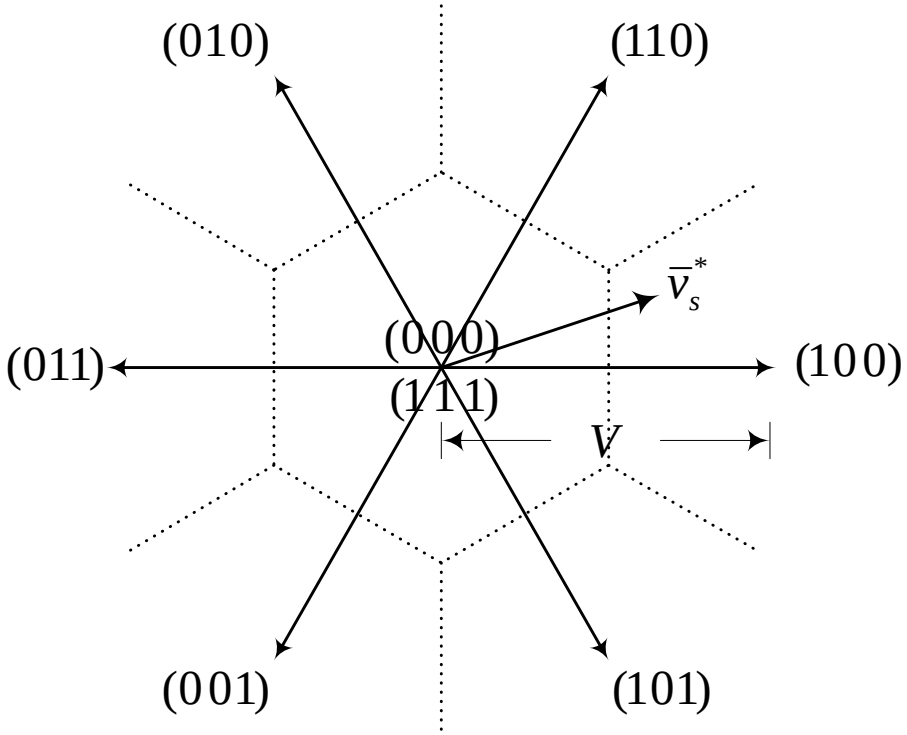
where $\quad \psi_{\sigma q}^* = L_\sigma T_e^* / (\frac{3}{2} p |\psi_s|^*)$

UFC: Minimum-distance vector selection scheme

$$v_A^* = v_D^*$$

$$v_B^* = -\frac{1}{2}v_D^* + \frac{\sqrt{3}}{2}v_Q^*$$

$$v_C^* = -\frac{1}{2}v_D^* - \frac{\sqrt{3}}{2}v_Q^*$$



$\left|v_A^*\right| \le \frac{1}{2}V$ and $\left|v_B^*\right| \le \frac{1}{2}V$ and $\left|v_C^*\right| \le \frac{1}{2}V$ then $(S_A\, S_B\, S_C) = (000)\ or\ (111)$

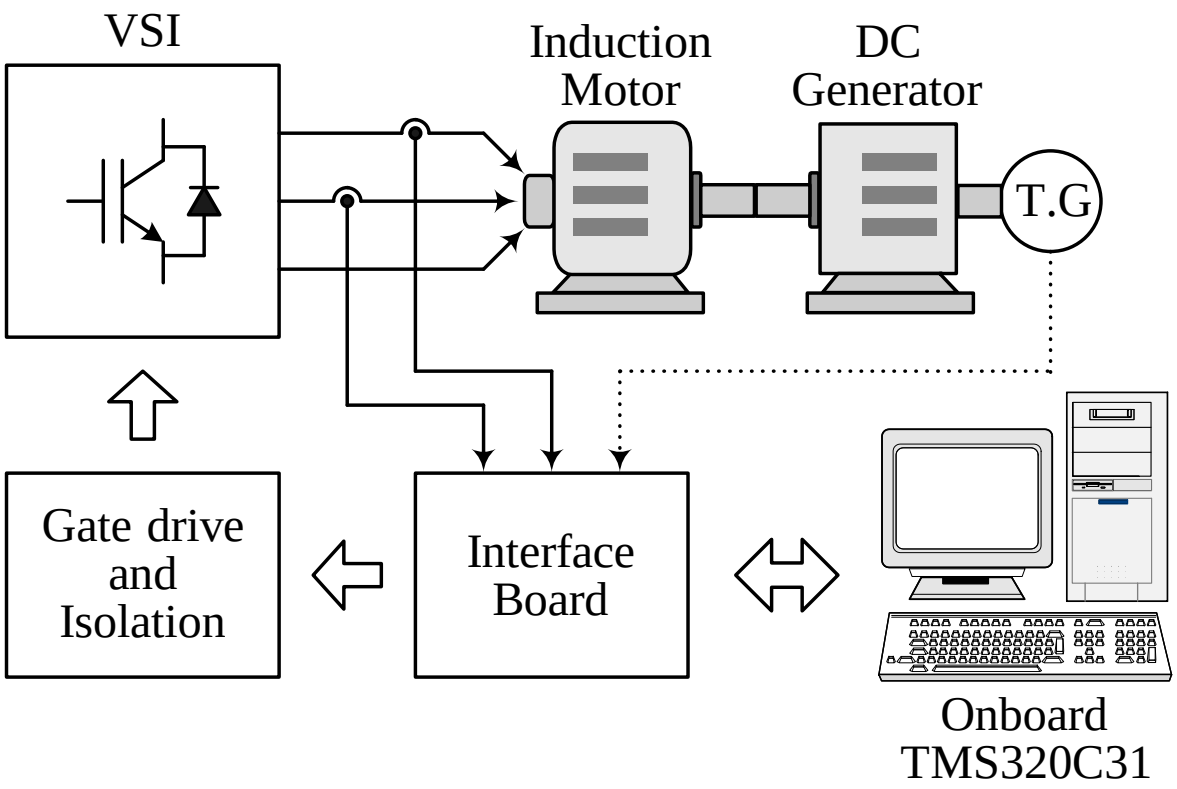
otherwise $S_A = \frac{1}{2}\mathrm{sgn}(v_A^*) + \frac{1}{2},\quad S_B = \frac{1}{2}\mathrm{sgn}(v_B^*) + \frac{1}{2},\quad S_C = \frac{1}{2}\mathrm{sgn}(v_C^*) + \frac{1}{2}$

UFC: Experimental setup(1)

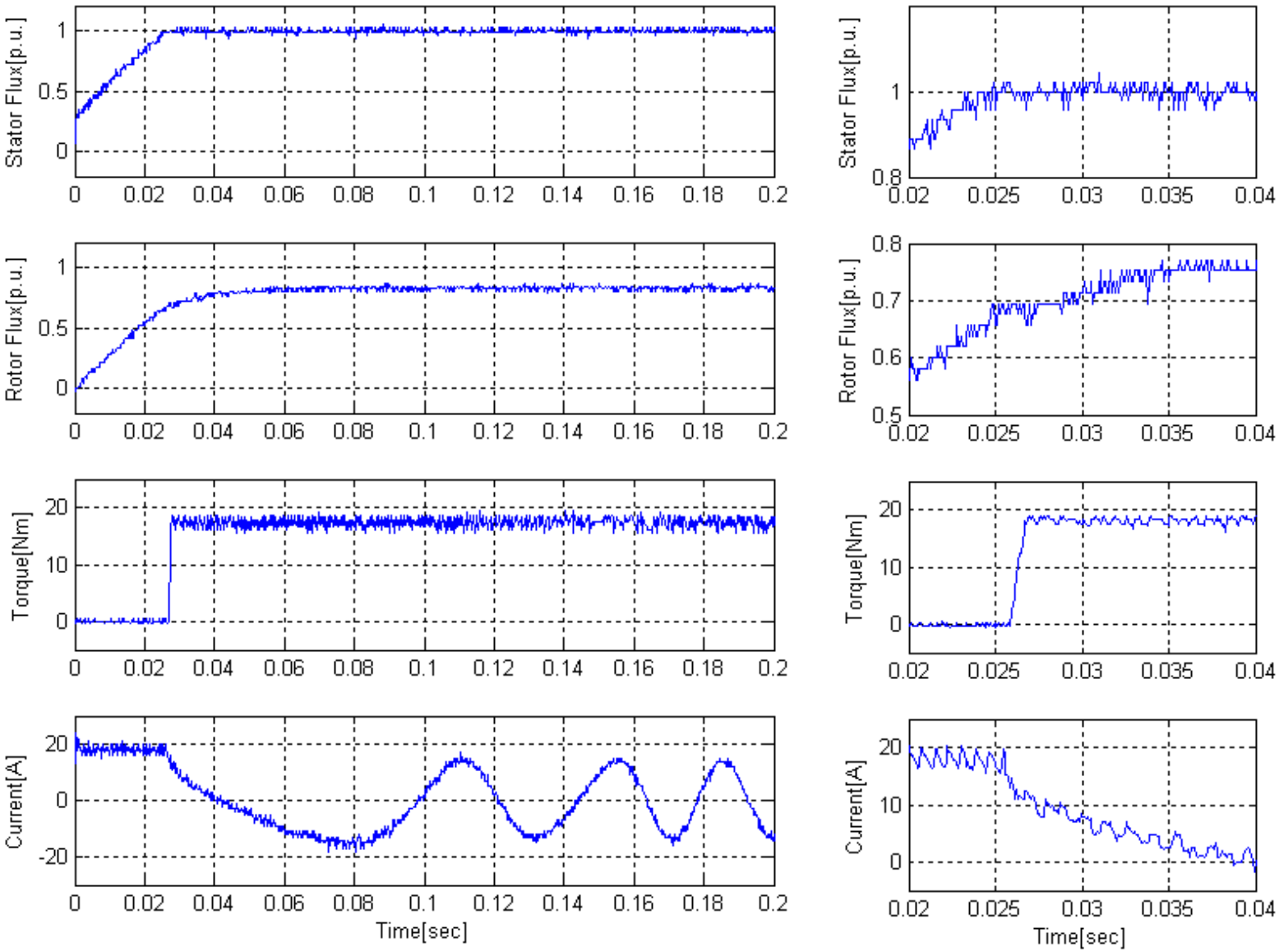
- Induction motor specifications and parameters.
  - 2.2kW, 3-phase, 60Hz, 4poles, 220/380V, 8.6/5.0A, 1740r/min
  - $R_s = 0.8\Omega$ $R_r = 0.9\Omega$

    $L_s = L_r = 76mH$ $L_m = 72mH$
- Switching sampling frequency of the VSI: 10 kHz.
- Sampling frequency of the control: 1 kHz.

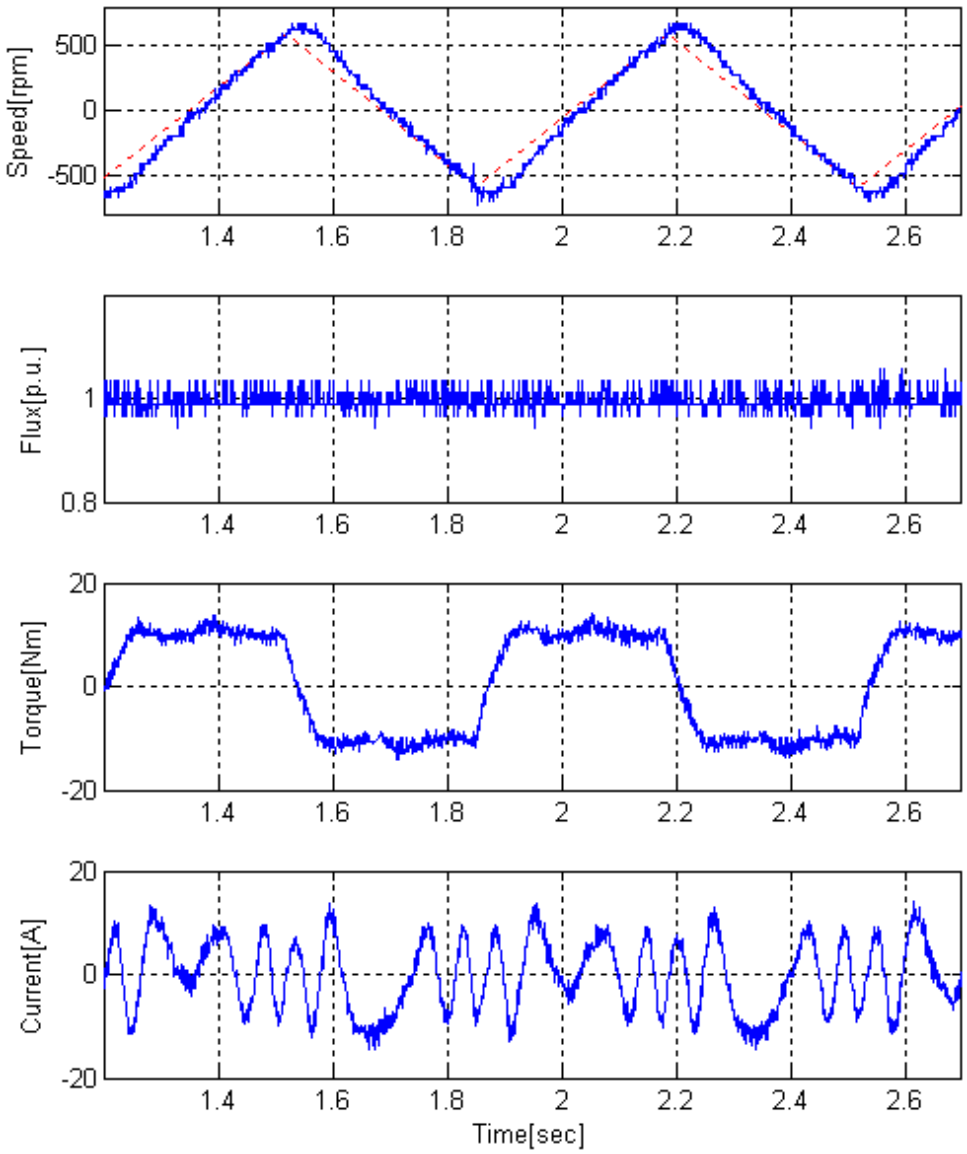
UFC: Experimental setup(2)



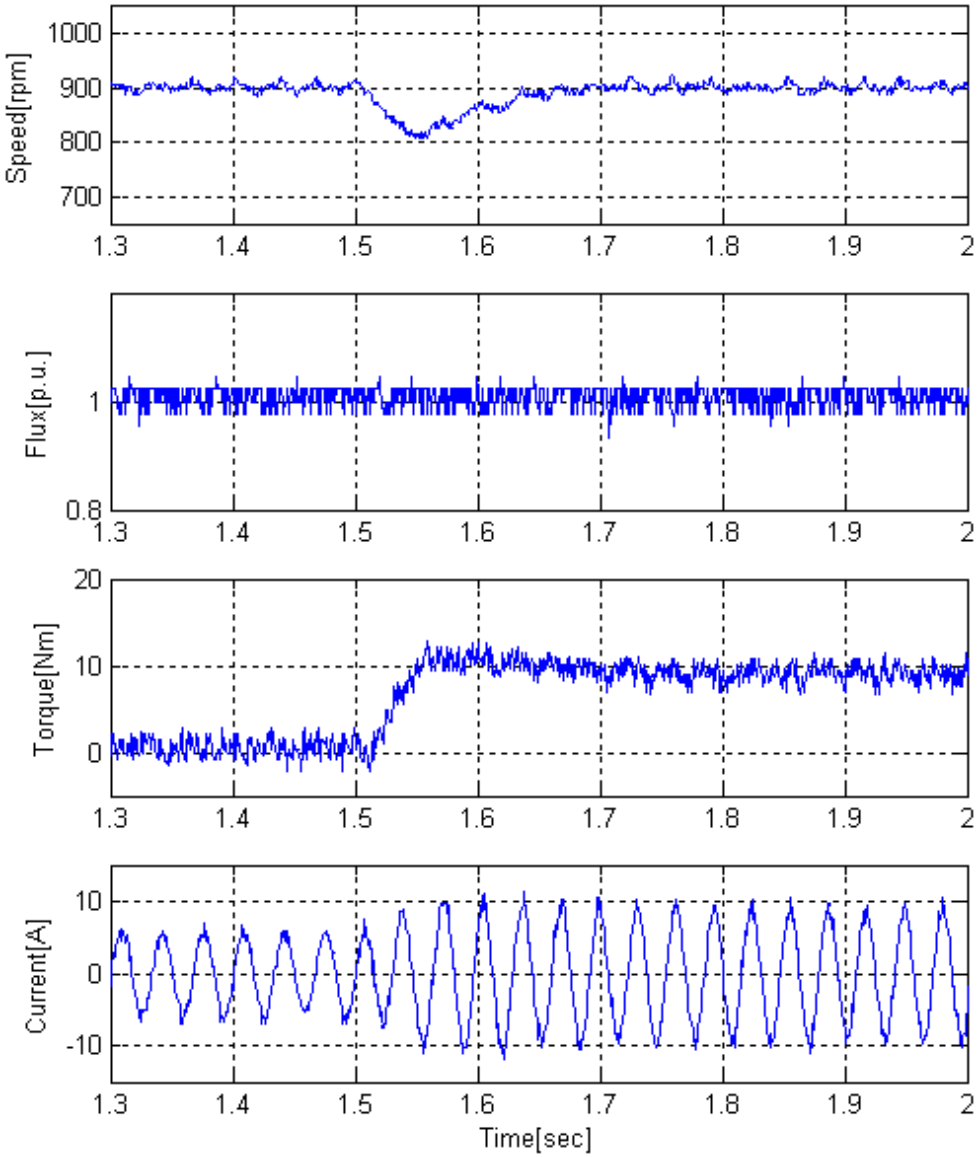
Experimental results: Starting transients



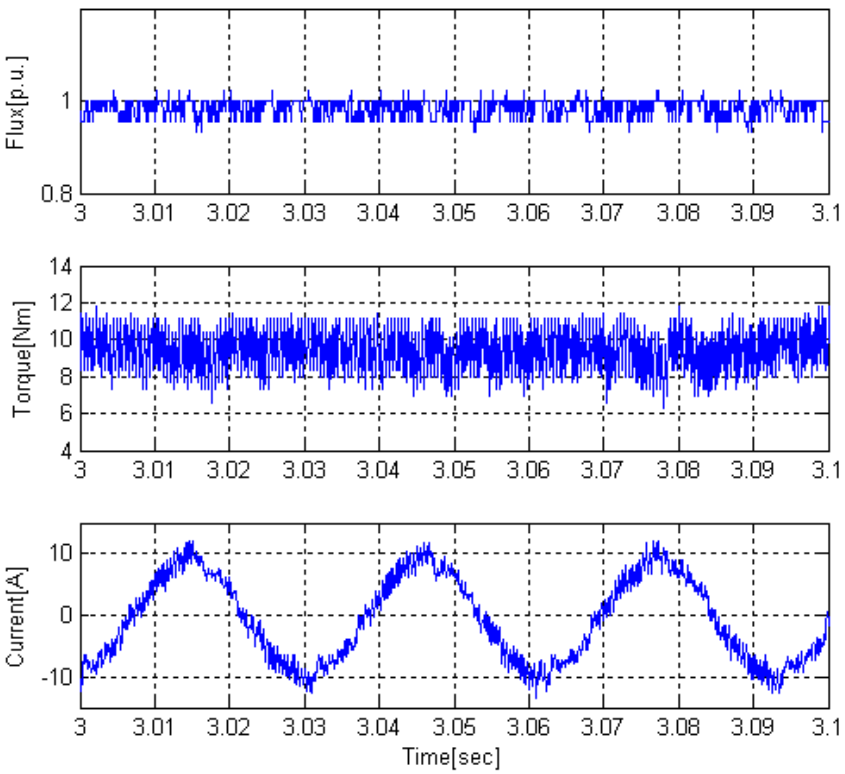
Experimental results: Speed response



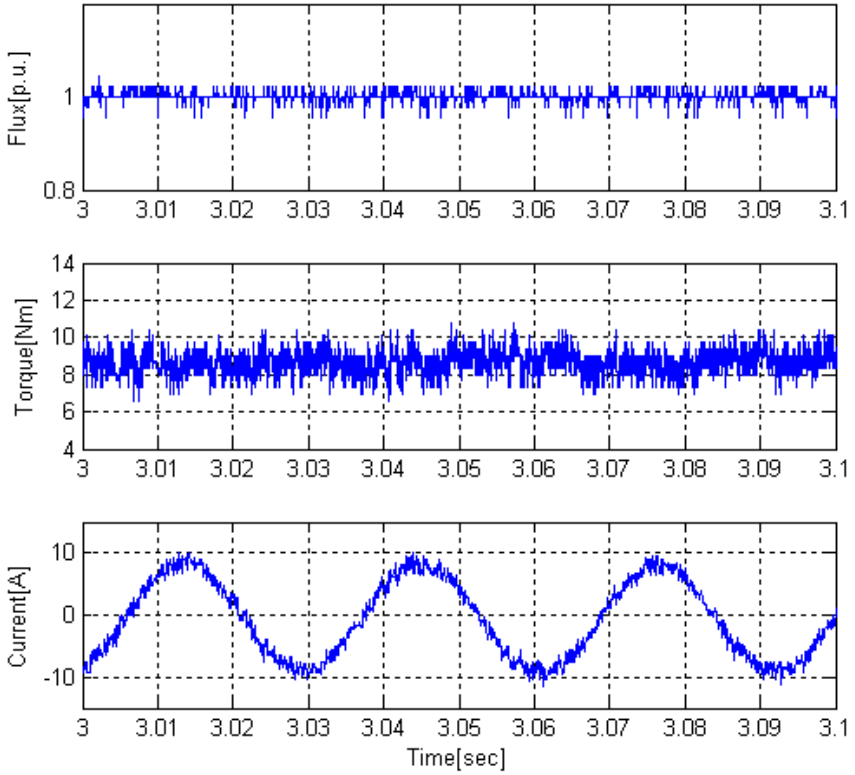
Experimental results: Response to a step load



Experimental results: Constant load condition

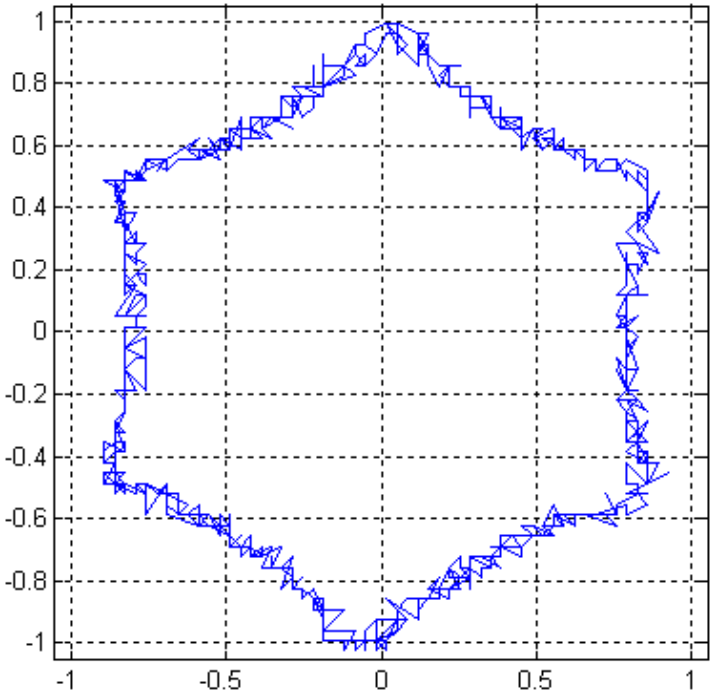


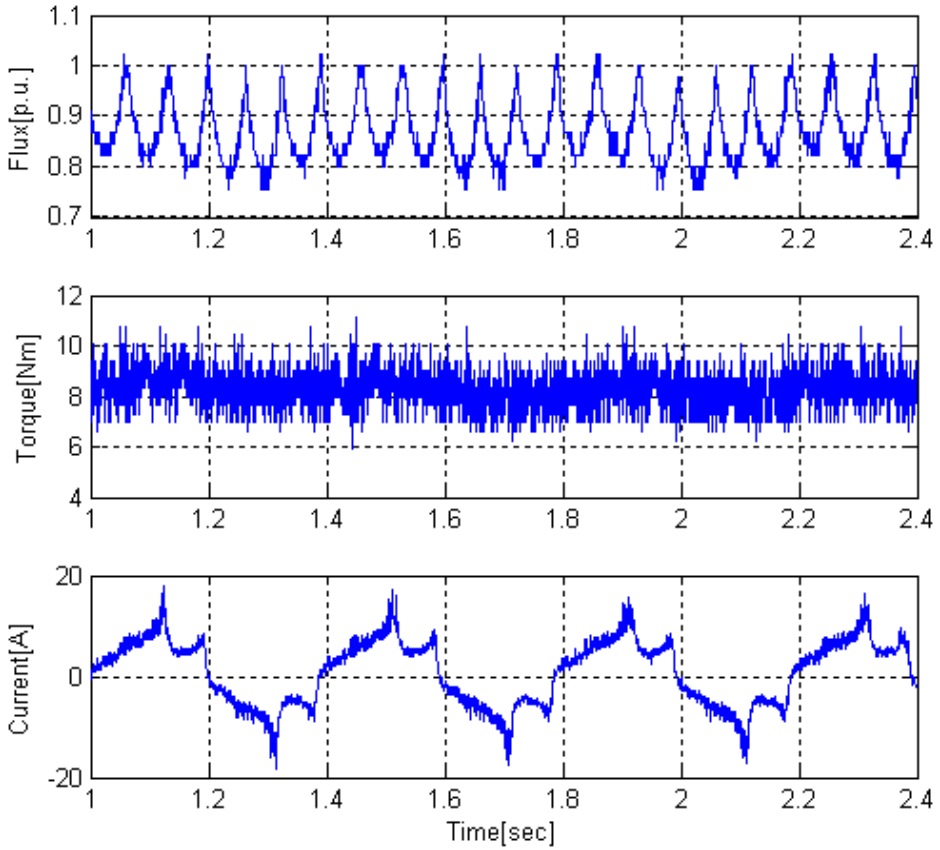
Conventional DTC



Proposed UFC

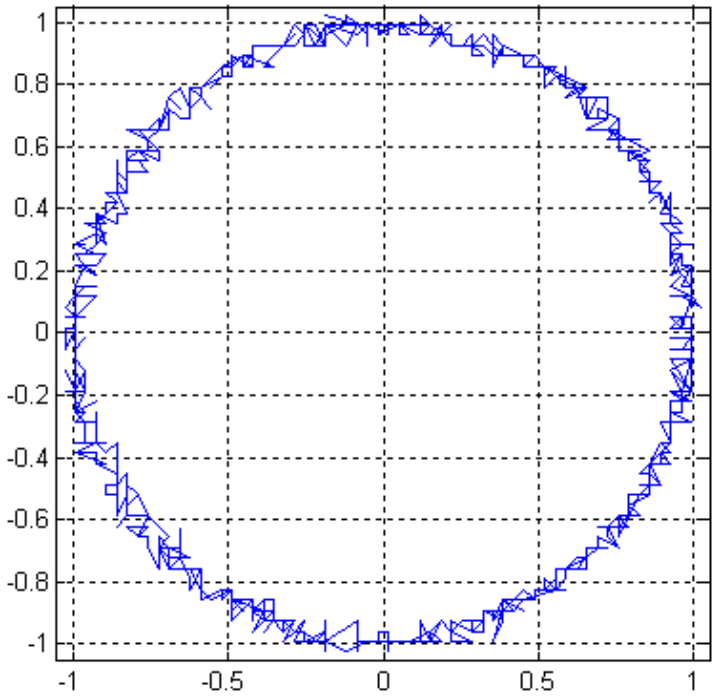
Experimental results: Zero speed characteristic

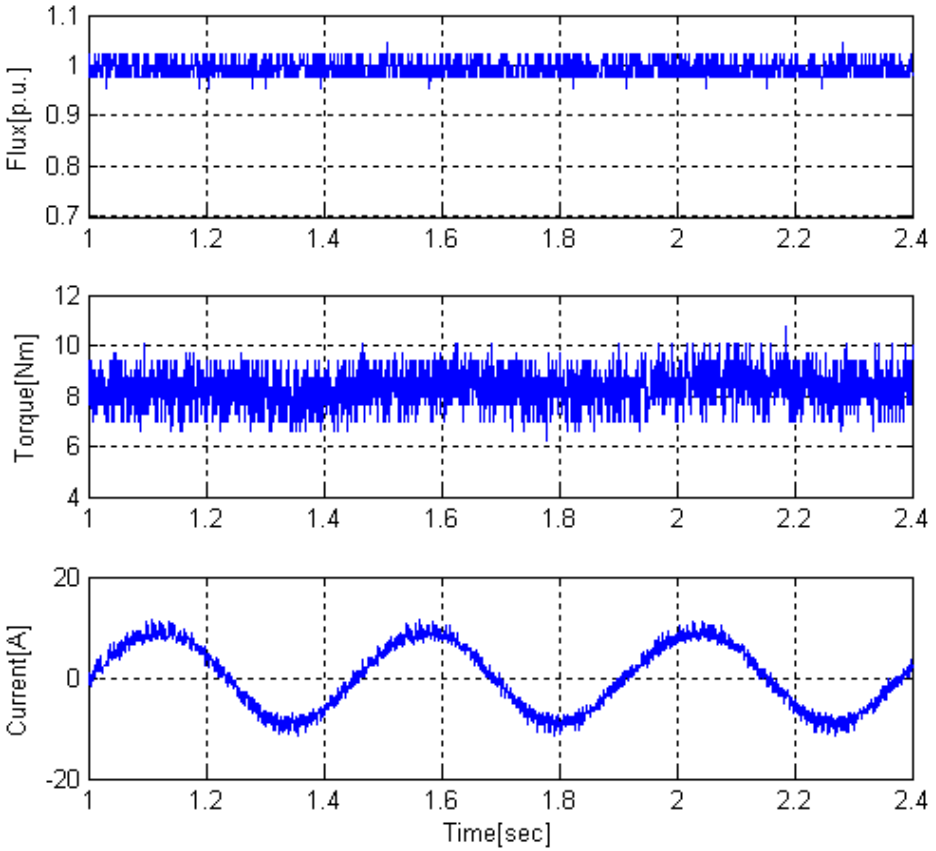




Conventional DTC

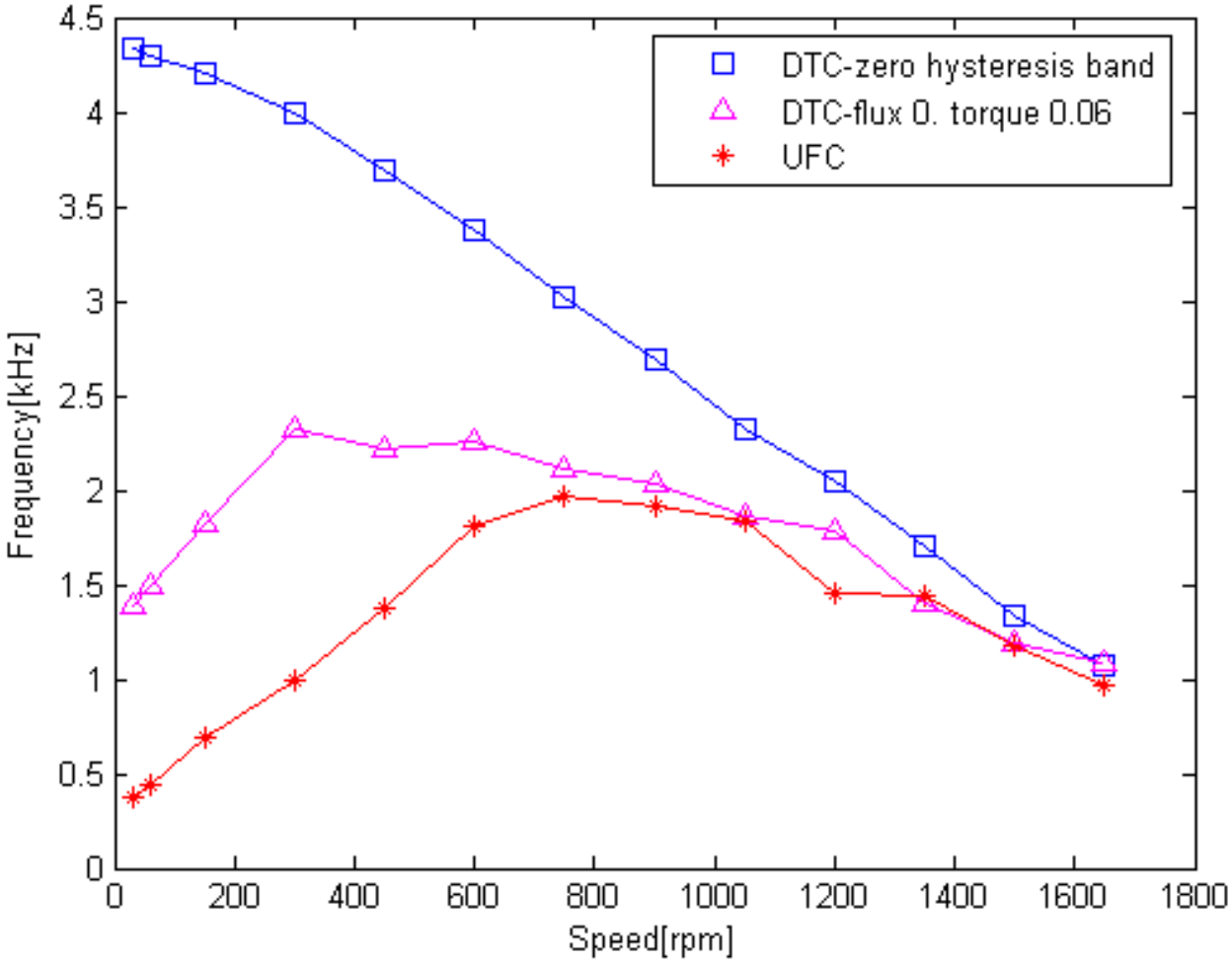
Experimental results: Zero speed characteristic



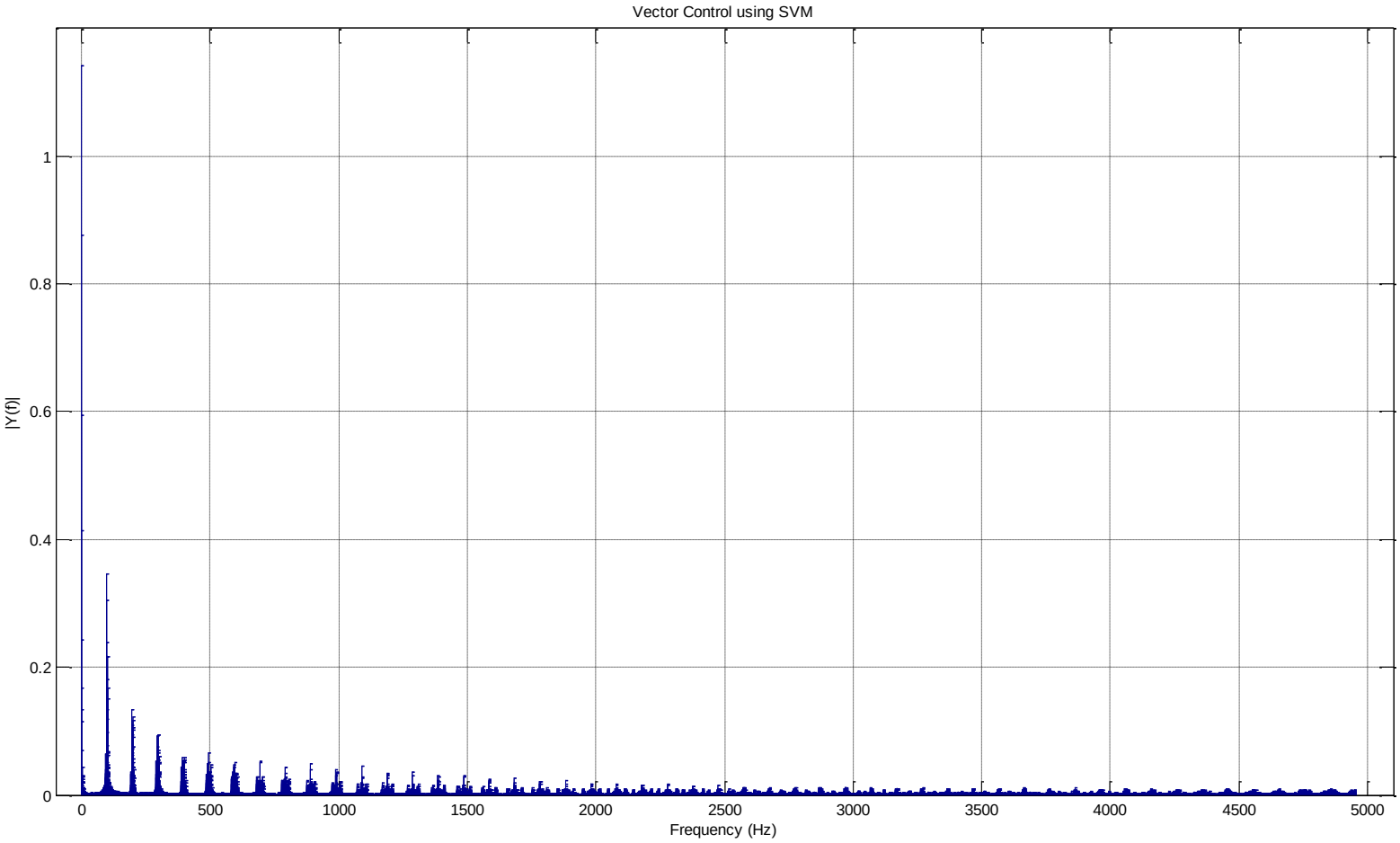


Proposed UFC

Simulation results: Switching frequency

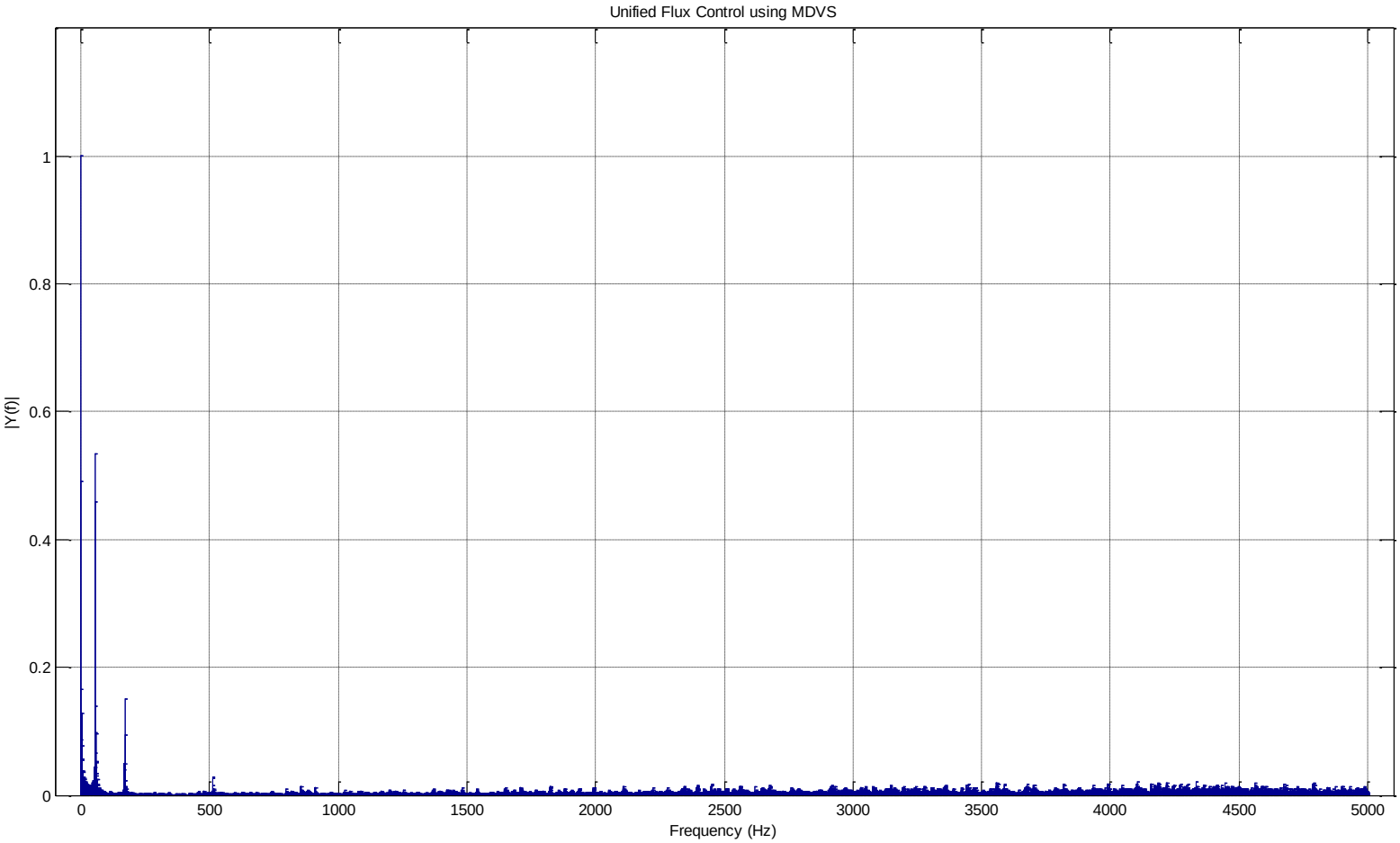


Simulation results: Switching status FFT



Vector control using SVM(10 kHz)

Simulation results: Switching status FFT



Unified flux control using MDVS(10 kHz)

Conclusion

- A unified flux control algorithm which reduces the flux and torque ripple is suggested.
- The rotational back-emf is compensated.
- A deadbeat stator voltage vector is made from flux and torque error.
- Two control modes are defined and a minimum-distance vector selection scheme replaces the switching vector look-up table.
- The actual switching frequency is reduced.
- Proposed algorithm effectively reduces the flux and torque ripples.

Future work

- A study on the estimator which achieves good performance in entire speed range with simpler structure.
- An experiment with increasing the switching sampling frequency of the UFC drive.
- A study on the application for an electric vehicle area.



Q & A

