Low Switching Frequency Pulse Width Modulation For Induction Motor Drives

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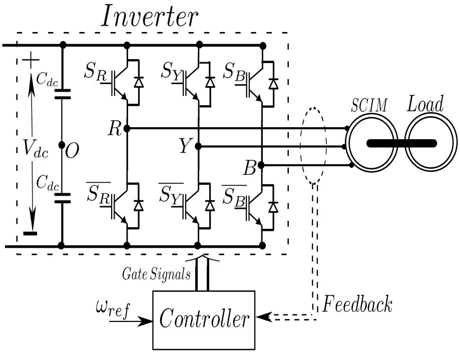
Voltage Source Inverter Fed Induction Motor Drive

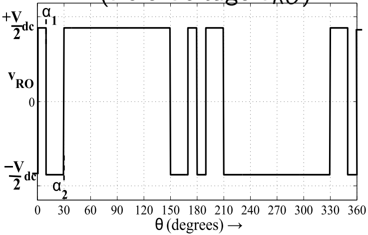


- Variable-amplitude variable-frequency voltage is generated to control the induction motor
- Switching frequency is generally much higher than maximum modulation frequency

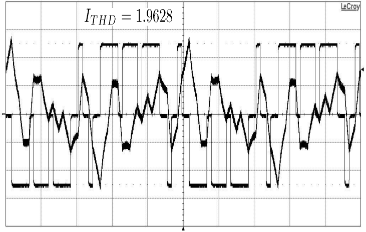
- Switching frequency is low in high-power IM drives due to high switching energy losses
- In high-speed IM drives the maximum modulation frequency is quite high
- This work addresses the problems associated with such cases where the ratio of switching frequency to fundamental frequency (pulse number, P) is low

Problems with Low Pulse Number Applications

(Pole Voltage v_{RO})

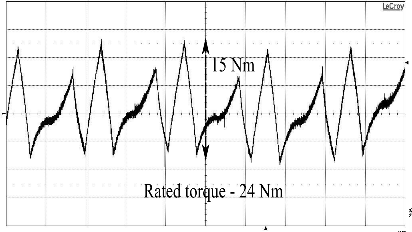


(L-L voltage and line current)

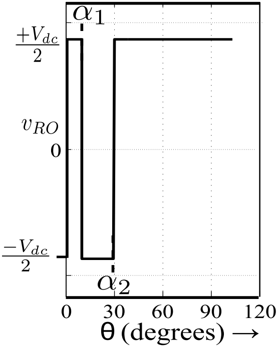


- Line-line voltage contains low-order voltage harmonics (*i.e.*, 5^{th}, 7^{th}, 11^{th}, 13^{th} ....)
- These voltage harmonics produce current and fluxes of same order
- High harmonic distortion in line current
- Pulsating torque is very high

(Torque Ripple)



Minimization of Pulsating Torque



- Amplitude of n^{th} harmonic voltage component is given as:

$$V_n = \frac{2V_{dc}}{n\pi}(1 - 2\cos(n\alpha_1) + 2\cos(n\alpha_2))$$

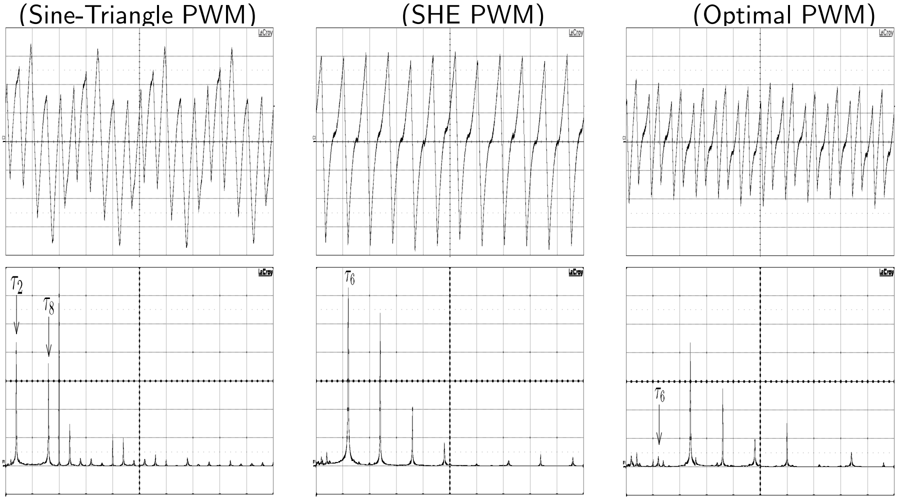
- Selective harmonic elimination (SHE) PWM eliminates (N-1) voltage harmonics for N switching angles per quarter, *e.g.*

$$V_5 = (1 - 2\cos(5\alpha_1) + 2\cos(5\alpha_2)) = 0$$

- In optimal, α_1 and α_2 are selected such that $\|\frac{V_5}{5} + \frac{V_7}{7}\|$ is minimized subject to $(\frac{V_5}{5} = \frac{V_7}{7})$ for minimization of τ_6

- The fundamental voltage component is kept at desired level in both the cases
- The theory of torque harmonic minimization is extended to other pulse numbers also
- First (N-1) torque harmonics are minimized for N switching angles per quarter

Experimental Comparison of Pulsating Torque for $P = 5$

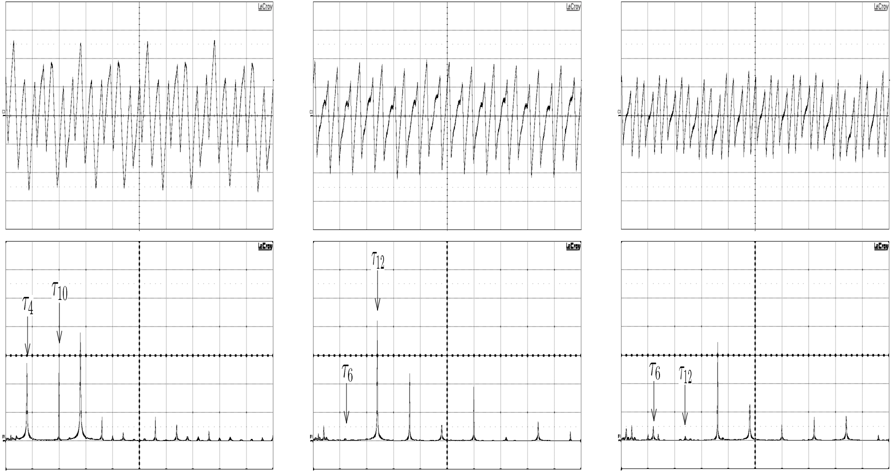


(scale: 5.0 Nm/div.; 5.0 ms/div. and 2.0 Nm/div.; 200 Hz/div.)($f_1 = 35$ Hz)

- Optimal PWM reduces the pk-pk torque ripple and sixth harmonic torque

Experimental Comparison of Pulsating Torque for $P = 7$

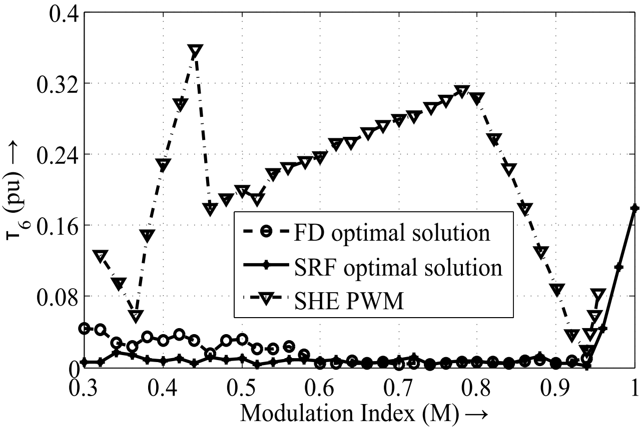
(Sine-Triangle PWM) (SHE PWM) (Optimal PWM)



(scale: 5.0 Nm/div.; 5.0 ms/div. and 2.0 Nm/div.; 200 Hz/div.)($f_1 = 35$ Hz)

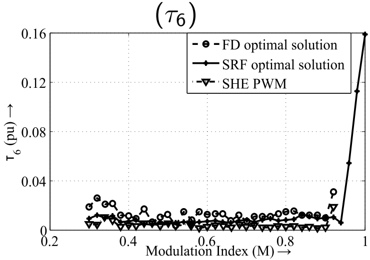
- Optimal PWM reduces the pk-pk torque ripple, sixth harmonic and twelfth harmonic torques

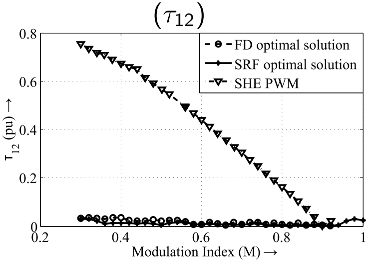
Experimental Comparison of Harmonic Torque for $P = 5$



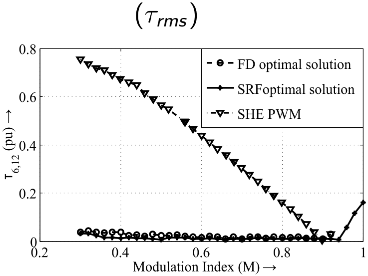
- Two optimal PWM methods are proposed - frequency domain and synchronous reference frame based
- Both are seen to reduce τ_6 as compared to SHE PWM, over wide range of speed

Experimental Comparison of Harmonic Torque for $P = 7$



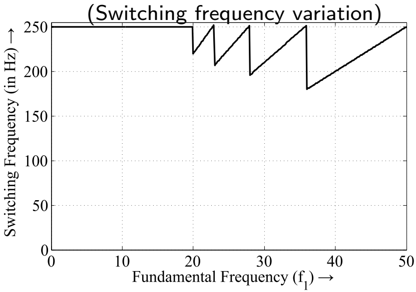


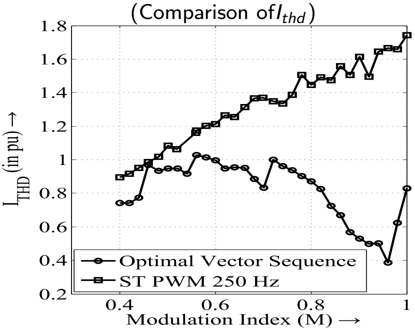
- SHE PWM eliminates τ_6 completely but τ_{12} is quite high
- Both optimal PWM reduce τ_{12} and combined RMS value of τ_6 and τ_{12} as compared to SHE PWM, over wide range of speed

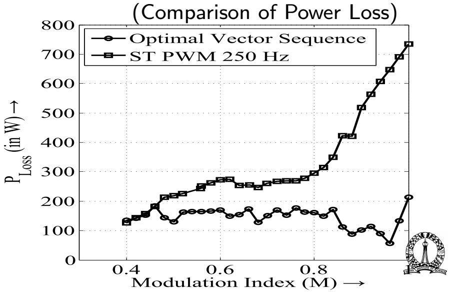


Hybrid Optimal PWM For Induction Motor Drive

- Optimal switching sequence is obtained for various pulse numbers
- A hybrid optimal PWM with max switching freq (f_{sw}) of 250 Hz is proposed
- $f_1 < 20$ Hz - asyn ST PWM; $f_1 \geq 20$ Hz - optimal PWM







Contributions of The Thesis

⇒ Optimal PWM for minimization of line current THD is proposed

⇒ Optimal switching sequences in space vector are determined

⇒ Frequency domain and synchronous reference frame based methods are proposed to minimize a set of harmonic torques

⇒ The proposed scheme is extended to neutral point clamped three-level inverter

⇒ A method to predict the current and torque ripple based on PWM voltage is proposed

⇒ Closed-loop control of IM drive operated with asynchronous and synchronous ST PWM for switching frequency varying between 250Hz and 500Hz is achieved

...Thank you