CONTROL OF ELECTRICAL DRIVE SYSTEMS AND CONVERTERS

Three-phase modulation

Tamas Kerekes

Department of
ENERGY TECHNOLOGY
Aalborg University

Control of electrical drive systems and converters

Lecture 1. Three phase converters

Sinusoidal modulation, harmonics, square wave operation, dc link current, converter model, dead-time, current control.

Problems: 8-10 and 8-7

Page: 225-243 in the book 'Power Electronics Converters, Application and Design. N. Mohan, T.M. Undeland and W.P. Robbins, John Wiley ISBN 0-471-58408-8'

Lecture 2. Three-phase modulation

Sinusoidal modulation with added 3rd harmonic, space vector modulation, 60 deg modulation, discontinuous modulation.

Papers: The use of harmonic distortion to increase the output voltage,   Simple Analytical and Graphical Methods for Carrier-Based PWM-VSI Drives

Lecture 3. Utility interface applications of power electronics

Interconnection of energy sources to the grid, control of switch mode interface, improved single and three phase utility interface.

Page: 475-480, 494 – 502 in the book 'Power Electronics Converters, Application and Design. N. Mohan, T.M. Undeland and W.P. Robbins, John Wiley ISBN 0-471-58408-8'

Lecture 4. Variable-frequency converter classifications

PWM-VSI, CSI , electromagnetic braking, speed control, square-wave vsi drive

Page: 418-432 in the book 'Power Electronics Converters, Application and Design. N. Mohan, T.M. Undeland and W.P. Robbins, John Wiley ISBN 0-471-58408-8'

Lecture 5. Soft-switching in PWM – converters

Hard and soft switching, classification of converters, basic resonant circuits, ZVS – VSI converters, phase shifted converters, resonant link inverters.

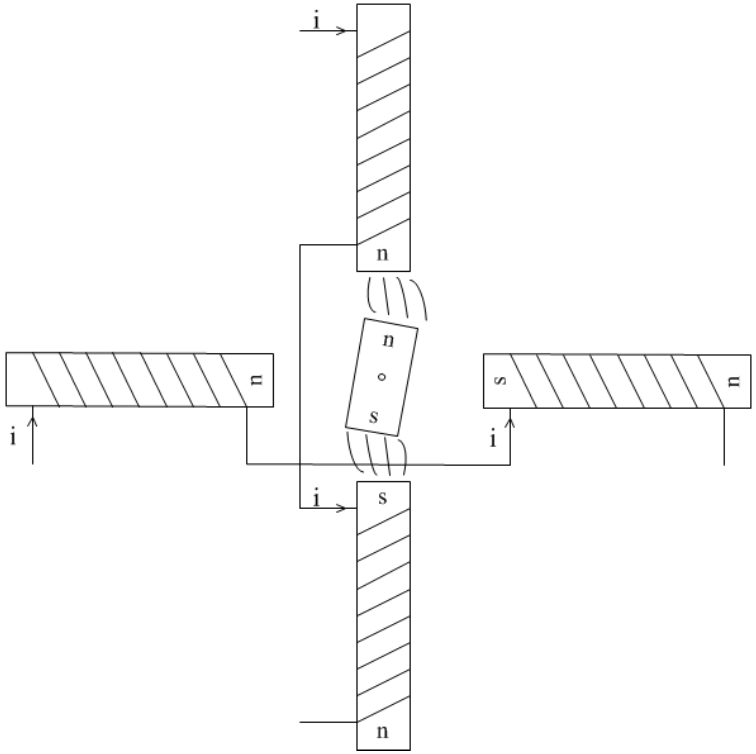
Page: 249-258,, 280-291 in the book 'Power Electronics Converters, Application and Design. N. Mohan, T.M. Undeland and W.P. Robbins, John Wiley ISBN 0-471-58408-8'

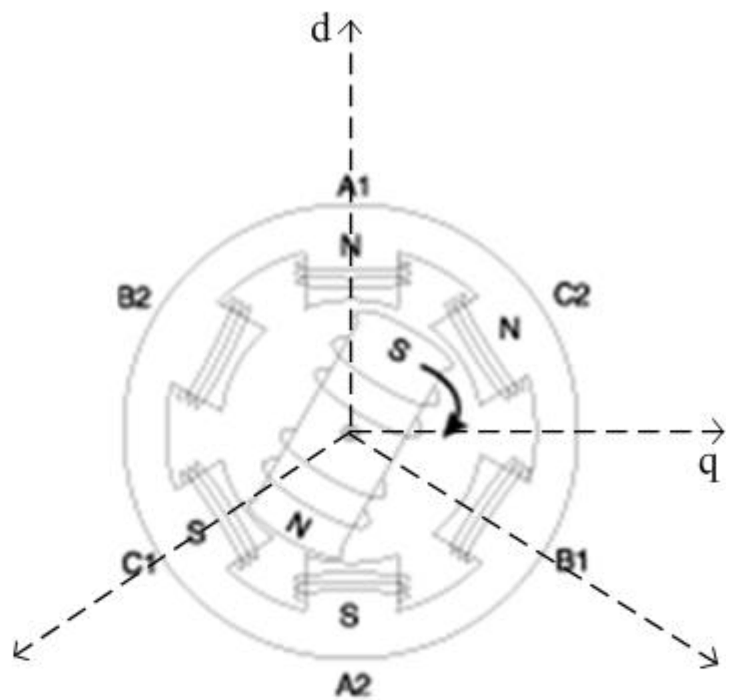
Lecture 2: Three-phase modulation

- Magnetomotive force generation in a motor
- ST-PWM with added 3rd harmonic
- SVM
- Discontinuous modulation
- Analytical spectrum calculation
- Current measurement

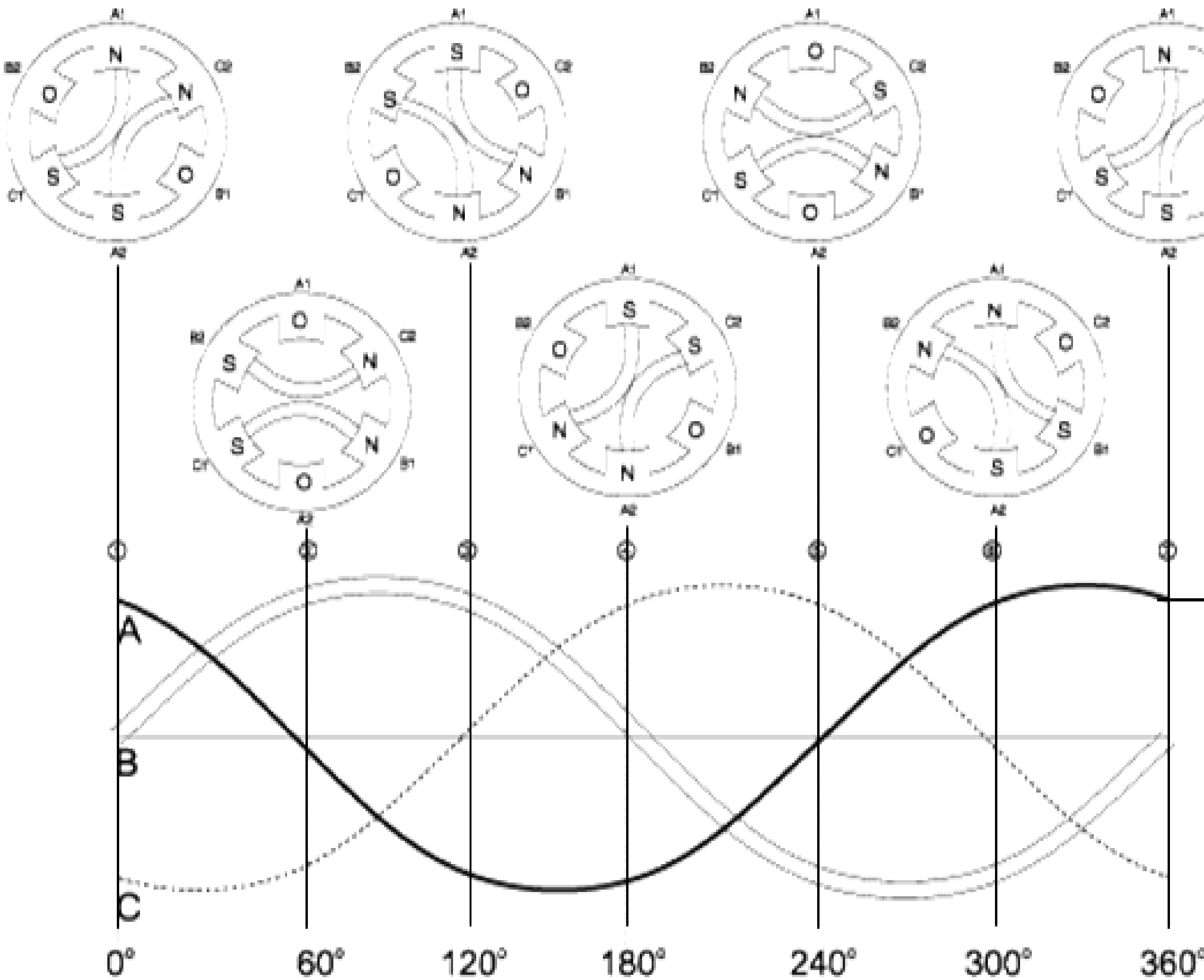
Magnetomotive force between a coil and PM

- Passing a current through a coil alines the magnet; reversing the current will rotate 180^0 the magnet (direction of rotation is not defined)
- By placing three pair coils, 120^0 shifted in space, the magnet can take an arbitrary position in the d-q plane





Rotating field generation



Motor current

- During one fundamental period one revolution of the rotor can be obtained

Third harmonic injection

Relation between the phase and line voltages

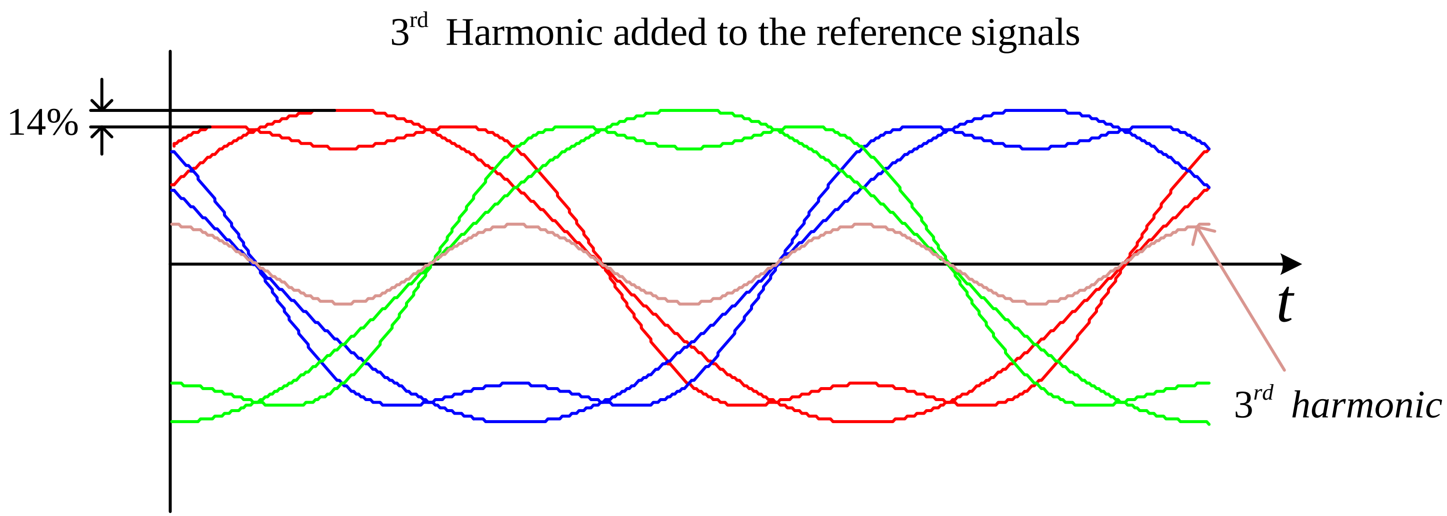
$$v_{AB} = v_{AN} - v_{BN}$$

$$v_{BC} = v_{BN} - v_{CN}$$

$$v_{AC} = v_{AN} - v_{CN}$$

Note: if the same value is added to the phase signals that will not affect the line to line voltage

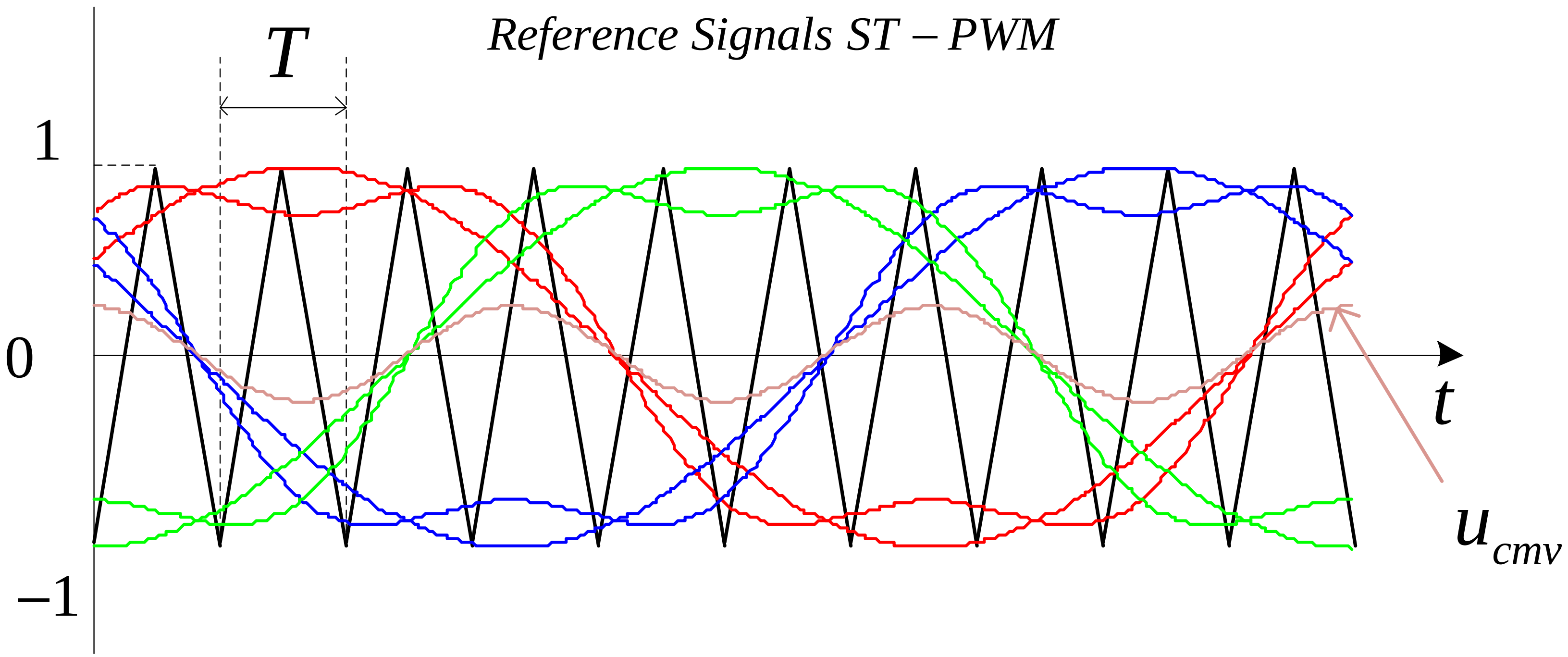
Third harmonic injection waveform



Note:

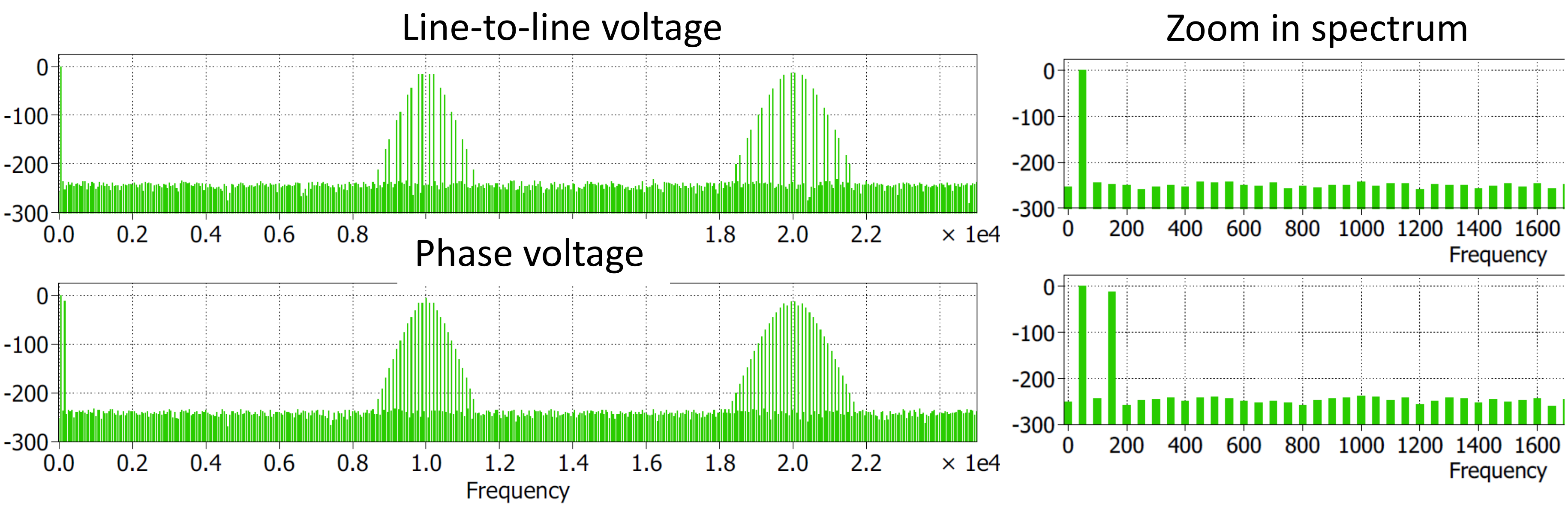
- By adding a sinusoidal signal to the phase voltage waveform the line to line voltage is maintained sinusoidal
- The peak of the phase voltage is reduced with around 14%

Modulation of THI-PWM waveforms



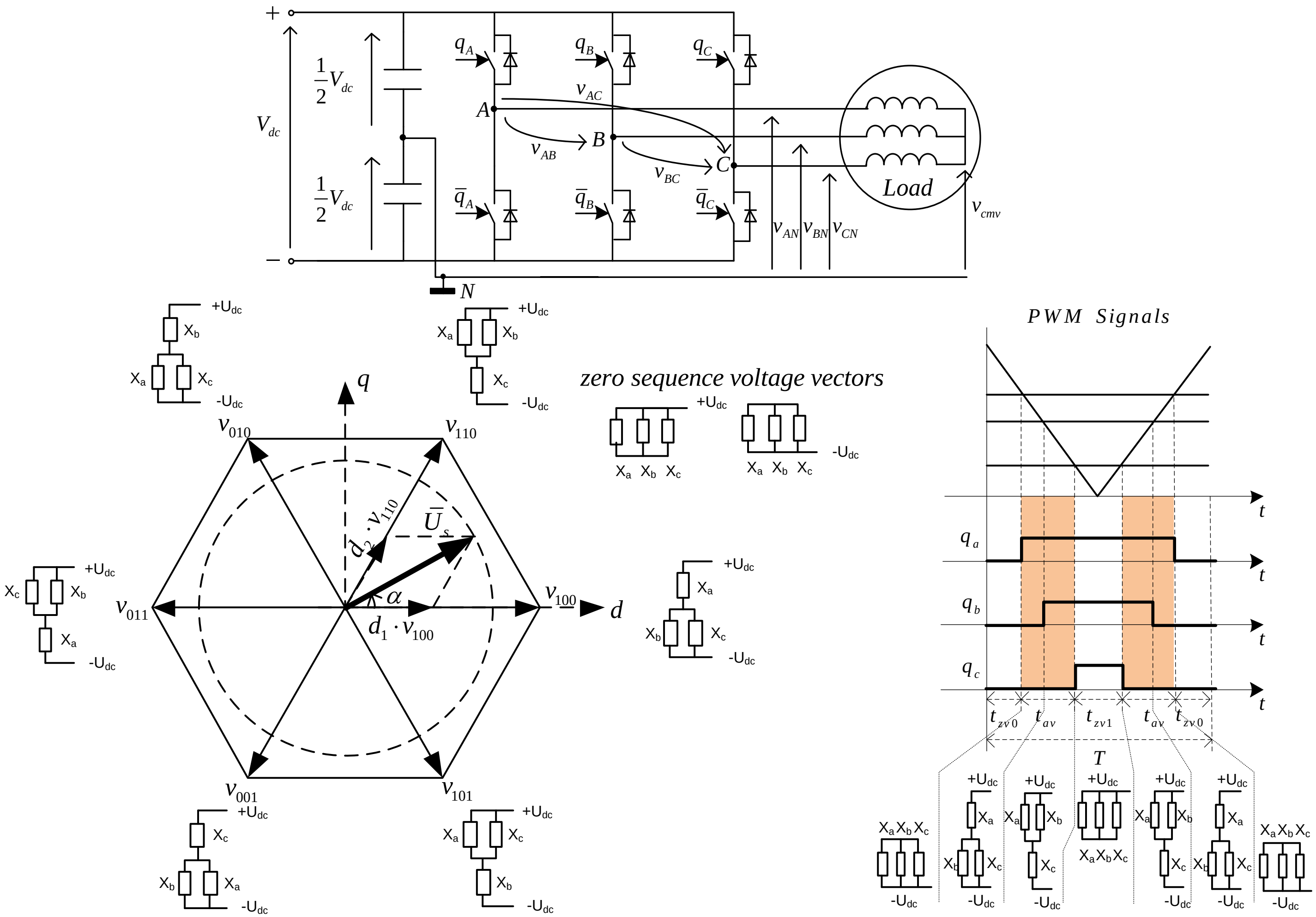
- Note: The linear range is extended with around 14%

Spectrum of THI-PWM



- The harmonic content is increased
- At low frequency the there is no change in spectrum

Space vector representation



- With the two level VSI 6 active and 2 zero sequence voltage vectors can be generated

Timing calculation

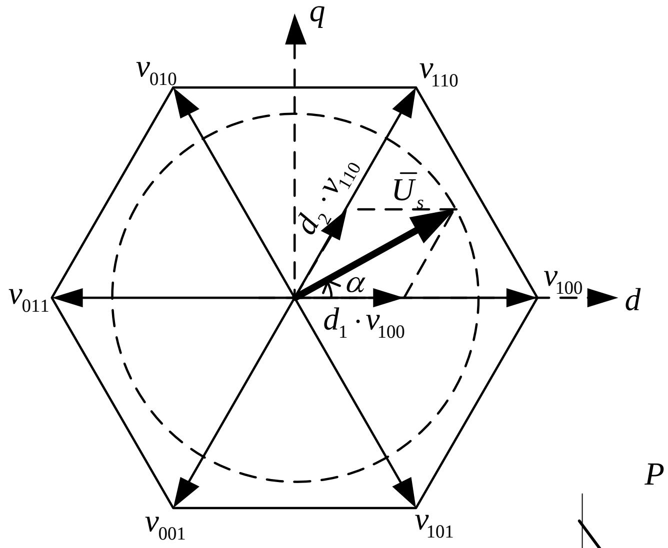
$$\bar{U}_s = d_1 \cdot \bar{v}_x + d_2 \cdot \bar{v}_y$$

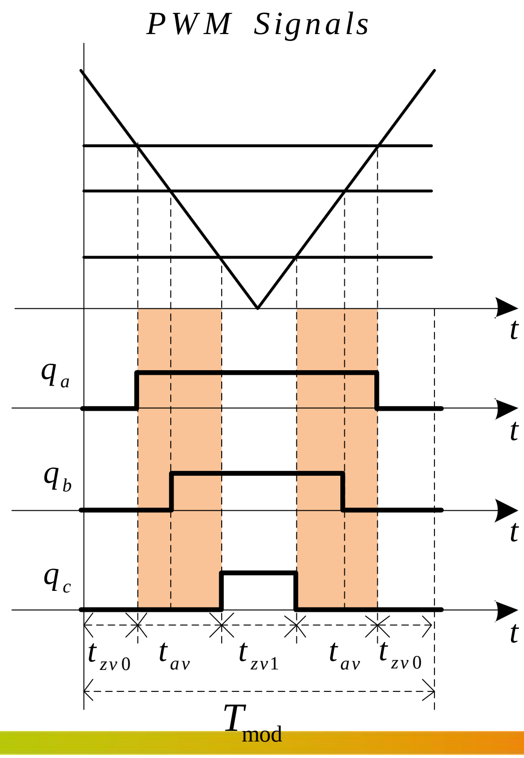
$$d_1 = \sqrt{3}\frac{|U_s|}{U_{dc}}\sin(\alpha)$$

$$d_2 = \sqrt{3}\frac{|U_s|}{U_{dc}}\sin(\frac{\pi}{3} - \alpha)$$

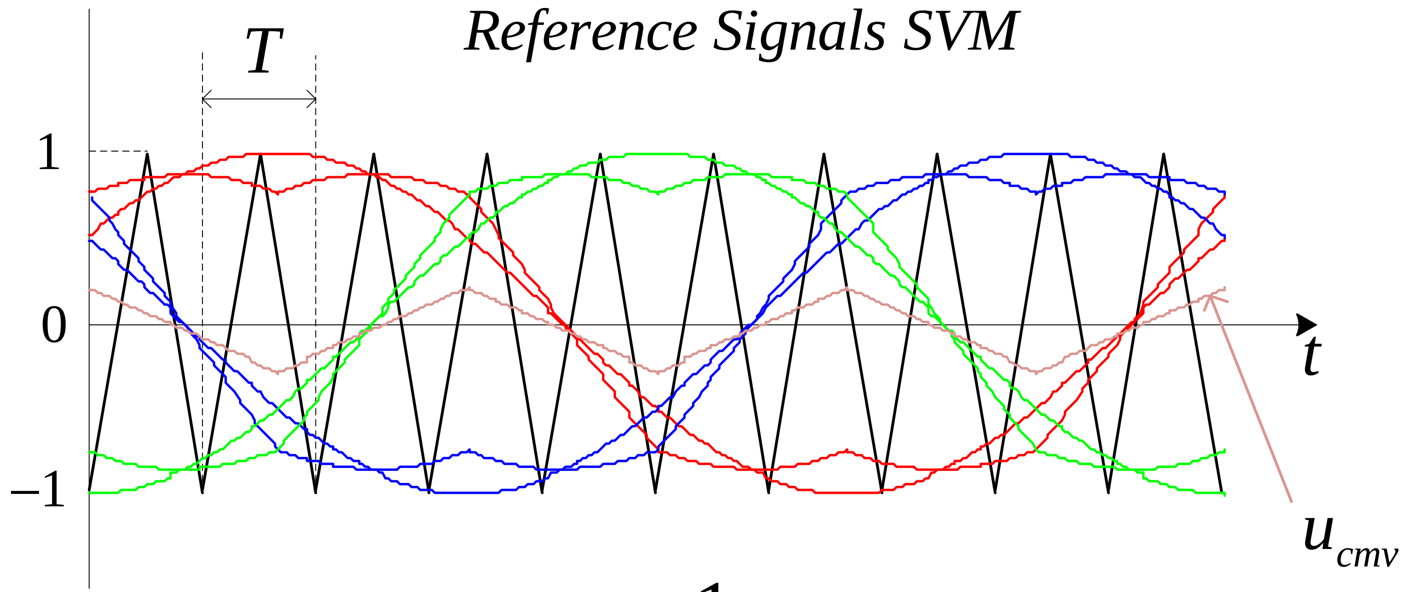
$$d_{zv} = 1 - (d_1 + d_2)$$

- *where d* is the duty cycle





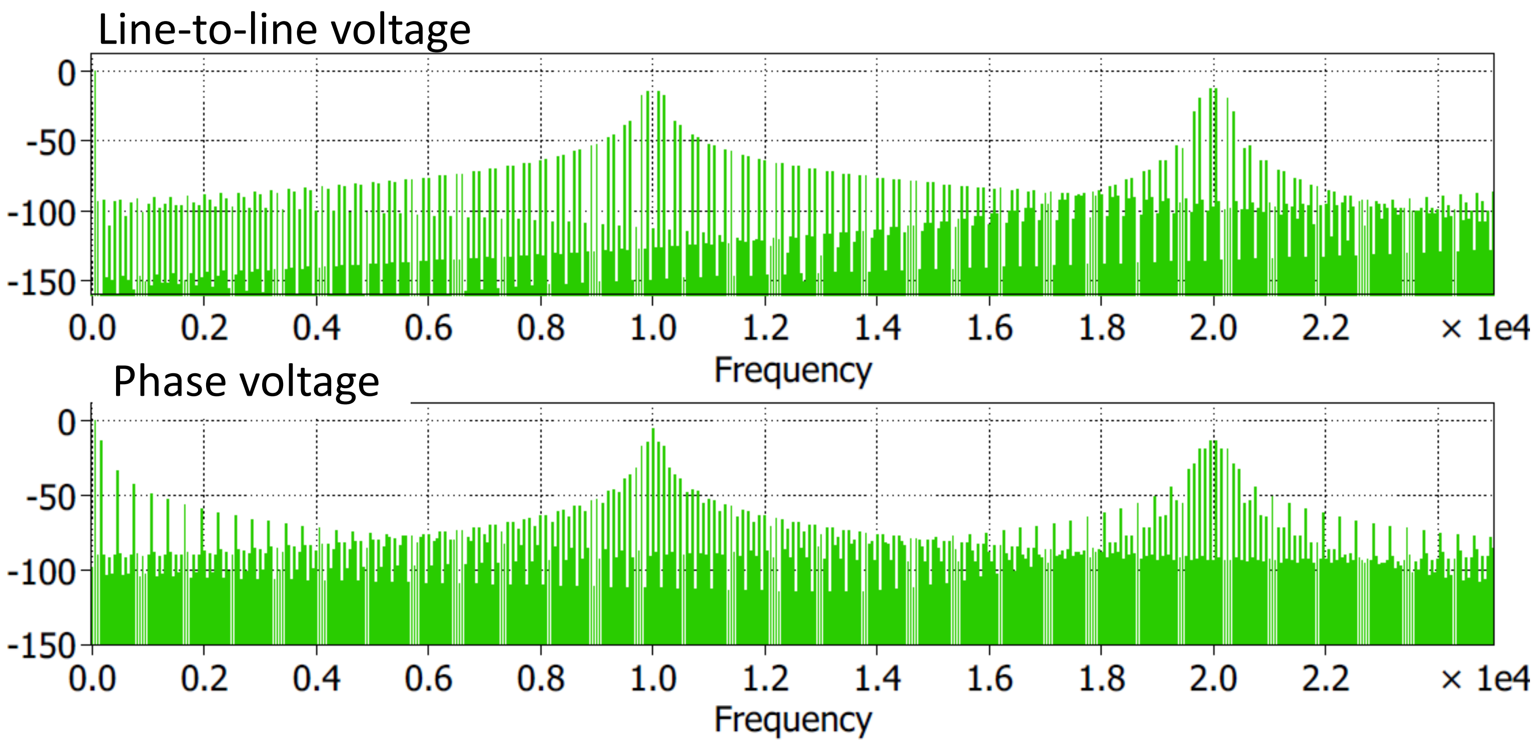
SVM waveforms



$$t_{zv0} = t_{zv1} = \frac{1}{2} d_{zv} \cdot T_{\mathrm{mod}}$$

- By making the time spent for the generation of the two zero vectors equal is similar to add a triangular signal is added to the phase voltages

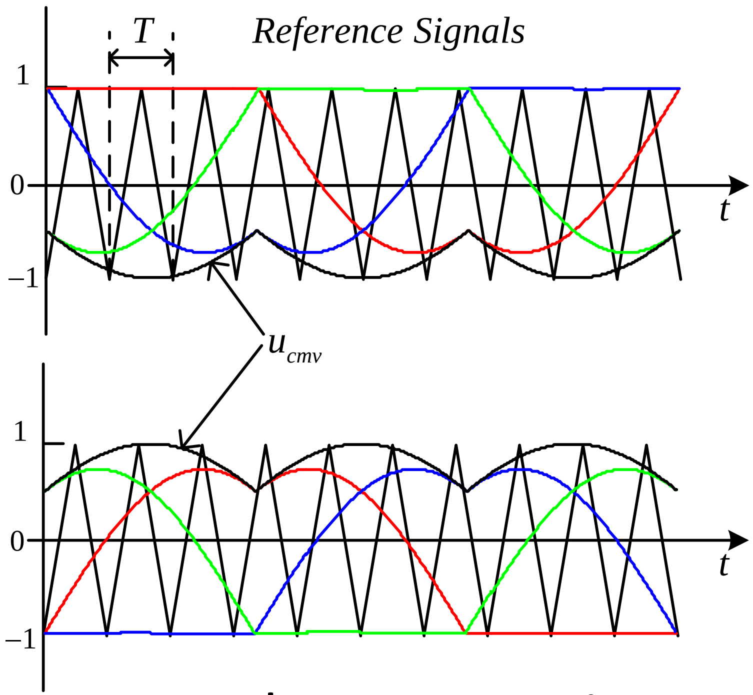
SVM spectrum

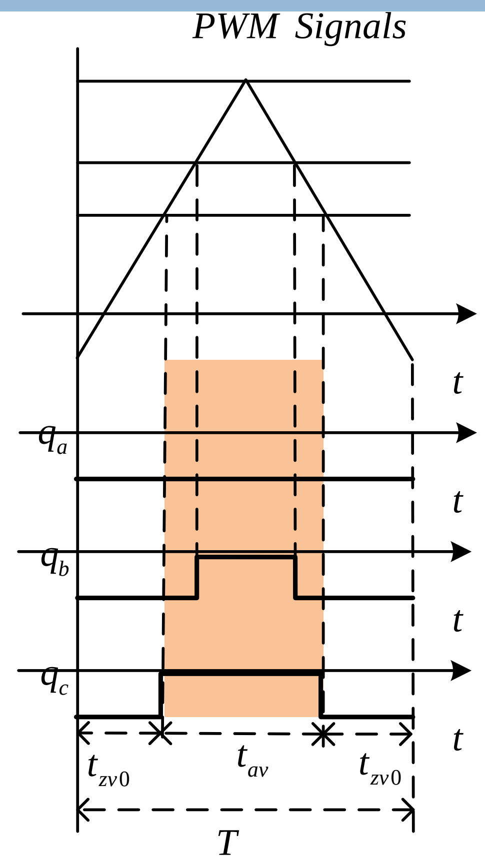


- High frequency region more harmonics are present, the amplitude of the harmonics are reduced with few dB

120^0 PWM

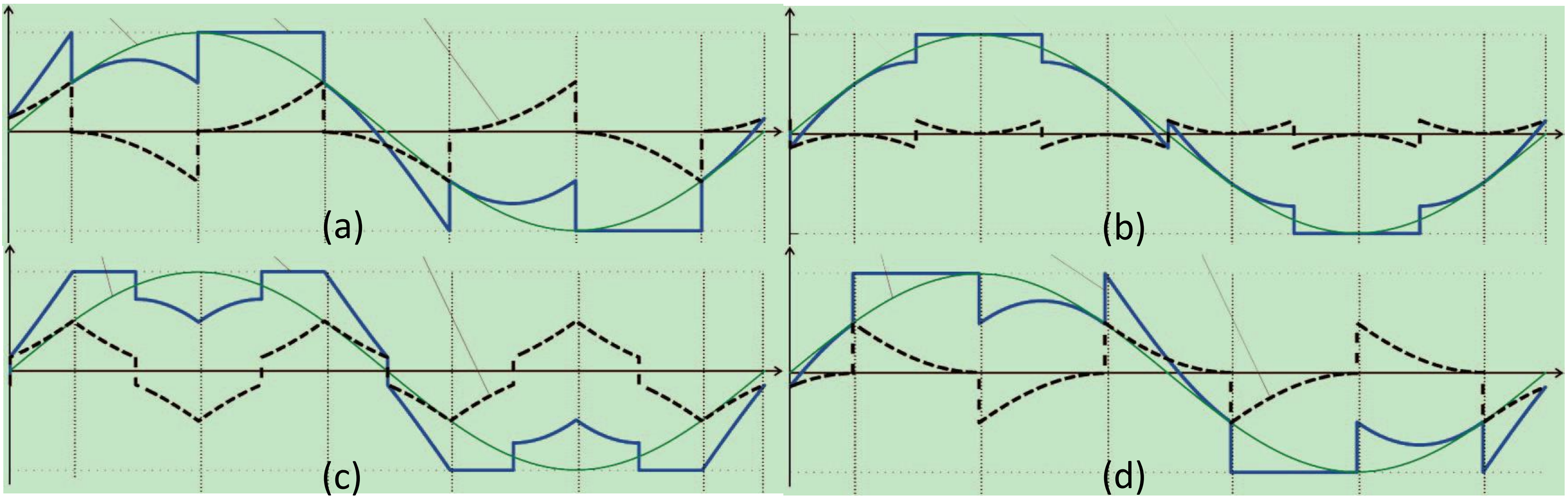
$$t_{zv0} = d_{zv} \cdot T_{\mathrm{mod}} \text{ and } t_{zv1} = 0 \text{ or}$$
$$t_{zv1} = d_{zv} \cdot T_{\mathrm{mod}} \text{ and } t_{zv0} = 0$$





- Only one zero voltage vector is generated
- Number of switching is reduced with 25% (reduced switching losses)
- Increased stress for some of the components

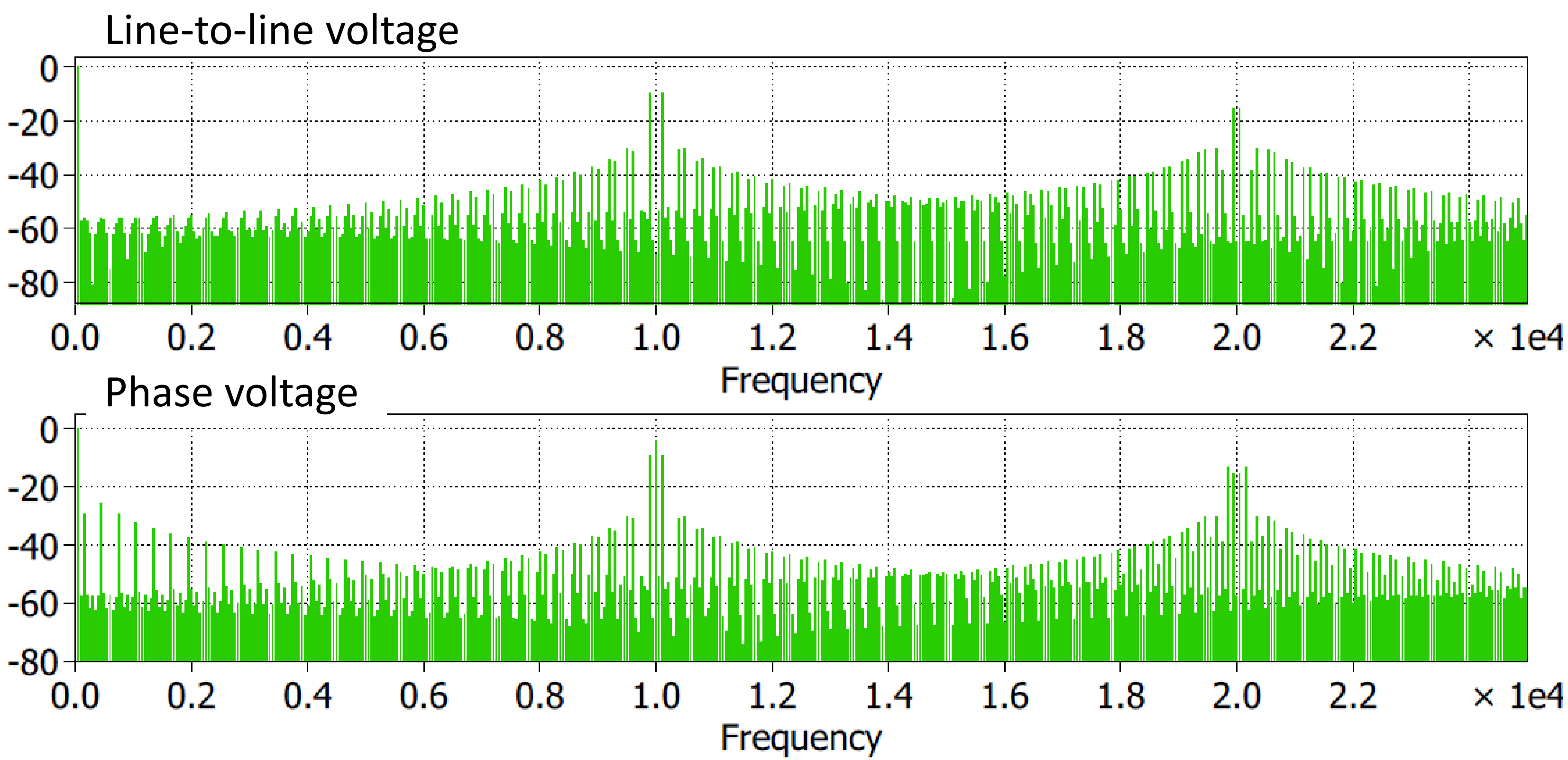
Discontinuous PWM strategies



The two 120^0 PWM are alternatively applied for 60^0, with a phase shift of: (a) 0 degree, (b)30 degree, (c)60 degree, (d) 90 degree

Advantage: better stress distribution for the switching devices

Spectrum of DPWM



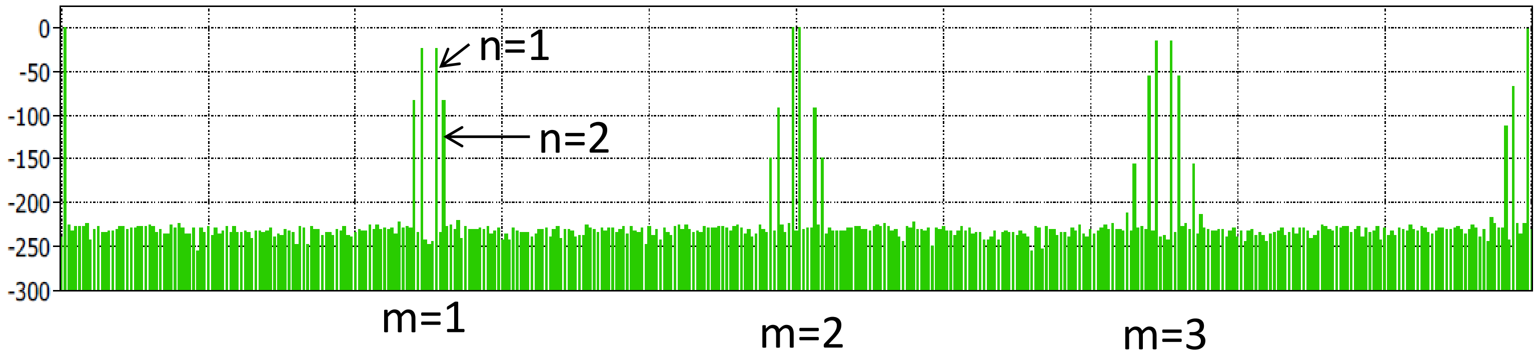
- Many harmonics are introduced

Spectrum of the PWM signals

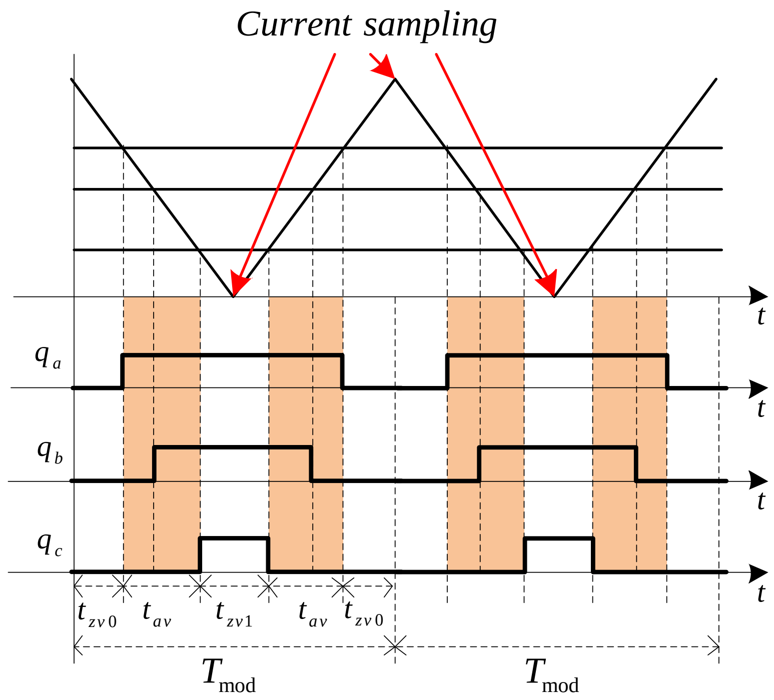
- The spectrum of the ST-PWM can be calculated by using:

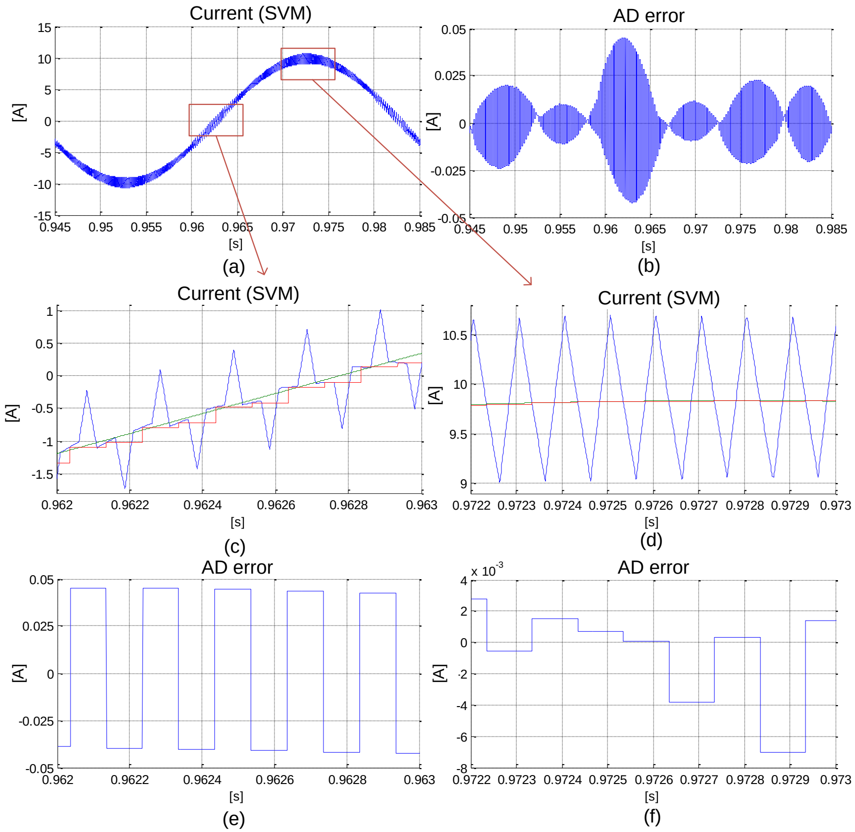
$$u_{ag} = \frac{U_{dc}}{2}\left(\begin{array}{l} 1 + M\cos\left(\omega_0 t + \theta_0\right) + \\ \frac{4}{\pi}\sum_{m=1}^{\infty}\sum_{n=-\infty}^{\infty}\left(\begin{array}{l} \frac{1}{m}J_n\left(m\frac{\pi}{2}M\right)\sin\left(\left(m+n\right)\frac{\pi}{2}\right)\times \\ \cos\left(\left(m\omega_c + n\omega_c\right)t + \left(m\theta_c + n\theta_0\right)\right) \end{array}\right) \end{array}\right)$$

where, $J_n(\beta)$ denotes the n-th order Bessel function of the first kind with the argument of β, M-is the modulation index, w_0-frequency of the fundamental component, w_c-carrier frequency, m- carrier harmonics and n-side band harmonics



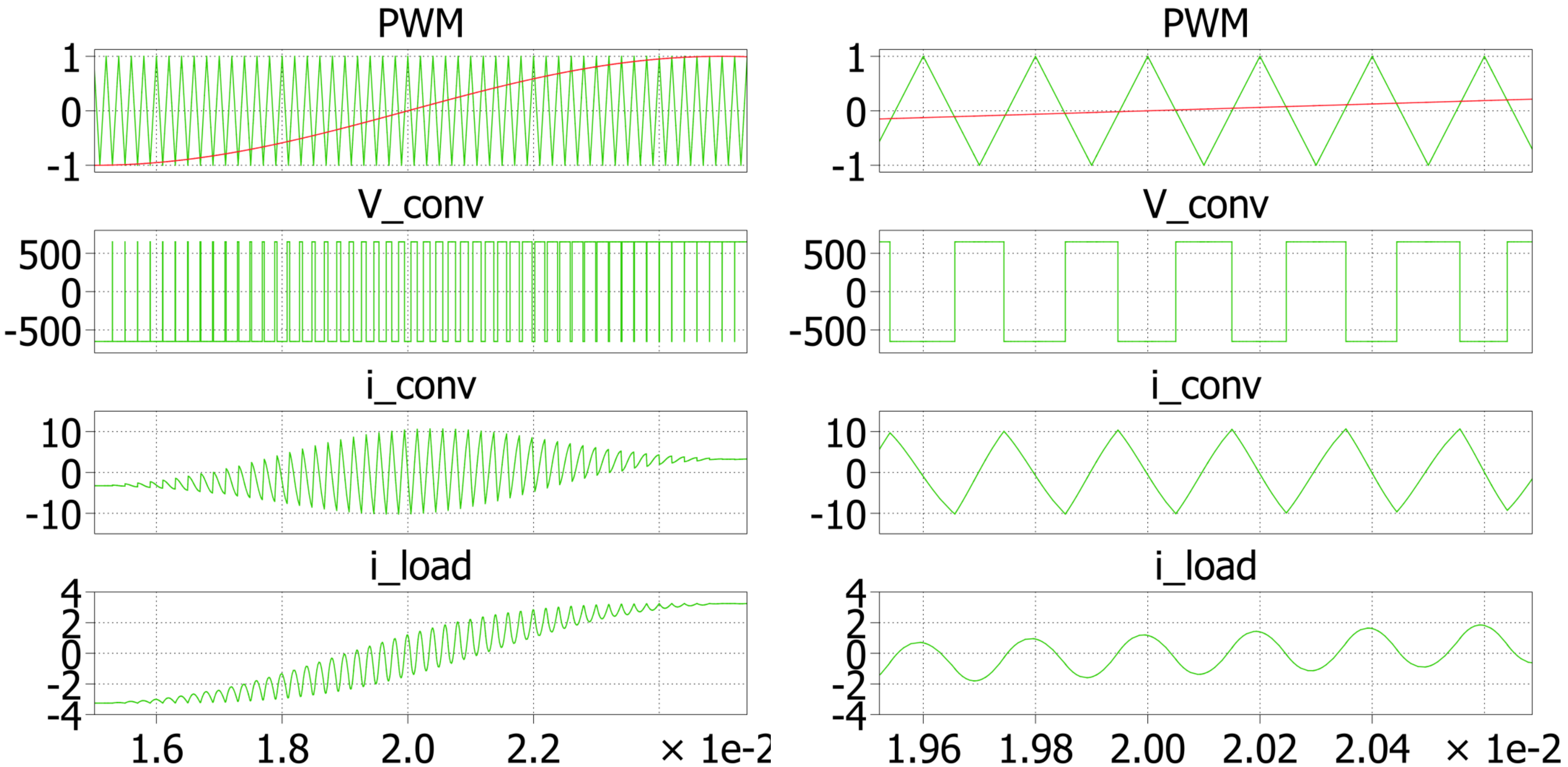
Current measurement





- Current sampling has to be done in the middle of the time spent for generation of zero vectors (top and/or bottom of carrier)
- Note: in case of the DPWM methods the sampling can be done only once in a modulation period
- Sampling at TOP and BOTTOM results in minimum error
- At zero crossing the current sampling error will be maximum due to the slope of the current

Current measurement



Summary

With a three phase system a rotating voltage vector can be created .

ST-PWM with added 3rd harmonic

- increase the linear range

Space vector modulation

- smallest current ripple can be achieved

Discontinuous modulation

- reduce the switching losses

Analytical spectrum calculation

- the spectrum can be determinated by using math. eq.

Current measurement

Exercise

- Implement the modulation types: SPWM, DPWM1, THIPWM and SVPWM in Simulink and use 'zero sequence signal calculator' the method is shown on Fig. 4.

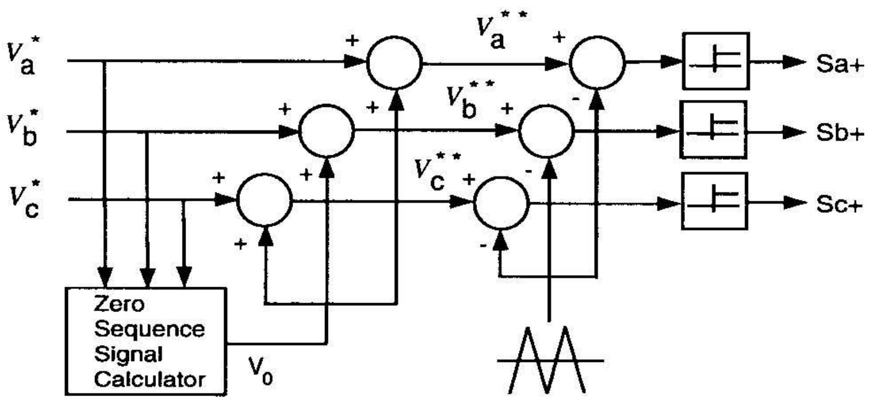


Fig. 4. The generalized signal block diagram of the triangle intersection technique-based PWM employing the zero-sequence injection principle.

1: Plot the v_a^{**} voltage of each modulation type.

2: Plot the inverter branch voltage:

V_{dc}=100V, f_1 = 50 Hz, f_s=1050Hz, m_a=0.8

3: Plot the inverter line to line voltage.

4: upload screen-shots to Moodle