Examination	**ENM060 Power Electronic Converters**
Date and time	Tuesday August 23rd, 2016, 14:00 – 18:00
Responsible Teacher:	Andreas Henriksson, tel. 0709-524924
Authorised Aids:	Chalmers-approved calculator (Casio FX82..., Texas Instruments Ti-30... and Sharp EL-W531...)
Grades:	U, 3, 4 or 5. (The limit for a 3 on the exam is 20p, a 4 is 30p and 5 is 40p. The maximum number of points is 50.)
Solutions:	Course webpage (Ping-Pong), August 24th 2016
Review of Exam	September 15th and September 19th, 12:00-13:00. Uno Lamms Room. Division of Electric Power Engineering (2nd floor). From September 20th 2016, the exams can be picked-up at the exam office, Department of Energy and Environment. Location: EDIT building, Maskingränd 2, 3Ö (east) floor, room 3434A. Opening hours during semesters: Monday-Friday 12:30-14:30

Observe that the questions are not arranged in any kind of order.

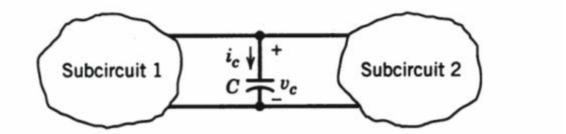
On the last pages there are some formulas that can be used in the examination. Always assume steady-state conditions in all tasks unless otherwise stated.

Please, read through the exam before you start.

---

1) The voltage curve-form (v_c) is applied over the capacitor which are connected to two arbitrary sub-circuits. (3p)

- **Explain the concept of steady state.**
- **Sketch the resulting current that flows into the capacitor (i_c).**

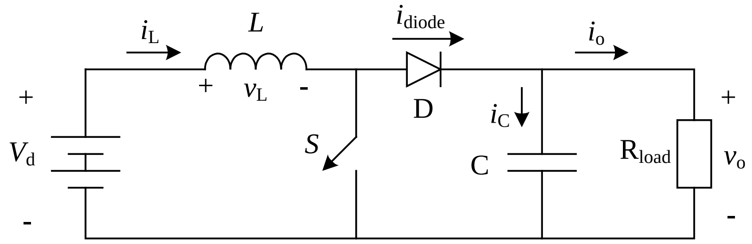


2) **Consider the ideal boost converter below.**

- **Calculate the peak-to-peak output voltage ripple for the specified operating point.**
- **Draw the curve form of the voltage ripple. (5p)**

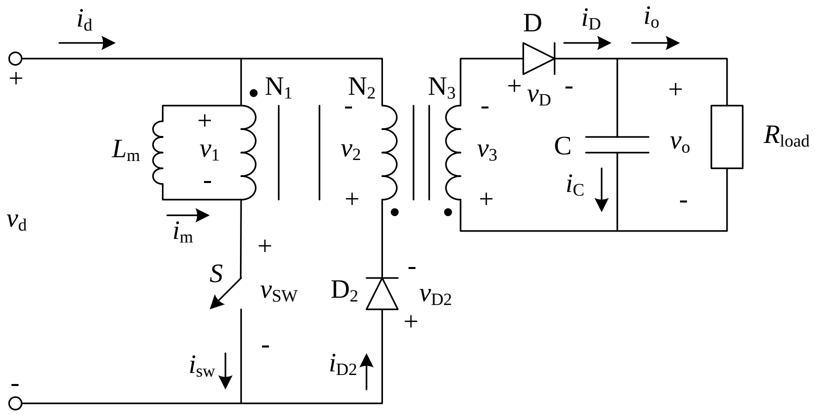
$V_d = 8V$ $\quad V_o = 12V$ $\quad I_o = 6A$

$f_{sw} = 320kHz$ $\quad C = 270\mu F$ $\quad L = 1.4\mu H$



3) **Consider the Flyback converter below. (5p)**

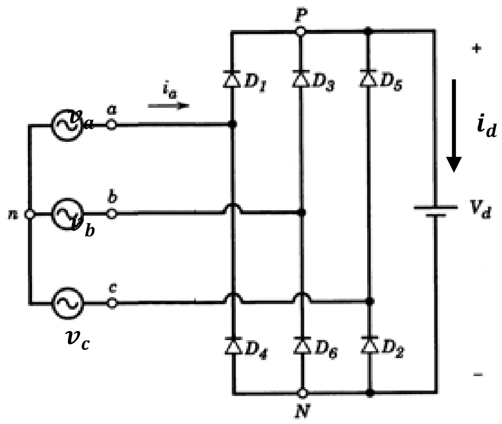
- **For the given operating point, check if the converter is operating in CCM or DCM.**
- **Calculate the resulting temperature of the output diode (*D*) if the ambient temperature is 30°C. Application of Simpsons formula must be used for full points.**



$L_m = 120\mu H$
$C = 330\mu F$
$V_d = 20V$
$V_o = 32V$
$f_{sw} = 250kHz$
$R = 4\Omega$
$(N_1 : N_2 : N_3) = (1 : 0.5 : 1)$
$V_f = 0.84V$
$R_{\theta ja} = 10°\, C/W$

4) **The three phase diode rectifier depicted below is used with a voltage stiff DC-link. The system operates with $50Hz$ and $v_a = v_b = v_c = 230V$ peak voltage. Draw the voltages and currents stated below. Clearly state the amplitudes and phase shifts between the voltages, exact amplitudes of the currents are not needed. (5p)**

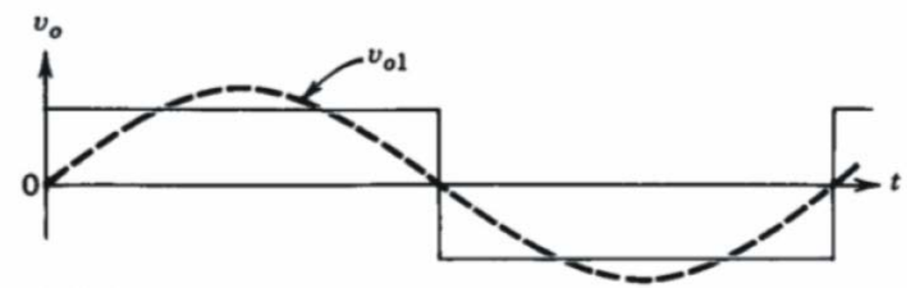
- **The phase voltage in phase *a* (v_{an})**
- **The line-to-line voltages for phase a (v_{ab} and v_{ac})**
- **The current in phase *a* (i_a).**
- **The DC-side current (i_d).**



5) **A single-phase diode rectifier with a voltage stiff DC-side (large DC-link capacitor) is connected to a grid with a source inductance. (4p)**

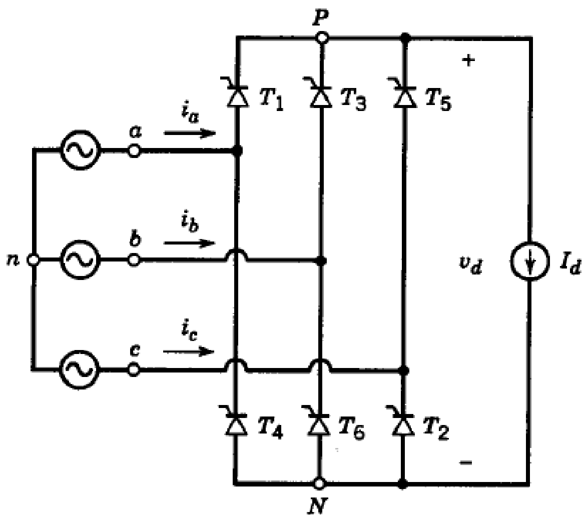
- **Sketch a typical waveform of the resulting line current (i_s)**
- **How will the source inductance affect the power factor (PF) and the displacement power factor (DPF)? Exemplify with e.g. graphs and Fourier components.**

6) **For a single phase inverter operating in square wave mode, calculate the peak-to-peak ripple in the output current. Assume that the fundamental frequency component of the output voltage is $v_{o(1)} = 156V$ (50Hz) and that the load consists of an inductor ($L = 100mH$) in series with a sinusoidally shaped back-emf voltage source $\left(e_o = \sqrt{2} \cdot E_o \cdot \sin(\omega_1 t)\right)$. The back-emf has the same amplitude, frequency and phase shift as the fundamental frequency component of the output voltage. The DC-link voltage (V_d) is 170V. (5p)**



7) **A three-phase thyristor inverter is operating with a constant current load ($I_d = 25A$). The three-phase network is assumed be a balanced system with no line impedance. (4p)**

- **Draw the voltage waveforms (v_{Nn}, v_{Pn}, v_d) for $\alpha = 150°$ on the enclosed dot-paper.**
- **Draw the current waveforms (i_a, i_b, i_c) and state the amplitude.**



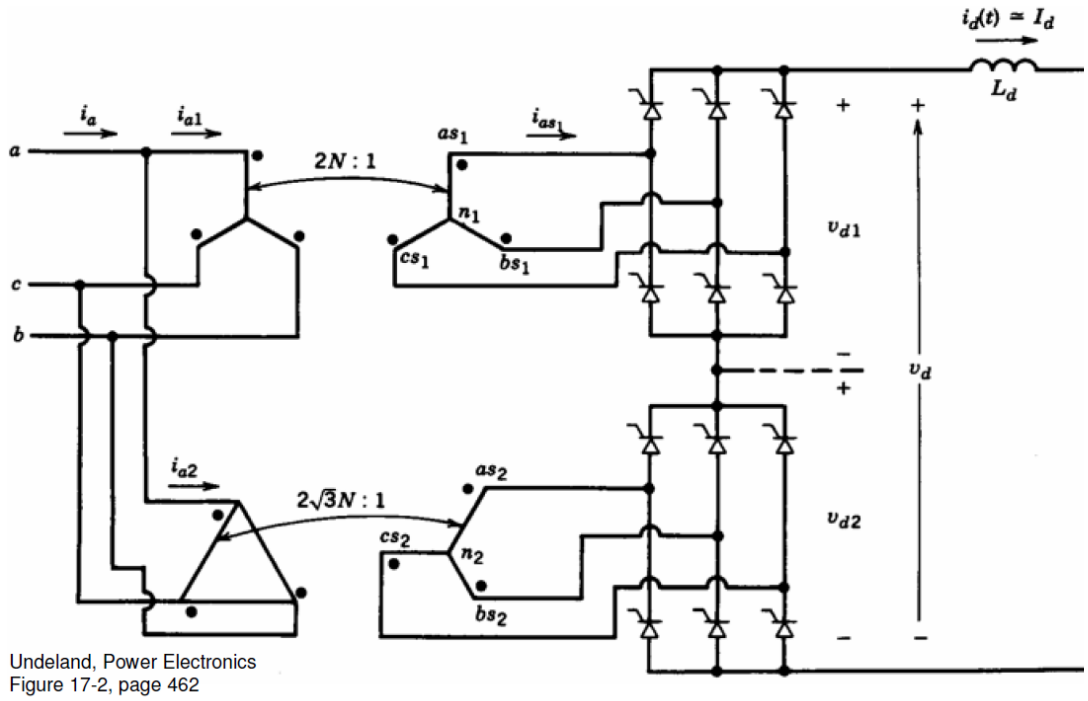
8) **For the Thyristor inverter in (7), each component is turned on by applying a pulse on the gate terminal. (3p)**

- **Is the thyristor a current or voltage controlled device?**
- **Explain why it could be a problem to operate this inverter with large firing angles (large α), for example 180°.**

9) **Heat can be transferred by three different mechanisms and it is important to design your application so that it does not become too hot. If a semiconductor becomes too hot and is exposed to extensive thermal cycling, it will eventually break down. (4p)**

- **Which are the three heat transfer mechanisms and which one is the most important in semiconductors for power electronic applications?**
- **What is the typical reason for component failure in a semiconductor for power electronic applications?**

10) **What are the main benefits of using 12-pulse rectification in a three-phase thyristor application (e.g. a HVDC classic)? Exemplify with e.g. input current and output voltage. (4p)**



Undeland, Power Electronics
Figure 17-2, page 462

11) **A Flyback converter with two secondary windings (i.e. two output voltages v_{01} and v_{02}) is used with real components including parasitic elements. The controller circuit only regulates one output voltage (v_{01}). Explain thoroughly what happens if a load step (e.g. sudden increase/decrease of the output current) is applied on output v_{01} and v_{02}, respectively. (4p)**

12) **Compare the transformer utilization for a flyback, forward and a full-bridge. Comment on how the transformer is used in each converter, i.e. advantages/disadvantages. (4p)**

	Flyback	Forward	Full-bridge
Transformer utilization			
Comment			

Formulas for Examination in Power Electronic Converters (ENM060)

Table 3-1 Use of Symmetry in Fourier Analysis

Symmetry	*Condition Required*	a_h and b_h
Even	$f(-t) = f(t)$	$b_h = 0 \quad a_h = \frac{2}{\pi}\int_0^{\pi} f(t)\cos(h\omega t)\, d(\omega t)$
Odd	$f(-t) = -f(t)$	$a_h = 0 \quad b_h = \frac{2}{\pi}\int_0^{\pi} f(t)\sin(h\omega t)\, d(\omega t)$
Half-wave	$f(t) = -f(t + \frac{1}{2}T)$	$a_h = b_h = 0$ for even h $a_h = \frac{2}{\pi}\int_0^{\pi} f(t)\cos(h\omega t)\, d(\omega t)$ for odd h $b_h = \frac{2}{\pi}\int_0^{\pi} f(t)\sin(h\omega t)\, d(\omega t)$ for odd h
Even quarter-wave	Even and half-wave	$b_h = 0$ for all h $a_h = \begin{cases} \frac{4}{\pi}\int_0^{\pi/2} f(t)\cos(h\omega t)\, d(\omega t) & \text{for odd } h \\ 0 & \text{for even } h \end{cases}$
Odd quarter-wave	Odd and half-wave	$a_h = 0$ for all h $b_h = \begin{cases} \frac{4}{\pi}\int_0^{\pi/2} f(t)\sin(h\omega t)\, d(\omega t) & \text{for odd } h \\ 0 & \text{for even } h \end{cases}$

Definition of RMS-value:

$$F_{RMS} = \sqrt{\frac{1}{T}\int_{t_o}^{t_o+T} f(t)^2 dt}$$

Definition of RMS-value with Fourier-series:

$$F_{RMS} = \sqrt{F_0^2 + \sum_{n=1}^{\infty} F_n^2} = \sqrt{\left(\frac{a_0}{2}\right)^2 + \sum_{n=1}^{\infty}\left(\frac{\sqrt{a_n^2 + b_n^2}}{\sqrt{2}}\right)^2}$$

$$\sin^2(\alpha) + \cos^2(\alpha) = 1$$

$$\sin(\alpha+\beta) = \sin(\alpha)\cos(\beta) + \cos(\alpha)\sin(\beta) \qquad \sin(\alpha-\beta) = \sin(\alpha)\cos(\beta) - \cos(\alpha)\sin(\beta)$$

$$\cos(\alpha+\beta) = \cos(\alpha)\cos(\beta) - \sin(\alpha)\sin(\beta) \qquad \cos(\alpha-\beta) = \cos(\alpha)\cos(\beta) + \sin(\alpha)\sin(\beta)$$

$$\sin(\alpha)\sin(\beta) = \frac{1}{2}\left(\cos(\alpha-\beta) - \cos(\alpha+\beta)\right) \qquad \sin(\alpha)\cos(\beta) = \frac{1}{2}\left(\sin(\alpha-\beta) + \sin(\alpha+\beta)\right)$$

$$\cos(\alpha)\cos(\beta) = \frac{1}{2}\left(\cos(\alpha-\beta) + \cos(\alpha+\beta)\right)$$

$$\int \sin(ax)dx = -\frac{1}{a}\cos(ax), \quad \int x\sin(ax)dx = \frac{1}{a^2}\left(\sin(ax) - ax\cos(ax)\right), \quad \int \cos(ax)dx = \frac{1}{a}\sin(ax)$$

$$\int x\cos(ax)dx = \frac{1}{a^2}\left(\cos(ax) + ax\sin(ax)\right)$$

$$PF = \frac{P}{S} = \frac{V_s I_{s1}\cos\phi_1}{V_s I_s}, \quad DPF = \cos\phi_1, \quad \%THD_i = 100\frac{I_{dis}}{I_{s1}} = 100\frac{\sqrt{I_s^2 - I_{s1}^2}}{I_{s1}} = 100\sqrt{\sum_{h\neq 1}\left(\frac{I_{sh}}{I_{s1}}\right)^2}$$

Electromagnetics

$$e = \frac{d}{dt}\psi \qquad \psi = N\phi \qquad \phi = BA \qquad R = \frac{l}{A\mu_r\mu_0} \qquad L = \frac{\Psi}{i}$$

$$NI = R\phi = mmf \qquad N\phi = LI \qquad L = A_L N^2 \qquad W = \frac{1}{2}LI^2$$

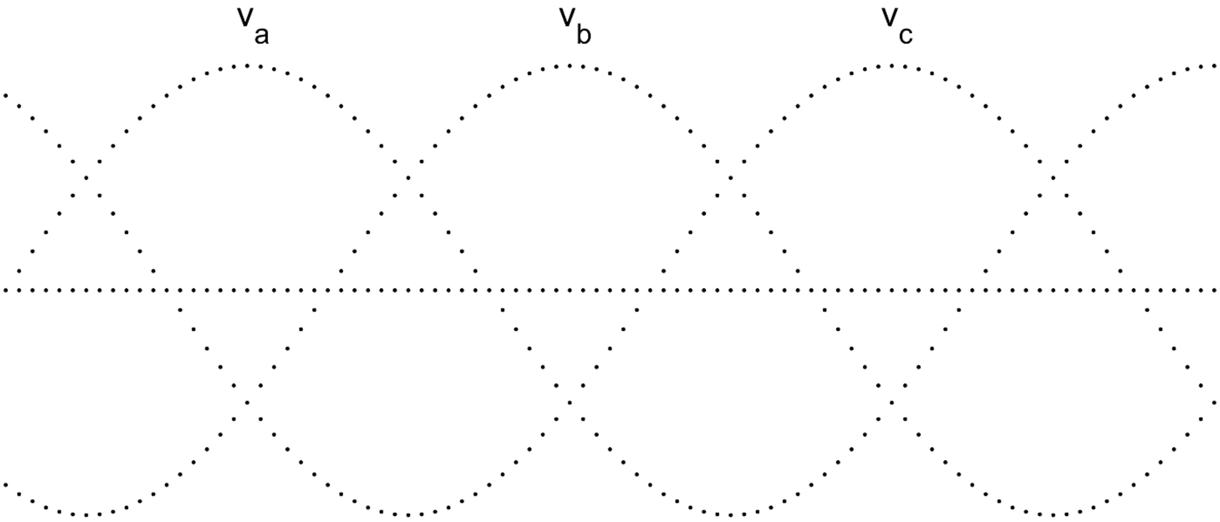
Simpson's rule

Let $f(x)$ be a polynomial of maximum third degree, this means

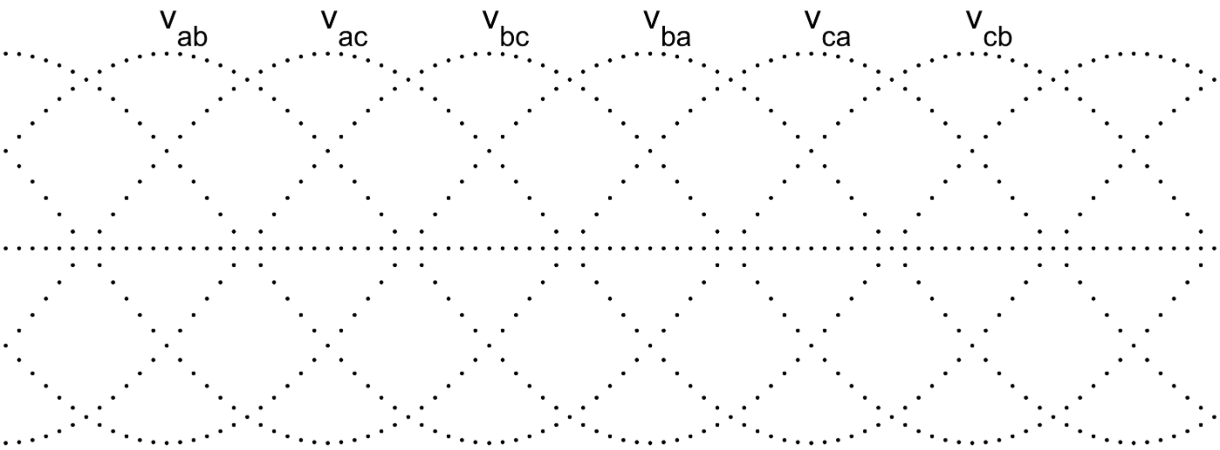
$$f(x) = a_1 + a_2 x + a_3 x^2 + a_4 x^3$$

For this function the integral can be calculated as

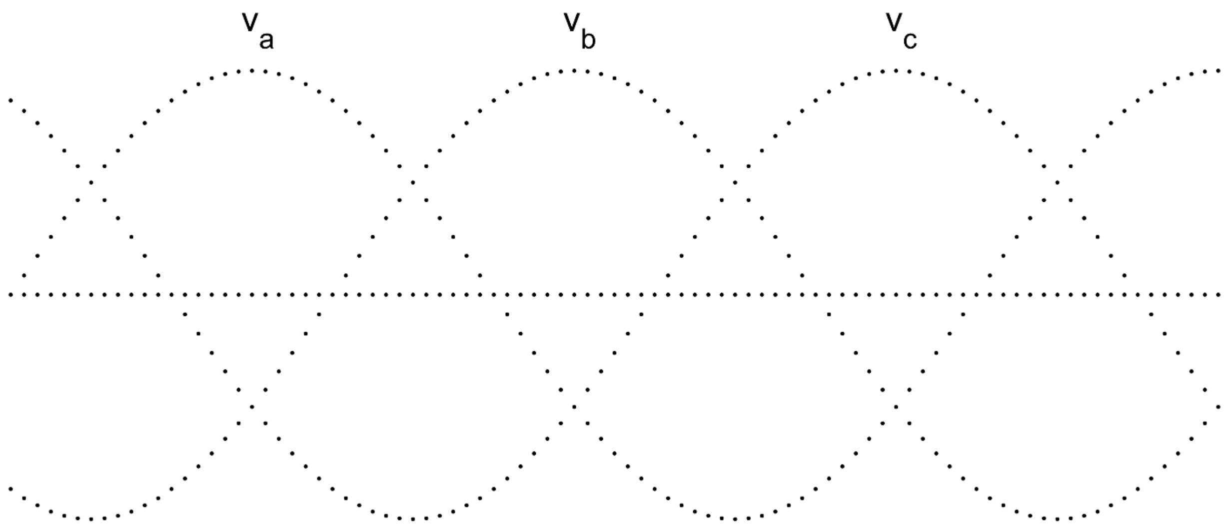
$$\frac{1}{T}\int_{t_0}^{t_0+T} f(x)dx = \frac{1}{6}\left(f(t_0) + 4f(t_0 + \frac{T}{2}) + f(t_0 + T)\right)$$

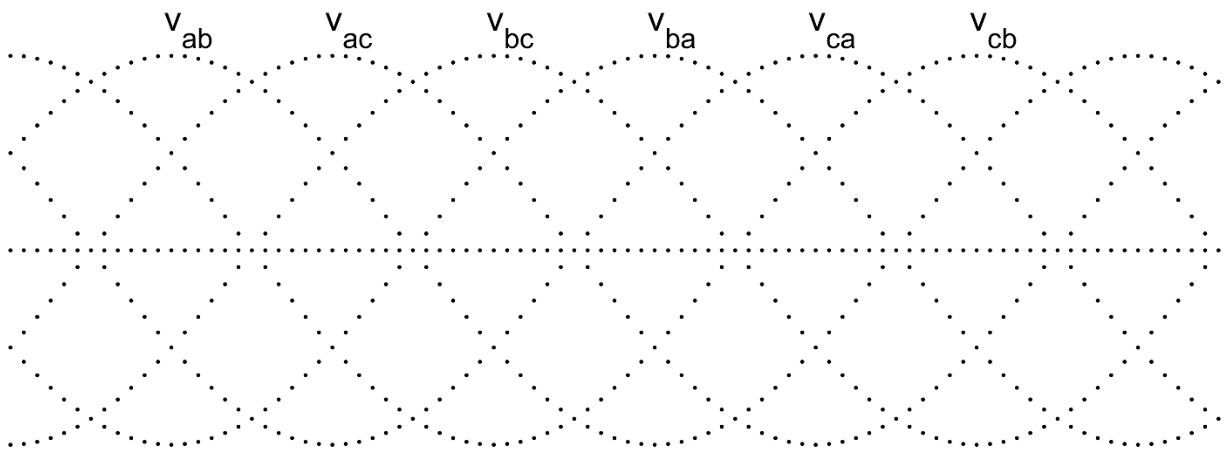


v_a
v_b
v_c



v_{ab}
v_{ac}
v_{bc}
v_{ba}
v_{ca}
v_{cb}


v_a
v_b
v_c


v_{ab}
v_{ac}
v_{bc}
v_{ba}
v_{ca}
v_{cb}