Tutorial–2

Dr. Suneel Kommuri

Email: Suneel.Kommuri@xjtlu.edu.cn

Dept. Electrical & Electronic Engineering

Problem 6.1

Q1) An ac voltage controller has a resistive load of $R = 10\Omega$ and rms input voltage is $V_s = 120\,V, 60$ Hz. The thyristors switch is ON for $n = 25$ cycles and is OFF for $m = 75$ cycles. Determine the (a) rms output voltage, V_{RMS}; (b) input power factor, and (c) average and rms current of thyristors.

Solution:

$R = 10\Omega, V_s = 120\,V, V_m = \sqrt{2} \times 120 = 169.7\,V$ and

$k = \frac{n}{n+m} = \frac{25}{100} = 0.25.$

Problem 6.1

Solution:

a) rms output voltage, $V_{RMS} = V_s\sqrt{k} = 120\sqrt{\frac{25}{100}} = 60\,V$

And the rms load current is, $I_{RMS} = \frac{V_{RMS}}{R} = \frac{60}{10} = 6\,A$

b) The load power is $P_o = I_{RMS}^2 R = 360\,W$. Since the input current is same as load current, the input VA is

$$VA = V_s I_s = V_s I_{RMS} = 120 \times 6 = 720\,W$$

The input power factor, PF = $\frac{P_o}{VA} = \frac{360}{720} = 0.5$

Problem 6.1

Solution:

c) The peak thyristor current is $I_m = \frac{V_m}{R} = 16.7\,A$. The average current of thyristor is

$$I_A = \frac{n}{2\pi(m+n)} \int_0^{\pi} I_m \sin\omega t \, d(\omega t) = \frac{I_m n}{\pi(m+n)} = \frac{kI_m}{\pi} = 1.35A$$

The rms current of thyristors is

$$I_R = \left[\frac{n}{2\pi(m+n)} \int_0^{\pi} I_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2} = \frac{I_m}{2}\sqrt{\frac{n}{n+m}} = 4.2A$$

Problem 6.2

Q2) A single-phase full-wave ac voltage controller has a load of 5 Ω and the input voltage is 230 V with 50 Hz. If the load power is 5 kW, determine (a) the firing angle, (b) input power factor, and (c) rms output voltage.

Solution:

a) The rms output voltage, $V_{RMS} = \frac{V_m}{\sqrt{2}}\left[\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2}$

The output power, $P_{out} = V_{RMS} I_{RMS} = \frac{{V_{RMS}}^2}{R} = 5000\ W$

$$\frac{230^2}{5}\left[\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right] = 5000 \rightarrow \alpha = 92.5^0 = 1.61 \text{ rad}$$

Lecture 6

Problem 6.2

Solution:

b) Input power factor, $\frac{P_{out}}{P_{in}} = \frac{5000}{V_s \times I_s} = \frac{5000}{230 \times 31.63} = 0.6871$

Input current, $I_s = I_{RMS} = \frac{5000}{V_{RMS}} = 31.63$ A

c) The rms output voltage,

$$V_{RMS} = \frac{V_m}{\sqrt{2}}\left[\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2} = 158.03\ V$$

Problem 7.1

Q3) A step-down dc-dc converter has a resistive load of 10 Ω and input voltage of 200 V. If the switching frequency is 1 kHz and duty cycle is 60%, determine (a) average output voltage and current, (b) rms output voltage and current.

Solution: $V_s = 200\,V, R = 10, f = 1\,kHz, k = 60\% = 0.6$

(a) Average output voltage, $V_o = kV_s = 0.6 \times 200 = 120\,V$

Average load current, $I_o = \frac{V_o}{R} = 12\,A$

(a) RMS output voltage, $V_{RMS} = \sqrt{k}V_s = 155\,V$

RMS load current, $I_{RMS} = \frac{V_{RMS}}{R} = 15.4\,A$

Problem 7.2

Q4) A 100 V step-down dc chopper has the maximum & minimum values of inductor current as 250 A and 50 A. The ON-time and OFF-time of chopper are 20 ms and 30 ms respectively. Determine (a) ripple current, (b) chopping frequency, (c) duty cycle, and (d) output voltage.

Solution:

(a) Ripple current, $\Delta I = I_2 - I_1 = 250 - 50 = 200\ A$

(b) Chopping frequency, $f = \frac{1}{T_{ON}+T_{OFF}} = \frac{1}{20\ ms+30\ ms} = 20\ Hz$

(c) Duty cycle, $k = \frac{T_{ON}}{T_{ON}+T_{OFF}} = 0.4$

(d) Output voltage, $V_o = kV_s = 0.4 \times 100 = 40\ V$

Problem 7.3

Q5) The buck-boost converter has an input voltage of $V_s = 12\,V$. The duty cycle $k = 0.25$ and the switching frequency is 25 kHz. The inductance $L = 150\,\mu H$ and the filter capacitance $C = 220\,\mu\text{F}$. The average load current $I_a = 1.25\,A$. Determine (a) the average output voltage V_a, (b) the peak-to-peak output voltage ripple, ΔV_c; (c) the peak-to-peak ripple current of inductor, ΔI, and (d) the critical values of L and C.

Solution:

$$V_s = 12\,V, k = 0.25, f = 25\,kHz, L = 150\,\mu H, C = 220\,\mu F$$

Problem 7.3

Solution:

a) The average output voltage, $V_a = -\frac{V_s k}{1-k} = -4V$

b) The peak-to-peak ripple voltage is $\Delta V_c = \frac{I_a k}{fC} = 56.8\, mV$

c) The peak-to-peak inductor ripple is $\Delta I = \frac{V_s k}{fL} = 0.8$ A

d) $\mathrm{R} = -\frac{\mathrm{V_a}}{\mathrm{I_a}} = 3.2\ \Omega$

$$L_C = L = \frac{(1-k)R}{2f} = 450\ \mu H$$

$$C_C = C = \frac{k}{2fR} = 1.56\ \mu F$$

Performance Parameters

The output of practical inverters contain harmonics & the quality of an inverter is normally evaluated in terms of these parameters:

- Harmonic factor of nth harmonic (HF_n): measure of individual harmonic contribution, is defined as

$$\text{HF}_n = \frac{V_{on}}{V_{o1}} \qquad \text{for } \ n > 1$$

where V_{o1} & V_{on} → rms values of fundamental & nth harmonic components.

- Total harmonic distortion (THD): measure of closeness in shape between a waveform and its fundamental component, is defined as

$$\text{THD} = \frac{1}{V_{o1}} \left(\sum_{n=2,3,\ldots}^{\infty} {V_{on}}^2 \right)^{1/2} = \frac{1}{V_{o1}} \left({V_o}^2 - {V_{o1}}^2 \right)^{1/2}$$

Performance Parameters

– Distortion factor (DF): gives total harmonic content, but does not indicate the level of each harmonic component.

$$\mathrm{DF} = \frac{1}{V_{o1}}\left[\sum_{n=2,3,..}^{\infty}\left(\frac{V_{on}}{n^2}\right)^2\right]^{1/2}$$

The DF of an individual (or nth) harmonic component is defined as

$$\mathrm{DF}_n = \frac{V_{on}}{V_{o1}n^2} \qquad \text{for } n > 1$$

– Lowest order harmonic (LOH): harmonic component whose frequency is closest to the fundamental one, and its amplitude is greater than or equal to 3% of the fundamental component.

Problem 8.1

Q6) The single-phase half-bridge inverter has a resistive load of $R = 2.4\,\Omega$ and the dc input voltage is $V_s = 48\,V$. Determine (a) the rms output voltage at the fundamental frequency V_{01}, (b) the output power P_o, (c) the average and peak currents of each transistor, (d) the average supply current I_s, (e) the THD, (f) the DF, (g) the HF and LOH.

Solution:

$$V_s = 48\,V, R = 2.4\,\Omega$$

a) $V_{01} = \frac{2V_s}{\sqrt{2}\pi} = 0.45 \times V_s = 0.45 \times 48 = 21.6\,V$

Problem 8.1

Solution:

b) The rms output voltage, $V_o = \frac{V_s}{2} = 24\,V$. The output power, $P_o = \frac{V_o^2}{R} = 240\,W$

c) The peak transistor current $I_p = \frac{24}{2.4} = 10\,A$. Because each transistor conducts for a 50% duty cycle, the average current of each transistor $I_Q = 0.5 \times 10 = 5\,A$

d) The average supply current, $I_s = \frac{P_o}{V_s} = \frac{240}{48} = 5\,A$

e) THD $= \frac{1}{V_{o1}}\left(V_o{}^2 - V_{o1}{}^2\right)^{1/2} = \frac{0.2176\,V_s}{0.45 V_s} = 0.4834 = 48.34\%$

Problem 8.1

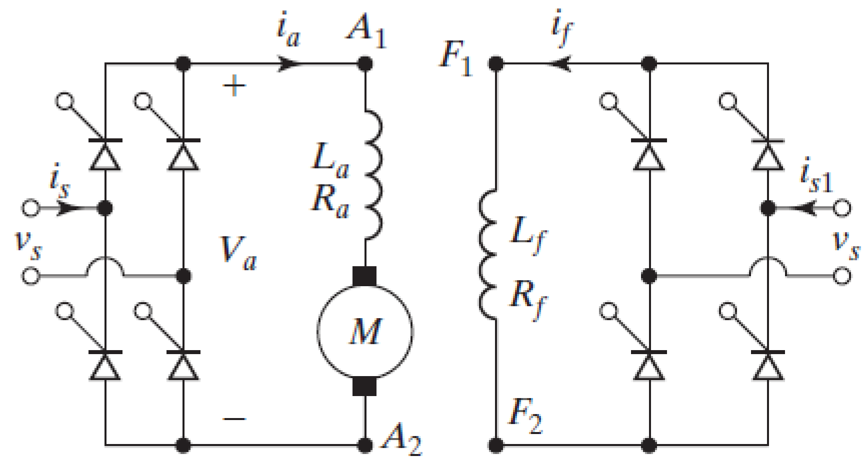
Solution:

f) DF$= \frac{1}{V_{o1}}\left[\sum_{n=3,5,..}^{\infty}\left(\frac{V_{on}}{n^2}\right)^2\right]^{1/2} = \frac{1}{0.45V_s}\left[\left(\frac{V_{o3}}{3^2}\right)^2+\left(\frac{V_{o5}}{5^2}\right)^2+\left(\frac{V_{o7}}{7^2}\right)^2+\cdots\right]^{1/2}$

$$= \frac{0.024V_s}{0.45V_s} = 5.38\%$$

g) LOH is the third harmonic, $V_{o3} = \frac{V_{o1}}{3} = 7.2\,V$. $\mathrm{HF}_3 = \frac{V_{o3}}{V_{o1}} = \frac{1}{3} = 33.33\%$. $\mathrm{DF}_3 = \frac{V_{o3}}{V_{o1}\times 3^2} = \frac{7.2}{21.6\times 9} = 3.704$. Because harmonic factor V_{o3}/V_{o1} is 33.33%, which is greater than 3%, LOH $= V_{o3}$.

Single-phase Full-converter Drives



- The armature voltage is varied by a single-phase full-wave converter.

- The average armature voltage, with a single-phase full-wave converter in the armature, as

$$V_a = \frac{2V_m}{\pi}\cos\alpha_a \quad \text{for } 0 \le \alpha_a \le \pi$$

- Similarly, the field voltage is,

$$V_f = \frac{2V_m}{\pi}\cos\alpha_f \quad \text{for } 0 \le \alpha_f \le \pi$$

- For three-phase full-wave converter,
  – the average armature voltage, $V_a = \frac{3\sqrt{3}V_m}{\pi}\cos\alpha_a \quad \text{for } 0 \le \alpha_a \le \pi$
  – the average field voltage, $V_f = \frac{3\sqrt{3}V_m}{\pi}\cos\alpha_f \quad \text{for } 0 \le \alpha_f \le \pi$

Problem 8.2

Q7) The speed of a separately excited motor is controlled by a single-phase full-wave converter. The field circuit is also controlled by a full converter and the field current is set to the maximum possible value. The ac supply voltage to the armature and field converters is one-phase, 440 V, 60 Hz. The armature resistance us $R_a = 0.25\,\Omega$, the field circuit resistance is $R_f = 175\,\Omega$, and the motor voltage constant is $K_v = 1.4$ V/A rad/s. The armature current corresponding to the load demand is $I_a = 45$ A. If the delay angle of the armature converter is $\alpha_a = 60^0$ and the armature current is $I_a = 45$ A. Determine (a) the torque developed by the motor T_d, (b) the speed and (c) total input power.

Problem 8.2

Solution:

$V_s = 440\,V, V_m = \sqrt{2} \times 440 = 622.25\,V, R_a = 0.25\,\Omega,\ R_s = 175\,\Omega, \alpha_a = 60^0, K_v = 1.4$ V/A rad/s.

a) Field voltage in a single-phase full-wave converter,

$$V_f = \frac{2V_m}{\pi}\cos\alpha_f$$

Therefore, the maximum field voltage for $\alpha_f = 0$ is

$$V_f = \frac{2V_m}{\pi} = \frac{2 \times 622.25}{\pi} = 396.14\,V$$

Field current, $I_f = \frac{V_f}{R_f} = \frac{396.14}{175} = 2.26\,A$

Problem 8.1

Solution:

The developed torque is

$$T_d = T_L = K_v I_f I_a = 1.4 \times 2.26 \times 45 = 142.4 \text{ N.m}$$

The armature voltage is

$$V_a = \frac{2V_m}{\pi} \cos 60^0 = \frac{2 \times 622.25}{\pi} = 198.07\ V$$

The back emf is

$$E_g = V_a - I_a R_a = 198.07 - 45 \times 0.25 = 186.82 \text{ V}$$

Problem 8.1

Solution:

b) The speed from back EMF is, $\omega = \frac{E_g}{K_v I_f} = 59.04$

c) Assuming lossless converters, total input power from supply is

$$P_t = V_a I_a + V_f I_f = 198.07 \times 45 + 396.14 \times 2.26 = 9808.4\,W$$

See you in the next (final☺) class (May 12th)

- **Probably Revision – Don't miss!!**
- **Please finish MQ feedback**

The End