Second Semester Examination
2018/2019 Academic Session

June 2019

EEK373 – Advanced Power Electronics
(Elektronik Kuasa Lanjutan)

Duration : 3 hours
(Masa : 3 jam)

Please check that this examination paper consists of NINE (9) pages and SEVEN (7) page of printed appendix material before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi SEMBILAN (9) muka surat dan TUJUH (7) muka surat lampiran yang bercetak sebelum anda memulakan peperiksaan ini.]

Instructions: This question paper consists of **FIVE (5)** questions. Answer **ALL** questions. All questions carry the same marks.

[***Arahan:*** *Kertas soalan ini mengandungi* ***LIMA (5)*** *soalan. Jawab* ***SEMUA*** *soalan. Semua soalan membawa jumlah markah yang sama.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai.]

...2/-

1. (a) Describe and compare the operation of on-off control, phase control and cyclo-converter of AC-AC voltage converters. Sketch simple diagrams to illustrate the output of each converter.

Terang dan bandingkan operasi kawalan on-off, kawalan fasa dan cyclo-converter AC-AC penukar voltan. Lakarkan gambar rajah mudah gelombang keluaran bagi setiap penukar

(30 marks/*markah*)

(b) The AC voltage controller is used for heating resistive load of R = 5Ω and the input voltage Vs = 230V, 50Hz. The thyristor switch is on for n = 125 cycles and is off for m = 75 cycles. Determine;

Pengawal voltan AC-AC digunakan untuk pemanasan beban rintangan sebanyak R = 5Ω. Input voltan adalah Vs = 230V, 50Hz. Suis tiristor dihidupkan untuk n = 125 kitaran dan dimatikan untuk m = 75 kitaran. Tentukan;

(i) The rms output voltage, V_o
Nilai rms voltan keluaran, V_o

(10 marks/*markah*)

(ii) The input power factor, PF
Nilai faktor kuasa input, PF

(10 marks/*markah*)

(iii) The average and rms thyristor currents
Nilai purata dan rms arus thyristor

(10 marks/*markah*)

(c) A single phase full wave ac voltage controller has a resistive load of R =10 Ω and the input voltage is Vs = 230V, 50Hz. The delay angle of thyristor T1 and T2 are equal: α1 = α2 = α = π/3. Determine

Suatu fasa tunggal pengawal AC gelombang penuh mempunyai beban rintangan R = 10 Ω dengan nilai voltan masukan Vs = 230V, 50Hz. Sudut kelewatan bagi tiristor T1 dan T2 adalah sama. Tentukan:

(i) Rms output voltage V_o

Nilai rms voltan keluaran, V_o

(10 marks/*markah*)

(ii) The input power factor PF

Nilai faktor input kuasa PF

(10 marks/*markah*)

(iii) The average current of thyristor

Nilai purata arus tiristor

(10 marks/*markah*)

(iv) The rms current of thyristor

Nilai rms arus tiristor

(10 marks/*markah*)

2. (a) A three-phase, 6-step inverter feeds a 3-wire load that is delta-connected. The inverter has a low-ripple DC input of 1410 V and delivers power to the load at 60 Hz.

Satu tiga fasa, 6-langkah penyongsang dibekalkan ke satu 3-dawai beban yang mempunyai sambungan delta. Penyongsang tersebut mempunyai masukan DC sebanyak 1410 V di mana riak adalah rendah dan ia menghantar kuasa ke beban pada frekuensi 60 Hz.

(i) Sketch a circuit diagram of the inverter including DC supply, switching devices, feedback diodes and load.

Lakarkan satu gambarajah litar bagi penyongsang tersebut. Lakaran anda perlu mengandungi bekalan DC, peranti pensuisan, diod suapan dan beban.

(20 marks/*markah*)

(ii) Sketch line-to-line output voltage waveform at terminal *ab* and determine its rms value.

Lakarkan bentuk gelombang bagi voltan keluaran talian pada pangkalan ab dan tentukan nilai rms voltan tersebut.

(20 marks/*markah*)

(iii) Use Fourier analysis to find the rms value of the fundamental for the waveform in part (ii).

Dengan menggunakan analisis Fourier, dapatkan nilai rms asasi bagi bentuk gelombang di bahagian (ii).

(29 marks/*markah*)

(iv) Find the THD of the waveform in part (ii).

Dapatkan nilai THD bagi bentuk gelombang di bahagian (ii).

(15 marks/*markah*)

(b) List four issues encountered in electrical system due to the disturbances caused by harmonics.

Senaraikan empat isu yang dihadapi oleh sistem elektrik disebabkan oleh gangguan akibat harmonik.

(16marks/*markah*)

3. A boost converter is operating at fixed frequency at 100 kHz with a duty cycle and is fed by a 100 V low-ripple DC source and delivers 150 V at a nominal power output of 300 W. The inductor has a peak-to-peak current that is 100 % of the average current. The output voltage ripple is negligible.

Satu penukar boost beroperasi pada frekuensi 100 kHz dengan kitar tugas dan disuapkan oleh satu bekalan voltan sebanyak 100 V di mana riak adalah rendah. Penukar tersebut menghantar 150 V pada kuasa keluaran namaan sebanyak 300 W. Pearuh tersebut mempunyai arus puncak-ke-puncak sebanyak 100 % daripada purata arus. Riak voltan keluaran boleh diabaikan.

(i) Sketch a circuit diagram and label important voltages and currents.

Lakarkan satu gambarajah litar dan labelkan voltan dan arus yang utama.

(20 marks/*markah*)

(ii) What is the value of load resistor?

Apakah nilai beban perintang?

(14 marks/*markah*)

(iii) Sketch inductor voltage and current waveforms.

Lakarkan bentuk gelombang bagi voltan dan arus pearuh.

(30 marks/*markah*)

(iv) What is the value of the inductor?

Apakah nilai pearuh?

(20 marks/*markah*)

(b) List four ripple effects on electrical equipment.

Senaraikan empat kesan riak yang ada pada peralaan elektrik.

(16 marks/*markah*)

4. (a) The series resonant inverter in Figure Q 4 (a) has $L_1 = L_2 = L = 50\ \mu H$, C = 6 µF and R = 2 Ω. The dc input voltage is V_s = 220 V and the frequency of output voltage is f_o = 7 kHz. The turn-off time of the transistor is t_{off} = 10 µs and the rms load current is 44.1 A.

Siri litar penyongsang resonan seperti ditunjukkan dalam Rajah Q 4 (a), mempunyai $L_1 = L_2 = L = 50\ \mu H$, $C = 6\ \mu F$ dan $R = 2\ \Omega$. Voltan masukan dc adalah $V_s = 220$ V dan frekuensi voltage keluaran adalah $f_o = 7$ kHz. Masa mematikan transistor adalah $t_{off} = 10\ \mu s$ dan nilai rms arus beban adalah 44.1 A.

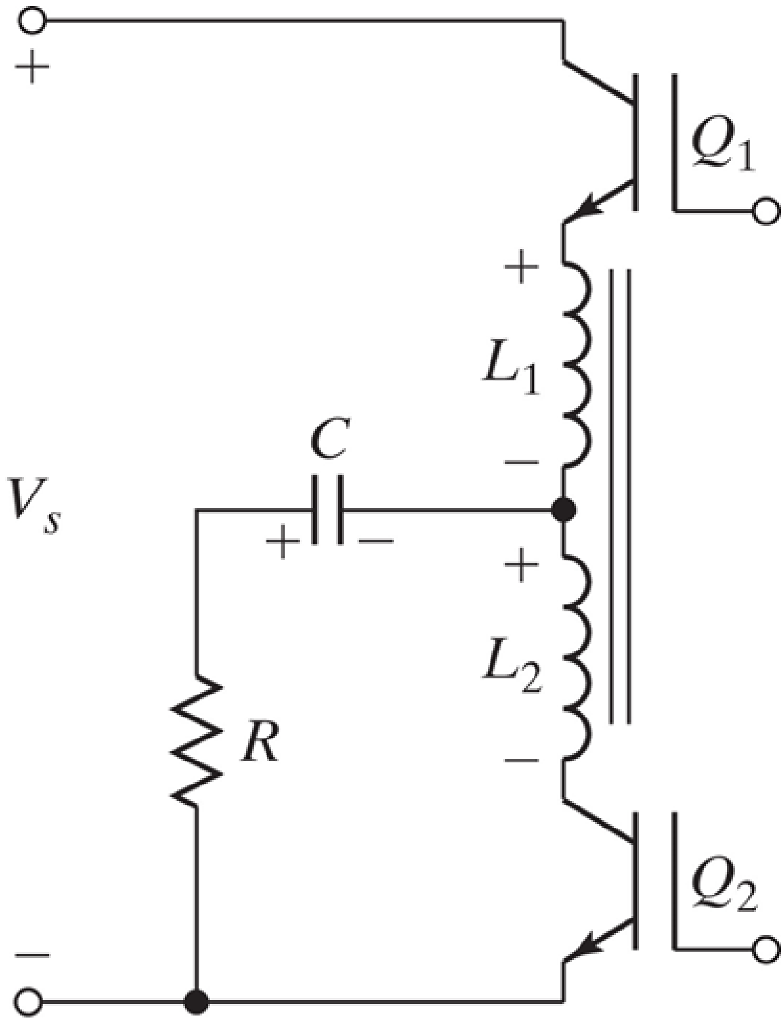

Figure Q 4 (a)
Rajah Q 4 (a)

(i) Determine the circuit turn-off time t_{off}

Tentukan masa mematikan litar t_{off}

(10 marks/*markah*)

(ii) Determine the maximum permissible frequency f_{max}

Tentukan frekuensi maksimum yang dibenarkan f_{max}

(10 marks/*markah*)

(iii) Determine the peak to peak capacitor voltage V_{pp}

Tentukan voltan puncak ke puncak kapasitor V_{pp}

(10 marks/*markah*)

(iv) Determine the peak load current I_p

Tentukan arus puncak beban I_p

(10 marks/*markah*)

(v) Determine the output power P_o

Tentukan kuasa keluaran P_o

(5 marks/*markah*)

(vi) Determine the average supply current I_s

Tentukan arus purata bekalan I_s

(5 marks/*markah*)

(b) The switches of a zero-current switching (ZCS) resonant converter turn on and off at zero current. It normally consists of a power electronic switches, inductor and capacitor.

Suis-suis penukar sifar semasa (ZCS) resonan menghidupkan dan mematikan pada keadaan arus sifar. Ia biasanya terdiri daripada suis-suis elektronik kuasa, induktor dan kapasitor.

(i) Sketch the switch types, Half-wave types and Full-wave types configuration of ZCS resonant converter

Lakarkan jenis-jenis suis, gelombang separuh dan gelombang penuh konfigurasi penukar resonan ZCS

(30 marks/*markah*)

(ii) Sketch the circuits of L-type and M-type zero current switching resonant converter.

Lakarkan litar jenis-L dan jenis-M penukar sifar resonan pensuisan arus.

(20 marks/*markah*)

5. (a) Figure Q 5 (a) shows an example of Forward converter.

Rajah Q 5 (a) menunjukkan satu contoh penukar hadapan.

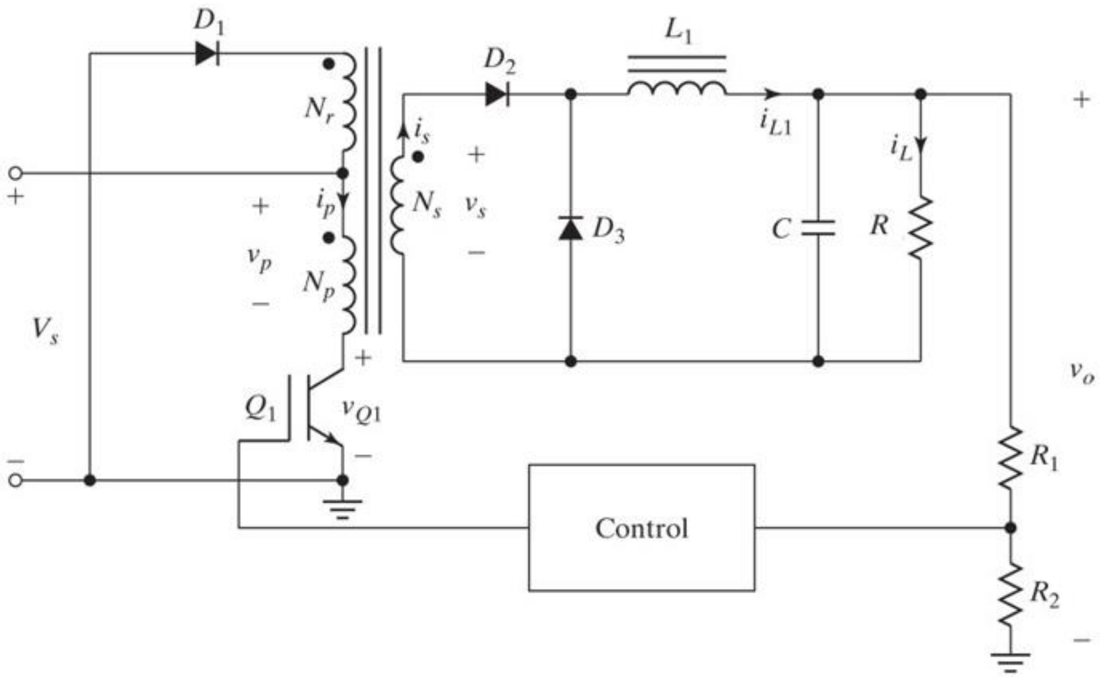

Figure Q 5 (a)
Rajah Q 5 (a)

(i) Sketch waveforms of primary voltage V_P, transistor Q1 voltage V_{Q1}, primary current I_p, current of diode D3 I_{D3}, current of inductor I_L and output voltage V_o

Lakarkan bentuk gelombang voltan utama V_p, voltan transistor Q1 V_{Q1}, arus utama I_p, arus diode D3 I_{D3}, arus induktor I_L dan voltan keluaran V_o

(30 marks/*markah*)

(ii) List 4 differences between a Flyback and Forward converter

Senaraikan 4 perbezaan antara penukar Flyback dan Forward

(20 marks/*markah*)

(b) The AC power supplies are commonly used as standby sources for critical loads and in applications where normal ac supplies are not available. The standby power supplies are also known as Uninterruptible power supply (UPS).

Bekalan kuasa AC biasanya digunakan sebagai sumber siap sedia untuk beban kritikal dan di dalam aplikasi di mana bekalan AC tidak tersedia. Bekalan kuasa siap sedia juga dikenali sebagai bekalan kuasa tidak terganggu.

(i) Draw two configuration of commonly used in Uninterruptible power supply or UPS systems

Lakarkan dua konfigurasi yang biasa digunakan dalam sistem bekalan kuasa tidak terganggu atau UPS

(30 marks/*markah*)

(ii) Explain briefly the operation of both configuration of UPS systems

Jelaskan secara ringkas operasi kedua-dua konfigurasi sistem UPS

(20 marks/*markah*)

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Course Outcomes (CO) – Programme Outcomes (PO) Mapping

Pemetaan Hasil Pembelajaran Kursus – Hasil Program

Questions *Soalan*	**CO**	**PO**
1	1	2
2	1	2
3	2	3
4	2	3
5	2	3

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1. **Formulae for AC-DC Converters (Rectifiers)**

$P_{dc} = V_0 I_0$	$V_{0,rms} = \frac{V_m}{\sqrt{2}}$
$P_{ac} = V_{ac} I_{ac}$	$I_{S,rms} = I_o$
$\eta = \frac{P_{dc}}{P_{ac}}$	$I_{S1,rms} = \frac{2\sqrt{2}}{\pi} I_o$
$V_{RL} = \sqrt{(V_{rms})^2 - (V_{dc})^2}$	$V_0 = \frac{V_m}{\pi}(1 + cos\alpha)$
$FF = \frac{V_{rms}}{V_{dc}}$	$V_{0,rms} = V_m \sqrt{\left[\frac{\pi - \alpha}{2\pi} + \frac{sin2\alpha}{4\pi}\right]}$
$RF = \frac{V_{ac}}{V_{dc}} = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1}$	$I_{S,rms} = I_o \sqrt{\left(1 - \frac{\alpha}{\pi}\right)}$
$TUF = \frac{P_{dc}}{V_S I_S}$	$I_{S1,rms} = \frac{2\sqrt{2}}{\pi} I_o \cos(\alpha/2)$
$DF = cos\alpha$	$V_0 = \frac{3\sqrt{3}V_m}{2\pi} cos\alpha = \frac{1.35V_{LL}}{2} cos\alpha$
$HF = \sqrt{\left(\frac{I_{S,rms}}{I_{S1,rms}}\right)^2 - 1}$	$V_0 = \frac{3\sqrt{3}V_m}{\pi} cos\alpha = 1.35V_{LL} \cdot cos\alpha$
$PF = \frac{I_{S1,rms}}{I_{S,rms}} cos\alpha$	$V_{0,rms} = \frac{3V_m}{2}\sqrt{\left[\frac{2}{3} + \frac{\sqrt{3}}{\pi} cos2\alpha\right]}$
$CF = \frac{I_{S(peak)}}{I_{S,rms}}$	$I_{S,rms} = \sqrt{\frac{2}{3}} \cdot I_o$
$P_i = V_{rms} \times I_{S1,rms} \times \cos(\alpha)$	$I_{S1,rms} = \frac{\sqrt{6}}{\pi} \cdot I_o$
$Q_i = V_{rms} \times I_{S1,rms} \times \sin(\alpha)$	$\overline{V_o}\big\|_{L_S \neq 0} = \overline{V_o}\big\|_{L_S = 0} - 6 f_S L_S I_o$
$V_0 = \frac{V_m}{2\pi}(1 + cos\alpha)$	$\mu = cos^{-1}\left[cos\alpha - \frac{2\omega L_S I_2}{\sqrt{2} \cdot V_{LL}}\right] - \alpha$
$V_{0,rms} = V_m \sqrt{\left[\frac{\pi - \alpha}{4\pi} + \frac{sin2\alpha}{8\pi}\right]}$	$V_0 = \frac{1.35V_{LL}}{2}(1 + cos\alpha)$
$V_0 = \frac{2V_m}{\pi} cos\alpha$	

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2. Formulae for AC voltage Controllers

$V_{0,rms} = V_S\sqrt{k}, \ and \ \sqrt{k} = \sqrt{\frac{n}{n+m}}$	$V_{0,rms} = V_S\sqrt{\left[\frac{\beta-\alpha}{\pi} + \frac{sin2\alpha}{2\pi} + \frac{sin2\beta}{2\pi}\right]}$
$V_{0,rms} = V_S\sqrt{\left[\frac{\pi-\alpha}{\pi} + \frac{sin2\alpha}{2\pi}\right]}$	$i_1 = \frac{\sqrt{2}V_S}{Z}\left[\sin(\omega t-\theta) - \sin(\alpha-\theta)e^{\left(\frac{R}{L}\right)\left(\frac{\alpha}{\omega}-t\right)}\right]$
$PF = \frac{V_{0,rms}}{V_S} = \sqrt{\left[\frac{\pi-\alpha}{\pi} + \frac{sin2\alpha}{2\pi}\right]}$	$\sin(\beta-\theta) = \sin(\alpha-\theta)e^{\left(\frac{R}{L}\right)(\alpha-\beta)/\omega}$
$I_{A(thy)} = \frac{V_m}{2\pi R}(1+cos\alpha)$	$\delta = \beta - \alpha$
$I_{rms(thy)} = \frac{V_m}{2R}\sqrt{\left[\frac{\pi-\alpha}{\pi} + \frac{sin2\alpha}{2\pi}\right]}$	$I_{o,rms} = \sqrt{(I_R)^2 + (I_R)^2} = \sqrt{2}\cdot I_R$
The rms thyristor current; $I_R = \frac{V_S}{Z}\sqrt{\frac{1}{\pi}\int_{\alpha}^{\beta}\left[\sin(\omega t-\theta) - \sin(\alpha-\theta)\,e^{\left(\frac{R}{L}\right)\left(\frac{\alpha}{\omega}-t\right)}\right]^2 d(\omega t)}$	
The average thyristor current; $I_A = \frac{\sqrt{2}V_S}{2\pi Z}\int_{\alpha}^{\beta}\left[\sin(\omega t-\theta) - \sin(\alpha-\theta)\,e^{\left(\frac{R}{L}\right)\left(\frac{\alpha}{\omega}-t\right)}\right] d(\omega t)$	
RMS output voltage in range 1: $V_{0,rms} = V_1\sqrt{\left[\frac{\pi-\alpha}{\pi} + \frac{sin2\alpha}{2\pi}\right]}$	RMS output voltage in range 2: $V_{0,rms} = (V_1+V_2)\cdot\sqrt{\left[\frac{\pi-\alpha}{\pi} + \frac{sin2\alpha}{2\pi}\right]}$
RMS output voltage in range 3: $V_{0,rms} = \sqrt{\left[\frac{(V_1)^2}{\pi}\left(\alpha - \frac{sin2\alpha}{2\pi}\right) + \frac{(V_1+V_2)^2}{\pi}\left(\pi - \alpha + \frac{sin2\alpha}{2}\right)\right]}$	
$i_o = \frac{\sqrt{2}V_1}{Z}\sin(\omega t-\theta)$	$Z = \sqrt{R^2 + (\omega L)^2}$
$VA = V_1I_1 + V_2I_2$	$I_1 = \sqrt{\left(\sqrt{2}\cdot I_{T1}\right)^2 + \left(\sqrt{2}\cdot I_{T3}\right)^2} \quad and \quad I_2 = \sqrt{2}\cdot I_{T1}$
Peak value of output voltage of cycloconverter: $V_P = \frac{2\sqrt{2}V_S}{\pi} = \sqrt{2}V_o$	RMS output voltage of cycloconverter: $V_o = \frac{2V_S}{\pi} = \frac{V_P}{\sqrt{2}}$

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3. Formulae for DC-AC Inverters

$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i_o^2(t)dt}$	$v_o(\omega t) = \sum_{n=1,3,5}^{\infty} \frac{4V_S}{n\pi}\sin\left(\frac{nD\pi}{2}\right)\cos\left(n\omega t - \frac{nD\pi}{2}\right)$
$I_o = \frac{V_{dc}\left(1-e^{-\frac{T}{2\tau}}\right)}{R\left(1+e^{-\frac{T}{2\tau}}\right)}$	$V_{H,rms} = \sqrt{(V_{rms})^2 - \left(V_{1,rms}\right)^2}$
$i_o(t) = \frac{V_{dc}}{R} - \left(I_o + \frac{V_{dc}}{R}\right)e^{-\frac{T}{2\tau}}$ *For time interval 0 to T/2*	$THD_V = \frac{\sqrt{(V_{rms})^2 - \left(V_{1,rms}\right)^2}}{V_{1,rms}}$
$i_o(t) = -\frac{V_{dc}}{R} + \left(I_o + \frac{V_{dc}}{R}\right)e^{-\frac{T}{2\tau}}$ *For time interval T/2 to T*	$THD_I = \frac{\sqrt{\sum_{n=2}^{\infty}\left(I_{n,rms}\right)^2}}{I_{1,rms}}$
$I_1 = \frac{V_{dc}}{R}\cdot\frac{\left(e^{-\frac{(1-D)T}{2\tau}} - e^{-\frac{T}{2\tau}}\right)}{\left(1+e^{-\frac{T}{2\tau}}\right)}$	$HF_n = \frac{V_{n,rms}}{V_{1,rms}}$
$I_2 = -I_1 e^{-\frac{DT}{2\tau}} + \frac{V_{dc}}{R}\left(1-e^{-\frac{DT}{2\tau}}\right)$	$\lvert Z_n\rvert = \sqrt{R^2 + (n\omega_1 L)^2}$
$i_o(t) = -I_1 e^{-\frac{t}{\tau}} + \frac{V_{dc}}{R}\left(1-e^{-\frac{t}{\tau}}\right)$ *For time interval t_o to t_2*	$I_{n,rms} = \frac{V_{n,rms}}{\lvert Z_n\rvert}$
$i_o(t) = \left[-I_1 e^{-\frac{DT}{2\tau}} + \frac{V_{dc}}{R}\left(1-e^{-\frac{DT}{2\tau}}\right)\right]e^{-\frac{t}{\tau}}$ *For time interval t_2 to t_3*	$P = \sum_{n=1,3,5}^{\infty} V_{n,rms}I_{n,rms}\cos\varphi_n$
$V_{n,rms} = \frac{4V_S}{\sqrt{2}n\pi}$	For 180° conduction: $V_{n,rms(l-l)} = \frac{2\sqrt{2}V_S}{n\pi}\sin\left(\frac{n\times 120}{2}\right) = \frac{\sqrt{6}V_S}{n\pi}$
$V_{n,rms} = \frac{4V_S}{\sqrt{2}n\pi}\sin\left(\frac{nD\pi}{2}\right)$	For 180° conduction: $V_{rms\,(l-l)} = \sqrt{2/3}\cdot V_S = 0.8165\cdot V_S$
$DF = \frac{1}{V_{1,rms}}\sqrt{\sum_{n=3,5}^{\infty}\left(\frac{V_{n,rms}}{n^2}\right)^2}$	For 120° conduction: $V_{n,rms(l-l)} = \frac{\sqrt{2}V_S}{n\pi}\left(1+\cos\left(\frac{n\pi}{2}\right)\right)$
$v_{rms} = \sqrt{D}V_S$	For 120° conduction: $V_{rms\,(l-l)} = V_S/\sqrt{2} = 0.707\cdot V_S$
$v_o(\omega t) = \sum_{n=1,3,5}^{\infty}\frac{4V_S}{n\pi}\sin(n\omega t)$	$DF = \frac{V_{1rms(l-l)}}{V_{rms(l-l)}}$, *and* $HF = \sqrt{\frac{1}{DF^2} - 1}$

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4. **Formulae for DC-DC Converters**

$V_o = DV_S$	$\Delta V_o = \frac{DV_o}{RCf}$
$\Delta i_L = \frac{V_S - V_o}{L} DT$	$V_o = \frac{DV_S}{1-D}$
$I_{L,max} = \left[\frac{V_o}{R} + \frac{V_o(1-D)}{2Lf}\right]$	$I_L = \frac{V_S D}{R(1-D)^2}$
$I_{L,min} = \left[\frac{V_o}{R} - \frac{V_o(1-D)}{2Lf}\right]$	$I_S = DI_L$
$L \geq \frac{(1-D)R}{2f}$	$I_{L,max} = \left[\frac{V_S D}{R(1-D)^2} + \frac{V_S D}{2Lf}\right]$
$V_o = \frac{D}{D+\Delta} V_S$	$I_{L,min} = \left[\frac{V_S D}{R(1-D)^2} - \frac{V_S D}{2Lf}\right]$
$\Delta V_o = \frac{(1-D)V_o}{8LCf^2}$	$L \geq \frac{(1-D)^2 R}{2f}$
$V_o = \frac{V_S}{1-D}$	$V_o = \frac{D}{\Delta_1} V_S$
$\Delta i_L = \frac{V_S}{L} DT$	$\Delta i_{L2} = \frac{V_S}{L_2} DT$
$I_L = \frac{V_S}{R(1-D)^2}$	$\Delta i_{L1} = \frac{V_S}{L_1} DT$
$I_{L,max} = \left[\frac{V_S}{R(1-D)^2} + \frac{V_S D}{2Lf}\right]$	$\Delta V_{C1} = \frac{DV_o}{RC_1 f}$
$I_{L,min} = \left[\frac{V_S}{R(1-D)^2} - \frac{V_S D}{2Lf}\right]$	$I_{L,rms} = \sqrt{(I_L)^2 + \left(\frac{\Delta i_L/2}{\sqrt{3}}\right)^2}$
$L \geq \frac{D(1-D)^2 R}{2f}$	$\Delta V_{C1} = \frac{I_S(1-D)}{fC_1}$
$V_o = \frac{\Delta_1}{\Delta_1 + D} V_S$	$\Delta V_{C2} = \frac{V_S D}{8f^2 L_2 C_2}$

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5. Formulae for Resonant Converters

$\alpha = \frac{R}{2L}$	$V_C^+ = V_C^- = V_S\left(\frac{e^Z+1}{e^Z-1}\right)$
$\omega_o = \frac{1}{\sqrt{CL}}$	$V_{C1}^- = -V_S\left(\frac{e^{2Z}-1}{e^{2Z}+1}\right)$
$\omega_o = \frac{1}{\sqrt{2CL}}$	$V_{C2}^+ = V_S\left(\frac{(e^Z+1)^2}{e^{2Z}+1}\right)$
$\omega_r = \sqrt{(\omega_o)^2 - (\alpha)^2}$	$I_p = \frac{V_S - V_{C1}^-}{L\omega_r} e^{-\alpha t_m}\sin(\omega_r t_m)$
$\omega_r = \sqrt{\left(\frac{1}{\sqrt{CL}}\right)^2 - \left(-\frac{1}{2RC}\right)^2}$	$\alpha = -\frac{1}{2RC}$
$Z_o = \sqrt{\frac{L}{C}}$	$i_o(t) = \frac{I_S}{C\omega_r} e^{-\alpha t}\sin(\omega_r t)$
$\int e^{ax}\sin bx\,dx = \frac{e^{ax}(a\sin bx + b\cos bx)}{a^2+b^2}$	$G(j\omega) = \frac{V_o}{V_1}(j\omega) = \frac{1}{1+jQ\left(\frac{\omega}{\omega_o}-\frac{\omega_o}{\omega}\right)}$
$i_o(t) = \frac{V_S + V_{Co}}{L\omega_r} e^{-\alpha t}\sin(\omega_r t)$	$G(j\omega) = \frac{V_o}{V_1}(j\omega) = \frac{1}{\left[1-\left(\frac{\omega}{\omega_o}\right)^2\right] + j\left(\frac{\omega}{\omega_o}\right)/Q}$
$V_{Co} = V_{C1}e^{-\alpha\pi/\omega_r}$ $V_{C1} = (V_S + V_{Co})e^{-\alpha\pi/\omega_r} + V_S$	$\frac{V_{o3}}{V_{i3}} = \sqrt{\frac{1}{1+Q^2\left(\frac{3\omega_o}{\omega_o}-\frac{\omega_o}{3\omega_o}\right)^2}}$
$t_m = \frac{1}{\omega_r}\tan^{-1}\left(\frac{\omega_r}{\alpha}\right)$	$Q = \frac{1}{CR\omega_o}$
$i_o(t) = \frac{V_S - V_{C1}^-}{L\omega_r} e^{-\alpha t}\sin(\omega_r t)$	$V_{C,peak} = \frac{V_1}{CR\omega_o}$
$I_A = -\frac{f_o(V_S - V_{C1}^-)C}{\omega_r}(\alpha e^{-\alpha t}\sin(\omega_r t) + \omega_r e^{-\alpha t}\cos(\omega_r t) - \omega_r)$	

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6. **Formulae for DC/AC Power Supplies**

$V_o = 2\frac{N_2}{N_1}DV_S$	$P_o = \eta P_i = I_P(av)\eta DV_S$
$I_P(av) = \frac{2P_o}{\eta DV_S}$	$\frac{V_o}{V_S} = \frac{D}{1-D}\left(\frac{N_S}{N_P}\right)$
$I_P(av) = \frac{P_o}{\eta DV_S}$	$I_{Lm} = \frac{V_o}{(1-D)R}\left(\frac{N_S}{N_P}\right)$
$P_o = \eta P_i = \frac{I_P(av)\eta DV_S}{2}$	$L_m = \frac{V_S DT}{\Delta i_{Lm}}$
$L_o = \frac{V_o(1-D)T}{\Delta i_{Lo}}$	$L_m \geq \frac{(1-D)^2 R}{2f}\left(\frac{N_P}{N_S}\right)^2$
$V_o = \frac{N_2}{N_1}DV_S$	$C_{min} = \frac{D}{Rf(\Delta V_o/V_o)}$
$I_C(max) = I_P(av) = \frac{2P_o}{\eta DV_S}$	$I_P = I_S$
$I_C(max) = I_P(av) = \frac{P_o}{\eta DV_S}$	$I_R = \sqrt{D}I_S$