BENGKEL KOMPONEN MAGNETIK DAN ELEKTRONIKA DAYA

HALF-BRIDGE DC-DC CONVERTER

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PROJECT WORK HALF-BRIDGE DC-DC CONVERTER 2021
(UNTUK NRP GENAP)

The Half-Bridge DC-DC Converter has following parameters :
V_S = 100 Volt
V_O = 19 Volt
I_O= 3 A
Duty cycle = 0.4
Switching Frekuensi (f_S) = 40 kHz

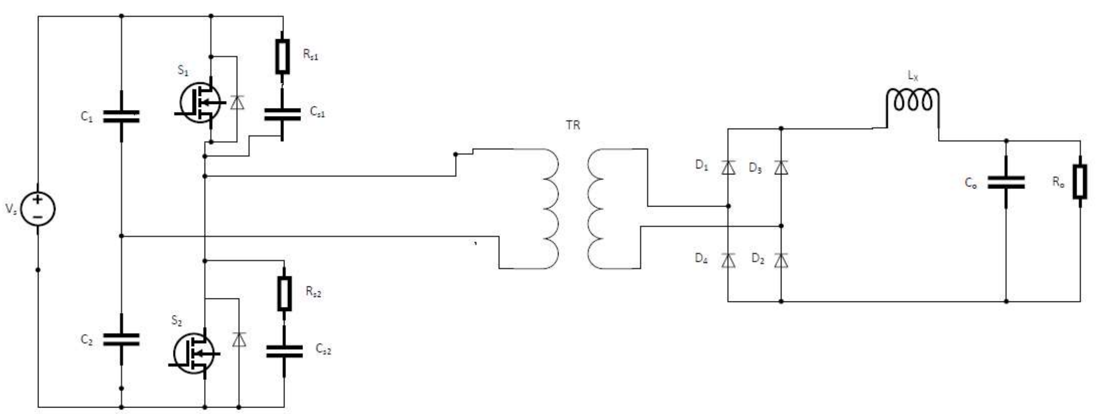

Figure 1. Half-Bridge DC-DC Converter Circuit
(created with Microsoft Visio app)

Component:

$S_1 = S_2$: MOSFET IRFP460(tf=75 ns based on datasheet)
$C_1 = C_2$: 470uF, 400 Volt
$D_1 = D_2 = D_3 = D_4$: MUR 1560 (Ultra Fast Recovery Diode) V_f = 1.5 volt(based on datashet MUR1560)
Inductor (L_x) : Ferrit Core PQ 3230 with Cross sectional are (A_c=1.61cm^2);
Bobbin diameter (D_{bob1} = 16 mm)
Transformer (TR) : Ferrit Core PQ 3535 with Cross sectional are (A_c=1.96cm$_2$);
Bobbin diameter (D_{bob2} = 17 mm)
C_o : Output capacitor (Calculation), 50 Volt
$R_{s1} = R_{s1}$: Snubber resistor (470 Ω, 10 watt)
$C_{s1} = C_{s1}$: Snubber capacitor (10nf, 1 kVolt)

SOLUTION:

A. HIGH FREQUENCY INDUCTOR DESIGN

- **Ouput Voltage:**

  V_o=$V_{in} \times \frac{N_2}{N_1} \times$ D

  19=100 $\times \frac{N_2}{N_1}$ x 0.4

  $\frac{N_2}{N_1} = \frac{19}{40} = 0.475$

  $\frac{N_1}{N_2} = \frac{40}{19}$ =2.1

- **Filter inductor**

  $$L_x = \frac{1}{\Delta i L_x} \times \left(V_{in(a)} - V_o\right) \times \left(\frac{1}{2f_s}\right) \times \left(\frac{V_o + 2V_f}{V_{in} + 2V_f}\right)$$

  Where:

  $$V_{in(a)} = \frac{V_{in}}{2 \times \frac{N_1}{N_2} - 2V_F}$$

  Vin(α) = $\frac{100}{2\times 2.1-2(1.5)} = \frac{100}{4.2-3}$= 82.61 volt

  $\Delta i L_x = 20\% \times I_o$

  $\Delta i L_x = 20\% \times 3$

  $\Delta i L_x = 0.6\ A$

  $$L_x = \frac{1}{0.6} \times (82.61 - 19) \times \left(\frac{1}{80 \times 10^3}\right) \times \left(\frac{19 + 2(1.5)}{100 + 2(1.5)}\right)$$

  $L_x = 2.8305 \times 10^{-4}\ H \approx 284\ \mu H$

- **The maximum inductor current**

  $$i_{L(max)} = i_{L(avg)} + \frac{\Delta i L_x}{2}$$

  $$i_{L(avg)} = \frac{V_o}{R} = I_o$$

  I_o= $\frac{V_o}{R}$=$i_{L(avg)}$= 3A

  $$i_{L(max)} = 3 + \frac{0.6}{2}$$

  $i_{L(max)} = 3.3\ A$

- **Winding number of inductor**

$n = \frac{L \times i_{L(max)}}{B_{max} \times A_c} \times 10^4; B_{max} = 0.25\ T\ \ , A_c = 1.61\ cm^2$

$$n = \frac{2.8305 \times 10^{-4} \times 3.3}{0.25 \times 1.61} \times 10^4$$

$n = 23.21$

$n \approx 24\ turns$

- **Wire size is based on RMS current of inductor**

$$i_{L(rms)t} = \sqrt{{i_{L(avg)}}^2 + \left(\frac{\Delta i_L / 2}{\sqrt{3}}\right)^2}$$

$$i_{L(rms)t} = \sqrt{(3)^2 + (\frac{0,3}{\sqrt{3}})^2}$$

$$i_{L(rms)t} = \sqrt{9 + (0.173)^2}$$

$$i_{L(rms)t} = \sqrt{9 + 0.03}$$

$$i_{L(rms)t} = \sqrt{9.03} = 3.01\ \text{A}$$

- **Calculation of Wire Size**
    - ➢ Cross sectional Area of Wire(qw)

      $q_{w(L)} = \frac{i_{L(rms)t}}{J}$; J = 4.5 A/mm^2 (current density)

      $q_{w(L)} = \frac{3.01}{4.5} = 0.67\ mm^2$
    - ➢ Recalculate by assuming number of split wire(Σsplit)=10?

      $i_{L(rms)split} = \frac{i_{L(rms)split}}{\Sigma split_L} = \frac{3.005}{10} = 0.3$

      $q_{w(L)split} = \frac{i_{L(rms)split}}{J} = \frac{0.3}{3.4} = 0.066\ mm^2$

      $d_{w(L)split} = \sqrt{\frac{4}{\pi} \times\ q_{w(L)split}}\ \ mm^2$

      $d_{w(L)split} = \sqrt{1.27 \times\ 0.066} = \sqrt{0.0838} = 0.289\ mm$

- Recalculate split based on choosen wire diameter(0.3mm)

$d_{w(L)split}= \sqrt{\frac{4}{\pi} \times q_{w(L)split}}\ mm^2$

$0.3= \sqrt{\frac{4}{\pi} \times q_{w(L)split}}$

$0.09=1.273\times q_{w(L)split}$

$q_{w(L)split}=\frac{0.09}{1.273} =0.07$

$q_{w(L)split}=\frac{iL(rms)split}{J}$

$i_{L(rms)split} = J \times q_{w(L)split}$

$i_{L(rms)split} =0.07\times 4{,}5=0{,}315$ A

$i_{L(rms)split}=\frac{i_{L(rms)split}}{\Sigma \text{split}_L}$

$\Sigma\text{split}_L = \frac{i_{L(rms)t}}{i_{L(rms)split}} = \frac{3.01}{0.315} =9.6\approx 10$ split

- **Wire size**

Diameter of bobbin PQ3230(D_{bob1})=16mm=1.6cm

Circumference of Bobin(K_{bob1}) = $\pi \times D_{bob1}$

Circumference of Bobin = π x 1.6 = 5.024 cm

Total Wire Length = $\left(n_{(winding)} \times K_{bob1} \times \Sigma\text{split}_L\right) + 0.4\left(n_{(winding)} \times K_{bob1} \times \Sigma\text{split}_L\right)$

Total Wire Length = (24×5.024× 10)+40%× (24×0.24× 10)

Total Wire Length = (1205,76)+40%× (653.12) =1688 cm $\approx 17\ m$

- Air Gap Length

$$l_g = \frac{\mu_o \times L_x \times {I^2}_{max}}{{B^2}_{max} \times A_c} \times 10^4$$

$$l_g = \frac{4\pi \times 10^{-7} \times 284 \times 10^{-6} \times 3.3^2}{0.25^2 \times 1.61} \times 10^4$$

$$l_g = 0.0004\ m = 0.4\ mm =$$

B. **HIGH FREQUENCY TRANSFORMER DESIGN**

- **Ouput Voltage:**

V_o=$V_{in} \times \frac{N_2}{N_1} \times$ D

19=100 $\times \frac{N_2}{N_1} \times$ 0.4

$\frac{N_2}{N_1} = \frac{19}{40}$ = 0.475

$\frac{N_1}{N_2} = \frac{40}{19}$ =2.1

- **Number of primary winding:**

$N_{1(min)} = \frac{D \times T \times V_{in}}{2 \times B_{max} \times A_c} \times 10^4$ Bmax=0,25 Tesla; Ac=1.96 in cm^2

T=$\frac{1}{f} = \frac{1}{40k}$ = 0.000025 s

$$N_{1(min)} = \frac{0.4 \times 2.5 \times 10^{-5} \times 100}{2 \times 0.25 \times 1.96} \times 10^4$$

$N_{1(min)} = 10.2\ turns$

$N_1 = 2 \times N_{1(min)}$

N_1 = 2×10.2=20.4≈ 21 turns

- **Number of secondary winding:**

$N_2 = n \times N_1$;n=transformer ratio

$$N_2 = \frac{19}{40} \times 20.4$$

$N_2 = 9.69 \approx 10\ turns$

- **RMS Primary Current**:

$$I_{1,rms} = \frac{N_2}{N_1} \times I_o \times \sqrt{D}$$

$$I_{1,rms} = \frac{19}{40} \times 3 \times \sqrt{0.4}$$

$I_{1,rms} = 0.9\ A$

- **Primary wire size**

$s = 4.5\ ^{A}/_{mm^2}$

$$d_1 = \sqrt{\frac{4 \times I_{1,rms}}{\pi \times s}}$$

$$d_1 = \sqrt{\frac{4 \times 0.9}{\pi \times 4.5}}$$

$$d_1 = 0.51\ mm$$

- **Σ Split primary Winding calculation based on choosen wire size(0.4 mm)**

$d_{w(p)split}$=0,4 mm

$$d_{w(p)split} = \sqrt{\frac{4 \times q_{w(p)split}}{\pi}}$$

$$0.4 = \sqrt{\frac{4 \times q_{w(p)split}}{3.14}}$$

$$0.16 = \frac{4 \times q_{w(p)split}}{3.14}$$

$0.5 = 4 \times q_{w(p)split}$

$q_{w(p)split} = 0.125$ mm^2

$i_{1(rms)split} = J \times q_{w(p)split}$

$$0.125 = \frac{i_{1(rms)split}}{4.5}$$

$i_{1(rms)split}$=1.25x4.5 = 0.5625 A

$$i_{1(rms)split} = \frac{i_{1(rms)})}{\Sigma\text{Split}_p}$$

$$\Sigma\text{Split}_p = \frac{i_{1(rms)}}{i_{1(rms)split}} = \frac{0.9}{0.5625} = 1.6 \approx 2 \text{ split}$$

- **RMS secondary current:**

$$I_{2,rms} = \frac{1}{2} \times I_o \times \sqrt{1 + D}$$

$$I_{2,rms} = \frac{1}{2} \times 3 \times \sqrt{1.4}$$

$$I_{2,rms} = 1.77\ A$$

- **Secondary wire size**

$$d_2 = \sqrt{\frac{4 \times I_{2,rms}}{\pi \times s}}$$

$$d_2 = \sqrt{\frac{4 \times 1.77}{\pi \times 4.5}}$$

$$d_2 = 0.71\ mm$$

- **Σ Split secondary Winding calculation based on choosen wire size(0.4 mm)**

$d_{w(s)split}$=0.4 mm

$$d_{w(s)split} = \sqrt{\frac{4\times\ q_{w(s)split}}{\pi}}$$

$$0.4 = \sqrt{\frac{4\times\ q_{w(s)split}}{3.14}}$$

$$0.16 = \frac{4x\ q_{w(s)split}}{3.14}$$

$0.5 = 4 \times q_{w(s)split}$

$q_{w(s)split}$= 0.125 mm^2

$$q_{w(s)split} = \frac{i_{2(rms)split}}{J}$$

$$0.125 = \frac{i_{2(rms)split}}{4.5}$$

$i_{2(rms)split}$=1.25×4.5 = 0.5625 A

$$i_{2(rms)split} = \frac{i_{2(rms)}}{\Sigma \mathrm{Split}_s}$$

$$\Sigma \mathrm{Split}_s = \frac{i_{2(rms)}}{i_{2(rms)split}} = \frac{1.77}{0.5625} = 3.14\ \approx 4\ split$$

- **Induktor magnitasi(L_m)**

$$L_m = \frac{V_{c1} \times D \times T}{20\% \times (i_1 + \frac{N_2}{N_1} \times i_2)}$$

$$L_m = \frac{50 \times 0.4 \times 2.5 \times 10^{-5}}{20\% \times \left(0.9 + \frac{19}{40} \times 1.77\right)}$$

$$L_m = \frac{50 \times 10^{-5}}{20\% \times (1.425 + 0.475 \times 1.77)}$$

$$L_m = \frac{50\times10^{-5}}{0.45} = 111\times 10^{-5} = 11.1\ \mu H$$

- **Split Pattern**

  2 split primer

  4 split sekunder

  additional = 1split primer+2split sekunder

  pattern:

  P1S1S2 P2S3S4 P3S5S6

  Split 1 split 2 additional

- **Length of wire**

  Diameter of bobbin PQ3535(D_{bob2})=17 mm =1.7 cm

  Circumference of Bobbin (K_{bob2}) = $\pi \times D_{bob2}$=1.7×3.14=5.338 cm

  $$P_p = \left(N_p \times K_{bob2} \times \Sigma\text{Split}_p\right) + 0.3\left(N_p \times K_{bob2} \times \Sigma\text{Split}_p\right)$$

  Pp = (20.4×5.338×2)+0.3(20.4×5.338×2)

  Pp=21.8+65.33 = 283.13 cm≈ $2.9\ m$

  $$P_s = \left(N_s \times K_{bob2} \times \Sigma\text{Split}_s\right) + 0.3\left(N_s \times K_{bob2} \times \Sigma\text{Split}_s\right)$$

  P_s= (9.69×5.338×4)+0.3(9.69×5.338×4)

  P_s =206,9+62 =268,97 cm≈ $3\ m$

C. FILTER CAPASITOR OUPUT

$$\frac{\Delta V_o}{V_o} = \frac{1-D}{8\times L_x \times C_o \times (2f_s)^2}$$

$\Delta V_o = \pm$ 0,1% x Vo = 0,001 x Vo

$\Delta Vo = \pm$ 0,1% x Vo = 0,001 x 19 = 0,019

$$\frac{0.019}{19} = \frac{1-0.4}{8\times 2.8305\times10^{-4} \times Co \times (2\times 40k)^2}$$

$C_o = 4.14017 \times 10^{-5}\ F$

$C_o \approx 42\ \mu F$

Rekomendasi = 47 μF, 50v

- **R and C snubber**

Kondisi off-state(S1)

$V_{OFF} = V_{C1} - V_{Lx} - V_o$

$$V_{OFF} = \frac{V_s}{2} - L_x \frac{di_L}{dt} - V_o$$

Kondisi on-State(S1)

$I_{on} = I_{L(avg)} = I_o$

$$V_{OFF} = \frac{V_s}{2} - L_x \frac{f \times \Delta i_L}{D} - V_o$$

$$V_{OFF} = \frac{100}{2} - 2.8305 \times 10^{-4} \times \frac{40 \times 10^3 \times 0.6}{0.4} - 19$$

$V_{OFF} = 14.02\ V$

$I_{on} = I_o$ = 3A

T=$\frac{1}{f}$ = $\frac{1}{40k}$ = 0.000025 s

$$C_{snubber} \approx \frac{I_{on} \times t_{fall}}{2 \times V_{OFF}}$$

$$C_{snubber} = \frac{3 \times 75 \times 10^{-9}}{2 \times 14.02}$$

$C_{snubber} = 8.024 \times 10^{-9}\ F$

$C_{snubber} \approx 9\ nF$

Rekomendasi:$\mathrm{C_{snubber}} = 10$ nF, 1kV

$$R_{snubber} < \frac{DT}{2 \times C_{snubber}}$$

$$R_{snubber} < \frac{0.4 \times 2.5 \times 10^{-5}}{2 \times 8.024 \times 10^{-9}}$$

$R_{snubber} < 623\ \Omega$

$R_{snubber} \approx 470\ \Omega$,10 watt

$rekomendasi$: $R_{snubber} = 470\ \Omega$,10 watt