MATHCAD FOR forward(active clamp.plane core) 24V18A

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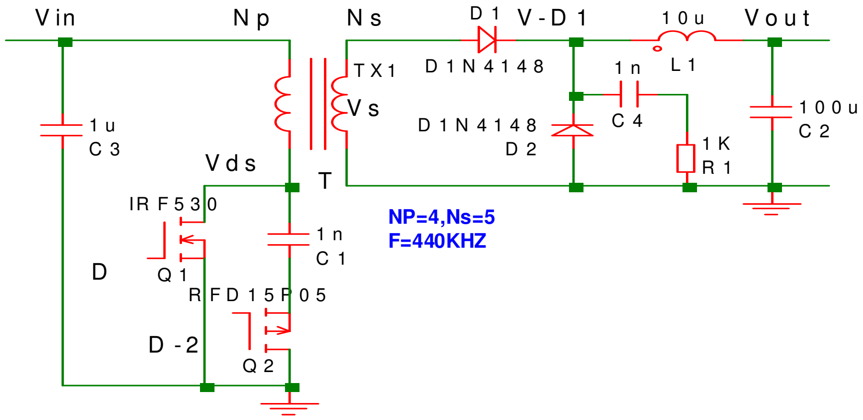


Purpose : This worksheet help to select the power components of forward series converter.

Usage of the worksheet : Please enter or change the value of parameters which highlighted in yellow color for the desired operating conditions.

Define the symbols

fs Switching frequency of the converter

Lp Primary inductance of power transformer

L1 inductor of inductance

D duty cycle of primary Q1,

Dpmax duty cycle of primary Q1 at Vin=Vimin

Npset Number of primary turns of power transformer

Nsset Number of secondary turns of power transformer

Vimax Input voltage of the converter

Vo Output voltage

Vs secondary voltage of power transformer winding

n Primary to secondary turn ratio of power transformer:Npset/Nsset

Poc output power limit:ocp

Po output power at full load

Reference:D:\My Documents\MATH\New Folder\Component_specification_Reference_with unit.mcd(R)

Reference:D:\My Documents\MATH\New Folder\WIRE_TABLE_UNIT_IMPROVED.MCD(R)

Reference:D:\My Documents\MATH\wire AWG calculation.mcd

contents page

1. Please enter or change the value of parameters which highlightedin yellow:

$Vimin := 36$ $Vimax := 58$ $fs := 400000$ $Vdio := 0.8$ $Vwinding := 0.2$

$Poc := 500$ $Vo := 24$ $Dpmax := 0.55$ $\eta := 0.92$ $Voringfet := 0.1$

$T := \frac{1}{fs}$ $T = 2.5 \times 10^{-6}$

$Dpmin := \frac{Vimin}{Vimax} \cdot Dpmax$ $Dpmin = 0.341$

Dpmin: duty cycle of primaryQ1 Q1,Q2,Q3,Q3 at Vimax0.57

2 . n & T & Ton & Vs calculation:

$Vs := Vo + Vdio + Vwinding$ $Vs = 25$ secondary winding voltage:

Np/Ns=Vin*Ton/Vs*T =Vin*Dp/Vs
so:

$ncal := Vimax \cdot \frac{Dpmin}{Vs}$ $ncal = 0.792$

$n := 0.8$

change Dpmin value make n is sharp
such:n=3,n=3.5, OR n=3.2

$THon := Dpmin \cdot T$ $THon = 8.534 \times 10^{-7}$ primary Q1 turn on time:s

$THoff := T - Dpmin \cdot T$ $THoff = 1.647 \times 10^{-6}$ primary Q1 turn off time:s

$Vx := 48$

$Dx := Dpmax \cdot \frac{Vimin}{Vx}$ $Dx = 0.413$ Vin=Vx 时的占空比

$Vout\_max := Vimax \cdot \frac{2 \times 0.44}{n}$ $Vout\_max = 63.8$ 失控时最大输出电压 :V

$Ioc := \frac{Poc}{Vo}$ $Ioc = 20.833$ current limit: **A**

$Po := \frac{Poc}{1.2}$ $Po = 416.667$ **output power: Watts**

$Io := \frac{Po}{Vo}$ $Io = 17.361$ FULL Load :**A**

$\eta = 0.92$ **DC DC converter efficiency:η**

3. T1 T2 AP calculation:

$\rho current := 1000$

tranformer winding current density : A/cm^3

wind cooling: 600A TO 1000A/cm^3

no wind : 300A TO 450A/cm^3

$K := 0.8$

K winding utilization

DCDC: K=0.8

isolation (acdc): K=0.45

$\Delta B := 0.21$

ΔB Flux density swing: Tesla

$$AP := \frac{0.5 \cdot Po}{(\eta Dpmax \cdot \Delta B \cdot fs \cdot \rho current \cdot K) \cdot 10^{-4}}$$

$AP = 0.061$ transformer Aw *Ae: **cm^4**

$$AP2 := \left(\frac{0.5 \cdot Po}{0.014 \cdot \Delta B \cdot fs}\right)^{\frac{4}{3}}$$

$AP2 = 0.099$ transformer Aw *Ae: **cm^4**

4. T1 T2 CORE select :

select CORE : PQ20

enter the transformer **core** parameter :

$Ae := 0.59$ effective area Ae: **cm^2**

$$AP2 := \left(\frac{Po}{0.014 \cdot \Delta B \cdot fs}\right)^{\frac{4}{3}}$$

$AP2 = 0.251$

$\mathbf{Ve} := 1.46 \cdot 2$ $\mathbf{Ve} = 2.92$ effective VolumeVe: **cm^3**

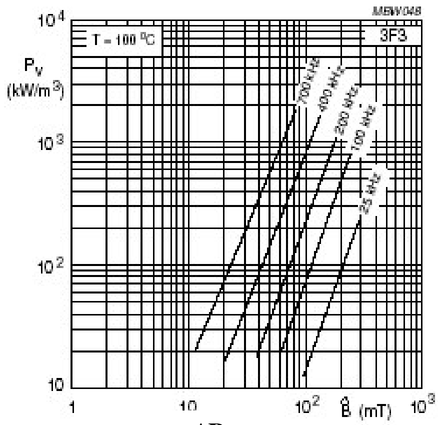
$\mathbf{Le} := 4.7 \cdot 2$ $\mathbf{Le} = 9.4$ effective Lenght Le: **cm^3**

$\mathbf{mg} := 3.5 \cdot 2$ $\mathbf{mg} = 7$ total weight m: **g**

$\mathbf{AL} := 2200$ 3F3 AL: **nH**

$\mathbf{Pv} := 150$ see right fig **ΔBfig** and fs:**mW/cm^3**

$\mathbf{Aw} := 0.12$ winding area : **cm^2**



$\mathbf{\Delta Bfig} := \frac{\mathbf{\Delta B}}{2}$ $\mathbf{\Delta Bfig} = 0.105$

NUMBER OF SECTIONS	WINDING AREA (mm^2)	MINIMUM WINDING WIDTH (mm)	AVERAGE LENGTH OF TURN (mm)
1	27.7	13.5	34.1

CORES

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
Σ(I/A)	core factor (C1)	1.52	mm^{-1}
V_e	effective volume	1460	mm^3
l_e	effective length	47.0	mm
A_e	effective area	31.0	mm^2
A_{min}	minimum area	29	mm^2
m	mass of core half	≈ 3.5	g

note: the Ve is mase of core half

$\mathbf{APture} := \mathbf{Ae} \cdot \mathbf{Aw}$ $\mathbf{APture} = 0.071$ $\mathbf{AP} = 0.061$ **APture ≥AP**

5. T1 Ns & Np calculation:

$\mathbf{Ns} := \mathbf{Vs} \cdot \frac{\mathbf{T} \cdot 10^4}{\mathbf{Ae} \cdot \mathbf{\Delta B}}$ $\mathbf{Ns} = 5.044$

$\mathbf{Nsset} := 5$

change ΔB value make Ns is sharp
such:Ns=3, Ns=4

$\mathbf{Np} := \mathbf{n} \cdot \mathbf{Nsset}$ $\mathbf{Np} = 4$

$\mathbf{Npset} := 4$

$\mathbf{\Delta Bset} := \mathbf{\Delta B} \cdot \frac{\mathbf{Ns}}{\mathbf{Nsset}}$ $\mathbf{\Delta Bset} = 0.212$

$\mathbf{B\_max} := \frac{\mathbf{\Delta Bset} \cdot 0.75}{\mathbf{Dpmin}}$ $\mathbf{B\_max} = 0.465$

验算： B_max<0.35
0.7=D_max

$\mathbf{Lt1} := \frac{\mathbf{Np}^2 \cdot \mathbf{AL} \cdot 10^{-9}}{10^{-6}}$

$\mathbf{Lt1} = 35.2$ tranformer T1 inductance :uH

enter the transformer **bobbin** parameter :

$\mathbf{Aw} = 0.12$ winding area : **cm^2**

$\mathbf{Bw} := 1.36$ winding width : **cm, 0.8cm**

$\mathbf{Hw} := 0.4775$ winding hidth : **cm**

$MLT := 5.64$ average Length : **cm**

6.Np & Ns wire Current stress (at ViL full load):

$Io = 17.361$

$KL := 0.15$ KL=ΔI/Ioc KL:0.1 to 0.15

$ILpp := 2KL \cdot Io$ $ILpp = 5.208$ inductor L1 PEAK current:A

$Ispk := Io + \frac{ILpp}{2}$ $Ispk = 19.965$ Ns Peak current : **A**

$Ispk\_a := Ispk - \frac{ILpp}{2}$ $Ispk\_a = 17.361$

$Isdc := Ispk\_a \cdot Dpmin$ $Isdc = 5.927$ Ns DC current : **A**

$Isac := Ispk\_a \cdot \sqrt{Dpmin \cdot (1 - Dpmin)}$ $Isac = 8.232$ Ns AC current : **A**

$Isrms := Ispk\_a \cdot \sqrt{Dpmin}$ $Isrms = 10.144$ Ns RMS current : **A**

$Ipdc := \frac{Isdc}{n}$ $Ipdc = 7.408$ Np DC current : **A**

$Ipac := \frac{Isac}{n}$ $Ipac = 10.29$ Np AC current : **A**

$Ippk := \frac{Ispk}{n}$ $Ippk = 24.957$ Np Peak current : **A**

$Iprms := \frac{Isrms}{n}$ $Iprms = 12.68$ Np RMS current : **A**

7.T1 wire selection:

8.T1 Losses calculation:

$Rsdc := 0.007$

$Rsac := 2 \cdot Rsdc$

$Rpdc := 0.007$

$Rpac := 2 \cdot Rsdc$

$Pt1core := \frac{Pv \cdot Ve}{1000}$ $Pt1core = 0.438$ core loss:W

$Psloss := Rsdc \cdot Isdc^2 + Rsac \cdot Isac^2$ $Psloss = 1.195$ 次级 winding loss: Watts

$Pploss := Rpdc \cdot Ipdc^2 + Rpac \cdot Ipac^2$ $Pploss = 1.867$ 初级 winding loss: Watts

$Pt1total := Psloss + Pploss + Pt1core$ $Pt1total = 3.499$ T1 total loss: Watts

transformer temperature rise calculation(fan speed=0)

$RT := \frac{36}{Aw}$ $RT = 300$ thermal resistance : ℃/Watts

$Crise := \frac{Pt1total \cdot RT}{2}$ $Crise = 524.89$ one transformer temperaturre rise:℃

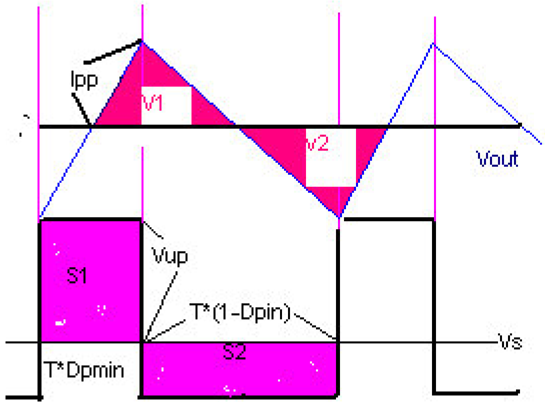
9. inductor L1 calculation (at ocp): (refer to **inductor design,** here is simple)

$KL = 0.15$ KL=ΔI/Ioc KL:0.1 to 0.15

$RL1 := 0.002$ inductor L1 resistor:Ω

$ILpp := KL \cdot Ioc$ inductor L1 Peak current:A

$ILpp = 3.125$



Vup*T*Dpmin=Vs*T*(1-Dpmin)

SO:

$Vup := \frac{Vs \cdot (1 - Dpmin)}{Dpmin}$ $Vup = 48.232$

$L1\_H := \frac{Vup \cdot Dpmin \cdot T}{2ILpp}$ $L1\_H = 6.586 \times 10^{-6}$ inductor L1 :H
92%:core AL tolerance

$L1 := L1\_H \cdot 10^{6}$

$L1\_SET := 92\% \cdot L1$

$L1\_SET = 6.059$ inductor L1 :uH

$Ae\_L1 := 0.58$

$Bs := 0.3$ Bs<0.35

$NL := Vup \cdot \frac{Dpmin \cdot T}{Ae\_L1 \cdot 10^{-4} \cdot \frac{2ILpp}{Ioc} \cdot Bs}$ $NL = 7.886$ inductor L1 winding :turn
N=ΔV*ΔT/(Ae*ΔB)

OR:

$NL1 := \frac{L1\_H \cdot 2ILpp}{\frac{2ILpp}{Ioc} \cdot Bs \cdot Ae\_L1 \cdot 10^{-4}}$ $NL1 = 7.886$ $NL1\_set := 8$ inductor L1 winding :turr

$gap := 4 \cdot \pi \cdot 10^{-7} \cdot NL1\_set^{2} \cdot \frac{Ae\_L1}{L1\_H} \cdot 10^{-2} \cdot 1.35$ $gap = 0.096$ **gap近似值:cm**

L1 :Ω

$RNL1set := 0.007$

$Pcu\_L1 := Io^{2} \cdot RNL1set$ $Pcu\_L1 = 2.11$ **L1 wire loss :W**

$AeL1 := 0.331 \cdot 10^{-4}$

$Vcore := 1.88$ Vcore :cm^3

$Pv\_core := 800$ Pv_core :mw/cm^3

$$Pcore\_L1 := \frac{Pv\_core \cdot Vcore}{10^3} \qquad Pcore\_L1 = 1.504$$ Pcore_L1 :W

$$Ptotal\_L1 := Pcore\_L1 + Pcu\_L1 \qquad Ptotal\_L1 = 3.614$$ L1 total loss :W

11.component stress calculation (at Vinmax & full load):

Q1-Vds Dio D1 D2 voltage stress:V:

$$VQ1 := Vimax + Vimax \cdot \frac{Dpmin}{1 - Dpmin} \qquad VQ1 = 88.063$$ Q1-Vds voltage stress: V. at active clamp.

$$Vd2 := Vs + Vup \qquad Vd2 = 73.232$$

$$Vd2set := \frac{Vd2}{0.6} \qquad Vd2set = 122.054$$ Dio D2 voltage stress:V.

$$Vd1 := \frac{VQ1 - Vimax}{n} \qquad Vd1 = 37.579$$

$$Vd1set := \frac{Vd1}{0.6} \qquad Vd1set = 62.631$$ Dio D1 voltage stress:V.

Dio D2 current stress:Ap-p:

$$Id2\_pp := \left(Io + \frac{ILpp}{2}\right) \qquad Id2\_pp = 18.924$$ Dio D2 current stress:Ap-p.

$$Id2\_a := Id2\_pp - \frac{ILpp}{2} \qquad Id2\_a = 17.361$$

$$D\_d2 := 1 - Dpmin$$

$$Id2\_ac := Id2\_a \cdot \sqrt{D\_d2 \cdot (1 - D\_d2)} \qquad Id2\_ac = 8.232$$

$$Id2\_dc := D\_d2 \cdot Id2\_a \qquad Id2\_dc = 11.434$$

$$Id2\_rms := Id2\_a \cdot \sqrt{D\_d2} \qquad Id2\_rms = 14.089$$ Dio D2 current stress:A-rms.

Dio D1 current stress:Ap-p.

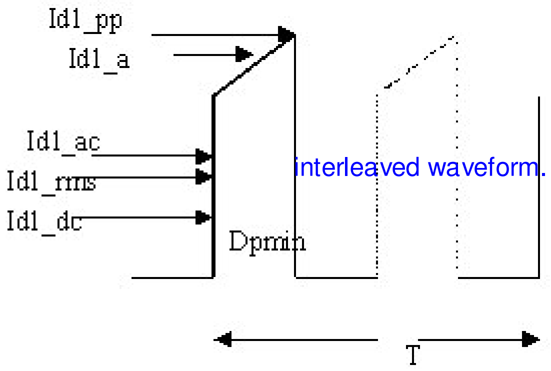
$$Id1\_pp := \left(Io + \frac{ILpp}{2}\right) \qquad Id1\_pp = 18.924$$ Dio D1 current stress:Ap-p.

$$Id1\_a := Id1\_pp - \frac{ILpp}{2} \qquad Id1\_a = 17.361$$

$$Id1\_ac := Id1\_a \cdot \sqrt{Dpmin \cdot (1 - Dpmin)} \qquad Id1\_ac = 8.232$$

$$Id1\_dc := Dpmin \cdot Id1\_a \qquad Id1\_dc = 5.927$$

$\mathbf{Id1\_rms} := \mathbf{Id1\_a} \cdot \sqrt{\mathbf{Dpmin}}$ $\mathbf{Id1\_rms} = 10.144$ Dio D1 current stress:A-rms.



$\mathbf{Io} = 17.361$

$\mathbf{Pd7loss} := \mathbf{Vdio} \cdot \mathbf{Io} \cdot (1 - \mathbf{Dpmin})$ $\mathbf{Pd7loss} = 9.148$ Dio D7 loss:Watts.

$\mathbf{Pd1loss} := \mathbf{Vdio} \cdot \mathbf{Io}\,\mathbf{Dpmin}$ $\mathbf{Pd1loss} = 4.741$ Dio D1 loss:Watts.

$\mathbf{Psnubber} := 0.5$ Dio D1D7 snubber total loss:Watts

$\mathbf{Precover} := 0.5$ Dio D1 D7 recover loss:Watts.

$\mathbf{Roringfet} := 0.0025$

$\mathbf{Poringloss} := \mathbf{Roringfet} \cdot \mathbf{Io}^2$

$\mathbf{Poringloss} = 0.754$

$\mathbf{Pd1d7loss} := \mathbf{Pd1loss} + \mathbf{Pd7loss} + \mathbf{Precover} + \mathbf{Psnubber}$ $\mathbf{Pd1d7loss} = 14.889$

$\mathbf{Pdiototalloss} := \mathbf{Pd1d7loss} + \mathbf{Poringloss}$ $\mathbf{Pdiototalloss} = 15.642$ **all Dio total loss:**Watts.

$\mathbf{Iq1} := \frac{\mathbf{Id1\_pp}}{\mathbf{n}}$ $\mathbf{Iq1} = 23.655$ Q1-Vds current stress: Ap-p

$\mathbf{Iq1rms} := \frac{\mathbf{Id1\_rms}}{\mathbf{n}}$ $\mathbf{Iq1rms} = 12.68$ Q1-Vds current stress: ARMS

12. FET loss calculation (for individual MOSFET-Q1):

Drain-Source On-State Resistance[a]	$r_{DS(on)}$	$V_{GS} = 10$ V, $I_D = 5$ A		0.041	0.050	Ω

$\mathbf{Rds25} := 0.06$ Q1导通电阻at 25℃：Ω

$\mathbf{Rds100} := (\mathbf{Rds25} \cdot 75 \cdot 0.035) + \mathbf{Rds25}$ $\mathbf{Rds100} = 0.218$ Q1导通电阻at 100℃：Ω

$\mathbf{Vdr} := 12$ Drive Voltage:V

$\mathbf{Vgsth} := 3$ turn Off Voltage:V

$\mathbf{Rdron} := 1$ Drive 电阻：Ω

$\mathbf{Qgs} := 7.6 \cdot 10^{-9}$ fet Qgs charge:C

$\mathbf{Qgd} := 14 \cdot 10^{-9}$ fet Qgd (miller)charge:C

$\mathbf{Coss} := 300 \cdot 10^{-12}$ all fet output capacitance:F

$FETn := 4$ fet 并联个数

$VQ1 = 88.063$ Q1-Vds voltage stress: V. at active clamp.

$Iq1 := \frac{Ispk}{n}$ $Iq1 = 24.957$ Q1-Vds current stress: Ap-p

$Iq1\_rms := \frac{Isrms}{n}$ $Iq1\_rms = 12.68$ Q1-Vds current stress: ARMS

$Pcond := \left[Rds100 \cdot \left(\frac{Iq1\_rms}{FETn} \right)^2 \cdot Dpmax \right] \cdot FETn$ $Pcond = 4.808$

conduction loss:W

$tsw := Qgd \cdot \frac{Rdron}{Vdr - Vgsth}$ $tsw = 1.556 \times 10^{-9}$ turn on time:sec

$Psw := \left[\left(tsw \cdot VQ1 \cdot \frac{Iq1}{FETn} \cdot fs \right) + \frac{Coss \cdot VQ1^2 \cdot fs}{2} \right] \cdot FETn$ $\frac{Coss \cdot VQ1^2 \cdot fs}{2} = 0.465$

$Psw = 3.229$ switching Loss:W

$Igare := fs \cdot Qgd$ $Igare = 5.6 \times 10^{-3}$ average drive current:A

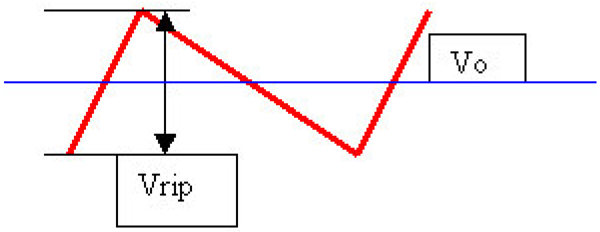
$Pgate := Igare \cdot Vdr$ $Pgate = 0.067$ average drive Loss:W

$Pfet := (Pcond + Psw + Pgate)$ $Pfet = 8.104$ one Fet total Loss:W

$Pfetall := Pfet$ $Pfetall = 8.104$ all Fet total Loss:W

13. output capacitor calculation :

$Vrip := 0.005 \cdot Vo$ $Vrip = 0.12$ Output ripple voltage:Vp-p



电容放电能量=电感充电能量:
So : for forward: **C=2Ipp*T/(8*Vripple)**

$C2 := 1.25 \frac{2ILpp \cdot T}{8Vrip} \cdot 10^6$ $C2 = 20.345$ Output Capacitance:uF
1.25 考虑电容利用率

$ESRc1 := \frac{Vrip}{2ILpp}$ $ESRc1 = 0.019$ Omaximum ESR value:Ω

$\mathbf{ILpprms} := \mathbf{ILpp}\cdot\sqrt{\frac{1}{3}}$ $\mathbf{ILpprms} = 1.804$ ripplecurrent(rms):A

$\mathbf{Pout\_cap\_loss} := \mathbf{ILpprms}^2\cdot\mathbf{ESRc1}$ $\mathbf{Pout\_cap\_loss} = 0.063$ Output Capacitor loss:w

实际上要用较大电容:　满足ESR要求:

14.converter loss list and efficiency (at full load):

$\mathbf{Pfetall} = 8.104$ 4FET total loss: Watts

$\mathbf{Pdiototalloss} = 15.642$ ALL Dio total loss:Watts.

$\mathbf{Pt1total} = 3.499$ T1T2 total loss: Watts

$\mathbf{Ptotal\_L1} = 3.614$ L1 total loss: Watts

$\mathbf{Pout\_cap\_loss} = 0.063$ Output Capacitance loss:w

$\mathbf{Pclame} := 2$ Dio2,3,5,6 clame loss: Watts

$\mathbf{Pcontrol} := 2$ control circuit total loss: Watts

$\mathbf{Pot} := \mathbf{Pclame} + \mathbf{Pcontrol}$

$\mathbf{Ptotalloss} := \mathbf{Pfetall} + \mathbf{Pdiototalloss} + \mathbf{Pt1total} + \mathbf{Ptotal\_L1} + \mathbf{Pout\_cap\_loss} + \mathbf{Pot}$

$\mathbf{Ptotalloss} = 34.922$ **converter total loss:** Watts

$\eta := \frac{\mathbf{Vo}\cdot\mathbf{Io}}{\mathbf{Vo}\cdot\mathbf{Io} + \mathbf{Ptotalloss}}$ $\eta = 0.923$ **converter total efficiency:** η

15. converter review:

$\mathbf{VQ1} = 88.063$ $\mathbf{Iq1\_rms} = 12.68$ $\mathbf{Ippk} = 24.957$ $\mathbf{Pfetall} = 8.104$

$\mathbf{Iprms} = 12.68$ $\mathbf{Ispk} = 19.965$ $\mathbf{Isrms} = 10.144$

$\mathbf{ESRc1} = 0.019$ for ripple:uf

$\mathbf{Rdron} = 1$

$\mathbf{fs} = 4\times10^{5}$ $\mathbf{T} = 2.5\times10^{-6}$ $\mathbf{Dpmax} = 0.55$

$\mathbf{Lt1} = 35.2$ $\mathbf{Nsset} = 5$ $\mathbf{Npset} = 4$

$\mathbf{L1} = 6.586$ $\mathbf{L1\_SET} = 6.059$ $\mathbf{NL1\_set} = 8$

$\mathbf{Vd2set} = 122.054$ Dio D7 voltage stress:V. $\mathbf{Id2\_rms} = 14.089$

$\mathbf{Vd1set} = 62.631$ Dio D7 voltage stress:V. $\mathbf{Id1\_rms} = 10.144$