Design Analysis of BSU

Problem 1 : Determine the begining - of - life kilowatt hour storage required in a BEV battery pack based on the following requirements : eight years of operation ' an average of 18 Km of driving per day Sday over the 365 days of the year , daily changing , and an average battery output energy per kilometer Ekm = 180 wh/km.

Assume L > 1 and N 100% = 1000 . Assume two parallel battery string with 96 Li-ion cells per string, with a total number of cells Ncell = 192, and a nominal voltage of 3.75 V per cell . Determine the ampere - hours per cell . What are the vehicle range at BOL and EOL ?

Solution :-

given values

$S_{day} = 48$ Km

$E_{km} = 180$ wh/km

$N_{cell} = 192$

$V_{nominal} = 3.75$

$N_{100\%} = 1000$, $L = 1$

Calculation

No. of cycles (N) = $365 \times 8 = 2920$

Average daily output energy (E_{day}) :

$E_{day} = S_{day} \cdot E_{km}$

$= 48 \times 180 = 8640$ wh

$\boxed{E_{day} = 8640 \text{ wh}}$

$$DOD = \left(\frac{N_{100\%}}{N}\right)^{1/2} \times 100\%$$

$$= \left(\frac{1000}{2920}\right)^{1/1} \times 100\% = 34.246\%$$

$$\boxed{DOD = 34.25\%}$$

$$E_{BOL} = \frac{E_{day}}{DOD} = \frac{8.64 \text{ kWh}}{0.3425} = 25.226 \text{ kWh}$$

$$\boxed{E_{BOL} = 25.23 \text{ kWh}}$$

$$E_{EOL} = 0.8 \times E_{BOL} = 0.8 \times 25.23 = 20.18 \text{ kWh}$$

$$\boxed{E_{EOL} = 20.18 \text{ kWh}}$$

→ Battery pack voltage (V_{bp}) :

$$V_{bp} = \frac{N_{cell}}{\text{No. of } \parallel^{el} \text{ strings}} \times V_n = \frac{192}{2} \times 3.75 = 360V$$

$$\boxed{V_{bp} = 360V}$$

$$Ah_{bp} = \frac{25.23 \times 10^3}{360} = 70.08 \text{ Ah}$$

$$\text{Cell Ah} = Ah_{cell} = \frac{70.8}{\text{No. of } \parallel^{el} \text{ String}} = \frac{70.08}{2} = 35.04 \text{ Ah}$$

$$\boxed{Ah_{cell} = 35.04 \text{ Ah}}$$

$$\underline{\text{Range BOL}} = \frac{E_{BOL}}{E_{km}} = \frac{25.23 \times 10^3}{180} = \boxed{140.2 \text{ km}}$$

$$\underline{\text{Range EOL}} = \frac{E_{EOL}}{E_{km}} = \frac{20.18 \times 10^3}{180} = \boxed{112.1 \text{ km}}$$

Problem - 2 : A 24 KWh battery pack can be fast charged from 0% to 80% SOC in 30 min. Determine the approximate charge current and power in order to achieve this charge time.

Solution :-

24 KWh → given when the Battery is fully charged

∴ 100% → 24 KWh

$$80\% \rightarrow 24 \times \frac{80}{100} = 19.2 \text{ KWh}$$

SOC → 30 min

0 to 80% → 30 mins are taken

Power = Energy / Time

$$P = \frac{19.2 \text{ KWh} \times 60}{30 \text{ min}} = 38.4 \text{ KW}$$

$$\boxed{P = 38.4 \text{ KW}}$$

If the nominal battery pack voltage is 360V

the approximate charge current = I.

$$I = \frac{P}{V}$$

$$I = \frac{38.4 \times 10^3}{360} = 106.67 \text{ A}$$

$$\boxed{I \simeq 107 \text{ A}}$$

Problem - 3 : A battery has 96 cells in series with two parallel strings. Each cell has a no-load voltage of 1.18 V and an internal resistance of 2.8 mΩ.

i) Determine the pack current and voltage under a 80 kW discharge if the battery is fully charged.

ii) Determine the discharge efficiency of the battery.

Solution :- Concept used :-

Current
+ve → discharging
-ve → charging

Power
+ve → discharging
-ve → charging

Formula Used :-

Current & Voltage

$$\rightarrow I_b = \frac{V_{b(nl)} - \sqrt{V_{b(nl)}^2 - 4 R_b (+P_b)}}{2 R_b} \quad \text{(discharging)} \rightarrow +ve$$

$$\rightarrow I_b = \frac{V_{b(nl)} - \sqrt{V_{b(nl)}^2 - 4 R_b (-P_b)}}{2 R_b} \quad \text{(charging)} \rightarrow -ve$$

$$\rightarrow V_b = V_{b(nl)} - R_b I_b$$

given values

$N_{series} = 96$ $R_b = 2.8\,m\Omega = 0.0028\,\Omega$

$N_{parallel} = 2$ $P_b = +80\,kW$

$V_{b(nl)} = 1.18\,V$

For 96 cells in series → $V_{b(nl)} = 96 \times 1.18 = 101.28\,V$

$\parallel^{ly}$ $R_b' = 96 \times 2.8\ m\Omega = 268.8\ m\Omega$

For two $\parallel^{el}$ strings - $R_b = \dfrac{268.8 \times 268.8}{2 \times 268.8} = 134.4$

$R_b = 134.4\ m\Omega$

(or)

Calculating R_b by using formula $\boxed{\dfrac{N_{series}}{N_{parallel}} \times R_b}$

$$\frac{96}{2} \times 2.8 = 134.4\ m\Omega$$

i) Pack current

$$I_b = \frac{401.28 - \sqrt{401.28^2 - 4 \times 134.4 \times 10^{-3} (80 \times 10^3)}}{2 \times 134.4 \times 10^{-3}}$$

$= 214.81\ A$

$$\boxed{I_b = 214.81\ A}$$

Voltage

$V_b = V_{b(nl)} - R_b I_b$

$= 401.28 - 134.4 \times 10^{-3} \times 214.81$

$= 372.4\ V$

$$\boxed{V_b = 372.4\ V}$$

ii) Discharge efficiency

$$\eta_{dis} = \frac{V_b}{V_{b(nl)}} \times 100 = \frac{372.4}{401.28} \times 100 = 92.8\%$$

$$\boxed{\eta_{dis} = 92.8\%}$$

Problem-4: Determine the pack current and voltage under a 50 kw charge if the battery is fully discharged. The cell voltage drop of 2.5 V when fully discharged. How efficient is the charging of the battery at this power level?

given Values

$N_{series} = 96$

$N_{parallel} = 2$

$R_b = 2.8\ m\Omega$

[Same as 1st Problem]

$V_{b(nl)} = 2.5V$

$P_b = -50KW$ (charge)

For 96 cells in series and two cells in $||^{el}$

$V_{b(nl)} = 96 \times 2.5 = 240V$

$R_b = 134.4\ m\Omega$

Formula Used

$$I_b = \frac{V_{b(nl)} - \sqrt{V_{b(nl)}^2 - 4 \times R_b \times (-P_b)}}{2R_b}$$

$$V_b = V_{b(nl)} - R_b I_b$$

$$\eta_{charging} = \frac{V_{b(nl)}}{V_b} \times 100$$

Calculations

$$I_b = \frac{240 - \sqrt{240^2 - 4 \times 134.4\ m\Omega \times (-50\ KW)}}{2 \times 134.4 \times 10^{-3}}$$

$$\boxed{I_b = -188.44\ A}$$

$$V_b = 240 - (134.4 \times 10^{-3})(-188.44)$$

$$\boxed{V_b = 265.32\ V}$$

Charging efficiency

$$\eta_{charging} = \frac{240}{265.32} \times 100 = 90.5\ \%$$

$$\boxed{\eta_{ch} = 90.5\ \%}$$

Problem-5: The capacity of the cell is approximately 33.3 Ah at C/3 with a rated voltage of 3.75V. Assume R = 2.8 mΩ. Summarize the following parameters for C/3, 1C and 3C.

Parameters	C/3	1C	3C
x	1/3	1	3
V	3.75	3.69	3.5
Ah	33.3	33.3	33.3
Wh	124.88	122.8	116.6
Efficiency	99.2	97.5	92.6

Solution :-

given Values :- $Ah_{rated} = 33.3\ Ah$

$C_{rated} = C/3$

$$I_{rated} = \frac{33.3}{3} = 11.1\,A$$

$$V_{rated} = 3.75\,V$$

$$R = 2.8\,m\Omega = 0.0028\,\Omega$$

__To calculate__ :: x, V, Ah, wh, Efficiency for $C/3$, $1C$ & $3C$.

__Formula Used__

1) $E_{cell} = Ah_{rated} \cdot V_{rated} + R_b \cdot I_{rated}^2 \cdot \frac{h}{C_{rated}}$ (wh)

2) $E_{xc} \simeq E_{cell} - R_b I_{xc}^2 \cdot \frac{h}{x}$ (wh)

3) $V_{xc} \simeq V_{rated} - R_b (I_{xc} - I_{rated})$

4) $\eta_{dis} = \frac{E_{xc}}{E_{cell}}$ (%) , $\eta_{charg} = \frac{E_{cell}}{E_{xc}}$ (%)

__Calculations__

$\boxed{\text{For } C/3}$

$$\boxed{x = 1/3}$$

$$I_{xc} = I_{rated} = 11.1\,A$$

$$\boxed{Ah = 33.3}$$

$$\boxed{V_{xc} \simeq V_{rated} = 3.75\,V}$$

$$E_{cell} = Ah_{rated} \cdot V_{rated} + R_b \cdot I_{rated}^2 \cdot \frac{h}{C_{rated}}$$

$$= \left(33.3 \times 3.75 + 0.0028 \times 11.1^2 \times \frac{1}{1/3}\right) wh$$

$$= \left(33.3 \times 3.75 + 0.0028 \times 11.1^2 \times 3\right) wh$$

$$E_{cell} = 125.91 \text{ wh}$$

$$E_{xc} = E_{cell} - R_b \cdot I_{xc}^2 \cdot \frac{h}{x}$$

$$= (125.91 - 0.0028 \times 11.1^2 \times 3) \text{ wh}$$

$$\boxed{E_{xc} = 124.88 \text{ wh}}$$

$$\eta_{dis} = \frac{E_{xc}}{E_{cell}} \times 100 = \frac{124.88}{125.91} \times 100$$

$$\boxed{\eta_{dis} = 99.18\% = 99.2\%}$$

Now, we have

$x = 1/3$, $V = 3.75V$, $Ah = 33.3$, $wh = 124.88$

$\eta = 99.2\%$

For 1C

$\boxed{x = 1}$ $\boxed{Ah = 33.3}$

$$I_{xc} = 33.3 \text{ A} \quad (33.3 \times 1)$$

$$V_{xc} = V_{rated} - R_b (I_{xc} - I_{rated})$$

$$= 3.75 - 0.0028 (33.3 - 11.1)$$

$$= 3.687 \text{ V}$$

$$\boxed{V_{xc} = 3.69 \text{ V}}$$

$E_{cell} = 125.91$ wh (Same as $C/3$)

$$E_{xc} = E_{cell} - R_b \cdot I_{xc}^2 \cdot \frac{h}{x}$$

$$= \left(125.91 - 0.0028 \times 33.3^2 \times \frac{1}{1}\right) Wh$$

$$\boxed{E_{xc} = 122.8 \ Wh}$$

$$\eta_{dis} = \frac{122.8}{125.91} \times 100 = 97.5\%$$

$$\boxed{\eta = 97.5\%}$$

Now, we have

$x = 1$, $V = 3.69V$, $Ah = 33.3$, $Wh = 122.8$, $\eta = 97.5\%$

For 3C

$$\boxed{x = 3}$$

$$\boxed{Ah = 33.3}$$

$$I_{xc} = 33.3 \times 3 = 99.9 A$$

$$V_{xc} = V_{rated} - R_b (I_{xc} - I_{rated})$$

$$= 3.75 - 0.0028 (99.9 - 33.3)$$

$$= 3.50$$

$$\boxed{V_{xc} = 3.5 V}$$

$E_{cell} = 125.91 \ Wh$ (Same as C/3)

$$E_{xc} = E_{cell} - R_b \cdot I_{xc}^2 \cdot \frac{h}{x}$$

$$E_{xc} = \left(125.91 - 0.0028 \times 99.9^2 \times \frac{1}{3}\right) Wh$$

$$= 116.59\ Wh$$

$$\boxed{E_{xc} = 116.6\ Wh}$$

$$\eta_{dis} = \frac{116.6}{125.91} \times 100 = 92.6\%$$

$$\boxed{\eta = 92.6\%}$$

Now, we have

$x = 3$, $V = 3.5V$, $Ah = 33.3$, $Wh = 116.6$, $\eta = 92.6\%$

<u>Problem - 6</u>: An EV battery has a 100% SOC of 85 KWh. The battery can be charged at high power when the battery DOD is maintained within a range of 20% to 100%. The pack has 96 cells in series per string with 74 parallel strings. Each cell has an average no-load cell voltage during charge of 3.64 V and an internal resistance of 65 mΩ.

i) Determine the battery terminal voltage, current, and efficiency for a 120 KW charge.

ii) What approximate time is required to charge the battery from a DOD of 100% to 20%?

<u>Solution</u>

<u>Given values</u> :-

$N_{series} = 96$

$N_{parallel} = 74$

$V_{b(nl)} = 3.64V$

$R_b = 65\ m\Omega = 0.065\ \Omega$

$P_b = -120\ kW$ (charging)

For 96 cells in series & 74 cells in parallel

$V_{b(nu)} = 96 \times 3.64 = 349.5\ V$

$V_{b(nu)} = 349.5\ V$

$$R_b = \frac{N_{series}}{N_{parallel}} \times R$$

$$= \frac{96}{74} \times 65 = 84.32\ m\Omega$$

$$\boxed{R_b = 0.08432\ \Omega}$$

To calculate V_b, I_b, $\eta_{charging}$

(i) Calculation of I_b

As, we know (for charging)

$$I_b = \frac{V_{b(nu)} - \sqrt{V_{b(nu)}^2 - 4R_b(-P_b)}}{2R_b}$$

$$I_b = \frac{349.5 - \sqrt{349.5^2 - 4 \times 84.32 \times 10^{-3}(-120 \times 10^3)}}{2R_b}$$

$$= -318.9\ A$$

$$\boxed{I_b = -318.9\ A}$$

Calculation of V_b

As, we have $V_b = V_{b(nu)} - R_b I_b$

$$= 349.5 - (0.08432) \times (-318.9)$$

$$= 376.38\ V$$

$$\boxed{V_b = 376.38\,V}$$

$$\eta_{charging} = \frac{V_{b(nl)}}{V_b} \times 100 = \frac{349.5}{376.38} \times 100$$

$$\boxed{\eta_{ch} = 92.85\,\%}$$

(ii) DOD → 100% to 20%

100% → 85 kWh till 20%.

$$85\,kWh \times \frac{20}{100} = 17\,kWh$$

17 kWh → tapping the energy from the battery

Remaining → (85 − 17) kWh = 68 kWh

68 kWh → we are consuming

$$= \frac{68\,kWh}{120\,kW} = \frac{68}{120}\,h = \frac{68 \times 60}{120}\,min$$

$$= 34\,min$$

$\boxed{T = 34\ mins}$ → approximate time is required to charge the battery

Problem - 7 : A Li-ion cell is rated at 3.6 V, 3.4 Ah at 0.2C and has an internal resistance of 65 mΩ. Determine the cell Wh, Ah, and efficiency for the 4C rate.

Solution

given values :- $V_{rated} = 3.6\,V$

$Ah_{rated} = 3.4$

$R_b = 65\,m\Omega = 0.065\,\Omega$

$I_{rated} = 34 \times 0.2 = 0.68\,A$

$C_{rated} = 0.2C$

To find :- cell wh, Ah & η

Calculations

For 4C rate

$x = 4$

$\boxed{Ah = 3.4}$

$I_{xc} = 3.4 \times 4 = 13.6\,A$

As we have

$$E_{cell} = Ah_{rated} \cdot V_{rated} + R_b \cdot I_{rated}^2 \cdot \frac{h}{C_{rated}}$$

$$= \left(3.4 \times 3.6 + 0.065 \times 0.68^2 \times \frac{1}{0.2}\right) wh$$

$$E_{cell} = 12.4\,wh$$

$$E_{xc} = E_{cell} - R_b \cdot I_{xc}^2 \cdot \frac{h}{x}$$

$$= \left(12.4 - 0.065 \times 13.6^2 \times \frac{1}{4}\right) wh$$

$$\boxed{E_{xc} = 9.39\,wh}$$

$$\eta = \frac{9.39}{12.4} \times 100 = 75.7\%$$

$$\boxed{\eta = 75.7\%}$$

Problem - 8 : A BEV has the following requirements: eight years of operation at an average of 24,000 km per year, averaged out over 365 days per year. Assume an average battery output of 204 wh / km and a rated cell voltage of 3.6 V, a capacity of 3.4 Ah, and a lifetime index of L=1.

i) Determine the BOL kWh storage.

ii) How many cells do you need and what is the BOL range.

iii) What is the BOL storage and how many cells are required for a larger pack in order to increase the BOL range to 425 km ?

iv) How many parallel strings are required if the pack has 96 cells in series ?

v) What is the battery pack mass, assuming a battery with a pack density of 150 wh/ kg ?

vi) If the peak power is 325 kW, what is the P/E ratio of the battery for the larger pack ?

Solution :-

given values :

$V_{rated} = 3.6\ V$

$E_{km} = 204\ wh/km$

$Ah_{cell} = 3.4\ Ah$

$L = 1$

Time $=$ 8 years

Calculation

i) The average daily battery output energy,

$$E_{daily} = S_{daily} \times E_{km}$$

$$S_{daily} = \frac{24000}{365}$$

$$E_{daily} = \frac{24000}{365} \times 204 \text{ wh}$$

$$= 13413.7 \text{ wh}$$

$$\boxed{E_{daily} = 13.4137 \text{ kWh}}$$

We have $E_{BOL} = \frac{E_{daily}}{DOD}$

$$DOD = \left(\frac{N_{100\%}}{N}\right)^{1/L} \times 100\%$$

Let $N_{100\%} = 1000$, $N = 365 \times 8 = 2920$

$$DOD = \left(\frac{1000}{2920}\right)^{1} \times 100\% = 34.2\%$$

$$DOD = 0.342465$$

$$E_{BOL} = \frac{13.4137}{0.342465} = 39.16 \text{ kWh}$$

$$\boxed{E_{BOL} = 39.16 \text{ kWh}}$$

ii) The cell Ah $= 3.4 = \frac{E_{BOL}}{V_{bp}}$

Assume that the no. of string = 1

V_{bp} = battery pack voltage

$$V_{bp} = \frac{E_{BOL}}{3.4} = \frac{39.16 \times 10^3}{3.4}$$

$$\boxed{V_{bp} = 11517.647 \text{ V}}$$

Also, we have $V_{bp} = N_{cell} \times 3.6$

$$\therefore \quad N_{cell} = \frac{V_{bp}}{3.6} = \frac{11517.647}{3.6} = 3199.346$$

$$N_{cell} = 3199.346 \simeq 3200$$

$$\boxed{N_{cell} \simeq 3200}$$

$$BOL\ range = \frac{E_{BOL}}{E_{km}} = \frac{39.16 \times 10^3}{204} = 191.96\ km \simeq 192\ Km$$

$$\boxed{BOL\ range = 192\ km}$$

iii) If BOL range increased to 425 km

then $\dfrac{E_{BOL}}{E_{Km}} = 425\ Km$

$$E_{BOL} = 425 km \times 204\ Wh/km = 86700\ Wh$$

$$\boxed{E_{BOL} = 86.7\ KWh}$$

$$\text{No. of cells required} = \frac{E_{BOL}}{Ah_{cell} \times V_{cell}} = \frac{86.7 \times 10^3}{3.4 \times 3.6}$$

$$7083.33$$

$$\boxed{N_{cells} = 7083}$$

iv) Let the no. of parallel string be N

→ The battery pack voltage (V_{bp}) = $N_{series} \times V_{rated}$

$$V_{bp} = 96 \times 3.6 \quad [\text{given } N_{series} = 96]$$

$$= 345.6\,V$$

$$\boxed{V_{bp} = 345.6\,V}$$

→ The battery pack Ah = $\frac{E_{BOL}}{V_{bp}}$ = Ah_{bp}

$$Ah_{bp} = \frac{86.7 \times 10^3}{345.6} = 250.86$$

$$\boxed{Ah_{bp} = 250.86\,Ah}$$

→ The cell Ah (Ah_{cell}) = $\frac{Ah_{bp}}{N}$

$$\frac{Ah_{bp}}{N} = 3.4\,Ah$$

$$N = \frac{250.86\,Ah}{3.4\,Ah} = 73.78$$

$$\boxed{N = 74}$$

v) Battery pack mass (M_{bp}) = $\frac{E_{BOL}}{\text{Pack density}}$

$$M_{bp} = \frac{86.7 \times 10^3}{150} = 578\,kg$$

$$\boxed{M_{bp} = 578\,kg}$$

vi) given $P = 325 kW$

$E = 86.7 \ kWh$ (above calculated)

$$\frac{P}{E} = \frac{325}{86.7} = 3.7$$

$$\boxed{P/E = 3.7}$$

Problem - 9 : A NiMH HEV battery pack is sized bas on the following requirements : 10,000 cycles of 100 Wh per year for 10 years, a 6.5 Ah cell with a rated voltage of 1.2V and an index of $L = 1.5$.

i) what is the BOL battery pack energy storage ?

ii) What is the total number of cells required ?

iii) What is the pack voltage if the cells are all in series ?

iv) If the peak power is 30 kW, what is the P/E ratio of the battery ?

Solution :-

given values :

$N = 10,000$

$E_{cycle} = 100 \ Wh / cycles$

$V_{cell} = V_{rated} = 1.2V$

$Ah_{cell} = 6.5 \ Ah$

$L = 1.5$

Calculation

i) $\text{No. of cycles per day} = \frac{10,000}{365 \times 10} = 2.739$

$E_{day} = S_{cycle} \times E_{cycle}$ $[S_{cycle} = 2.739]$

$E_{day} = 2.739 \times 100 = 273.9\ wh$

$$\boxed{E_{day} = 273.9\ wh}$$

Assume $N_{100\%} = 1000$

$$DOD = \left(\frac{N_{100\%}}{N}\right)^{1/2} \times 100\%$$

$$= \left(\frac{1000}{10{,}000}\right)^{1/1.5} \times 100\%$$

$$\boxed{DOD = 21.54\%}$$

$$E_{BOL} = \frac{E_{day}}{DOD} = \frac{273.9\ wh}{0.21} = 1304.2\ wh$$

$$\boxed{E_{BOL} = 1.3\ kwh}$$

ii) No. of cell required $= \frac{E_{BOL}}{Ah_{cell} \times V_{cell}}$ (Assume no. of strings $= 1$)

$$= \frac{1.3 \times 10^3}{6.5 \times 1.2} = 166.67$$

$$\boxed{\text{No. of cells} = 166}$$

i) Pack voltage $(V_{pack}) = 166 \times 1.2 = 199.2V$

$$\boxed{V_{pack} = 199.2V}$$

iv) $P = 30\ kw$ (given), $E = 1.3\ kwh$ (above cal)

$$\frac{P}{E} = \frac{30}{1.3} = 23.07 \qquad \boxed{\frac{P}{E} = 23}$$

Sizing the EVs drive System

Problem - 1 : 1250 CC capacity of IC engine car is having 14 inches of wheel diameter. It can run the maximum speed of 240 kmph with 190 Nm. If it is modified as battery operated vehicle. what is the required motor sizing (BHP) and also estimate the number of batteries to run 8 hrs continuously while driving consistently 60 kmph. Each battery has the rating of 100 Ah for 240V DC.

Solution :-

given values:

V = 240 Km/h
Diameter = 14 inches
T = 190 Nm
Time = 8 hrs
Ah rating = 100 for 240V DC

To calculate : No. of batteries

Calculation :

$$\text{Km/h} \longrightarrow \text{rpm}$$

$$\text{Km/h} = \text{Diameter} \times \text{rpm} \times 1.885 \times 10^{-3}$$

$$1 \text{ inch} = 2.54 \text{ cm}$$

$$\text{rpm} = \frac{\text{Km/h}}{\text{Diameter} \times 1.885 \times 10^{-3}}$$

$$\text{Diameter} = 14 \times 2.54 \text{ cm} = 35.56 \text{ cm}$$

$$\text{rpm} = \frac{240 \text{ Km/h}}{35.56 \text{ cm} \times 1.885 \times 10^{-3}}$$

$$= 3580.45$$

$$\boxed{N = 3580.45 \text{ rpm}}$$

Calculation of Power

$$P = \frac{2\pi N T}{60} \quad (kW)$$

$$P = \frac{2\pi \times 3580.45 \times 190}{60}$$

$$P = 71.24 \text{ kW}$$

$$P(HP) = \frac{71.24 \times 10^3}{746} = 95.49$$

$$\boxed{P(HP) = 95.5 HP}$$

Ah rating

kWh → $71.24 \times 8 = 569.92$ kWh

570 units

$$\frac{570 \times 10^3 \text{ Wh}}{240 \text{ V}} = \boxed{2375 \text{ Ah}}$$

Number of batteries required to run 8 h.

$$= \frac{2375 \text{ Ah}}{100 \text{ Ah}} = 23.75 = 24$$

$\boxed{24 \text{ batteries}}$

Problem - 2 : Design a medium duty electric vehicle to run 60 kmph with 50 Nm. It should run at least 5 hrs continuously while the wheel diameter of 10 inches. (Ah rating, Motor sizing, suitable motor, power converter circuit for regeneration and power devices rating).

Solution :-

Given values :-

$$V = 60 \text{ km/h}$$

$$T = 50 \text{ Nm}$$

$$\text{Time} = 5 \text{ hrs}$$

$$\text{Diameter} = 10 \text{ inches}$$

Assume $V = 240V$

Calculation

$$\text{Diameter} = 10 \times 2.54 \text{ cm}$$

$$= 25.4 \text{ cm}$$

$$\text{rpm} = \frac{60 \text{ km/h}}{10 \times 2.54 \times 1.885 \times 10^{-3}}$$

$$= \boxed{1253.16 \text{ rpm}} \qquad \boxed{N = 1253.16 \text{ rpm}}$$

$$P = \frac{2\pi NT}{60}$$

$$= \frac{2\pi \times 1253.16 \times 50}{60} \text{ kW}$$

$$= 6.56 \text{ kW}$$

$$P(\text{HP}) = \frac{6.56 \times 10^3}{746} = 8.79 \text{ HP}$$

$$\boxed{P = 8.8 \text{ HP}}$$

KWh $\longrightarrow$ $6.56 \times 5 = 32.8$ KWh

Ah $\longrightarrow$ $\dfrac{32.8 \times 10^3}{240} = 136.67$ Ah

$$\boxed{\text{Ah rating} = 136.67 \text{ Ah}}$$

Motor sizing

→ In this case 6.56 Kw is the requirement of the mechanical power equivalent to electric power So, Motor rating has to accept this much maximum power so that our design should be 1.25 to 1.5 time of higher than this one

$$6.56 \times 1.25 = 8.2 \text{ Kw}$$

(or)

$$6.56 \times 1.5 = 9.84 \text{ Kw}$$

Range of Motor sizing := (8.2 $\xrightarrow{to}$ 9.84) Kw

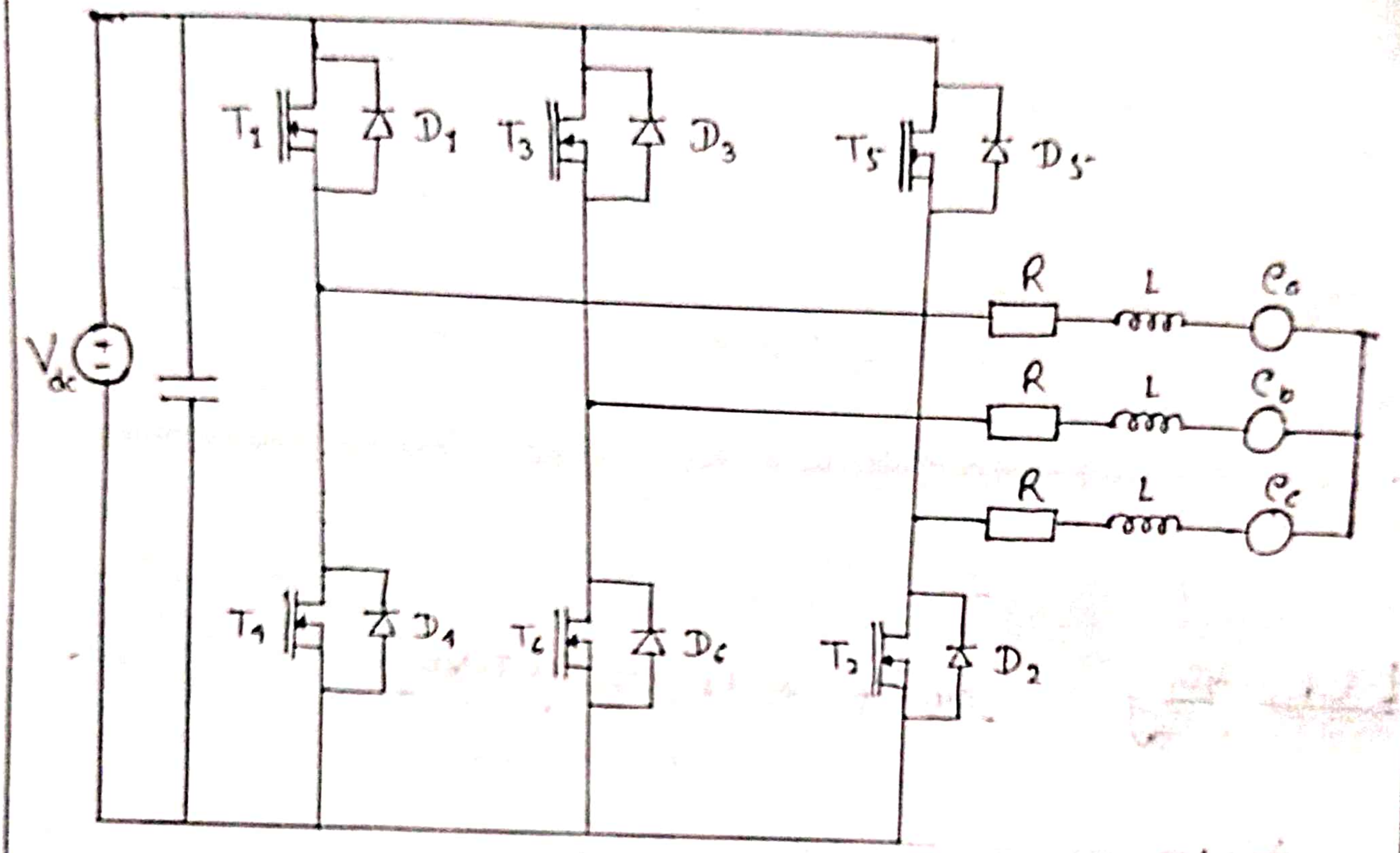
Suitable Motor

→ For Medium duty electric vehicle, BLDC is the best suitable Motor.

Circuit for regeneration of BLDC :

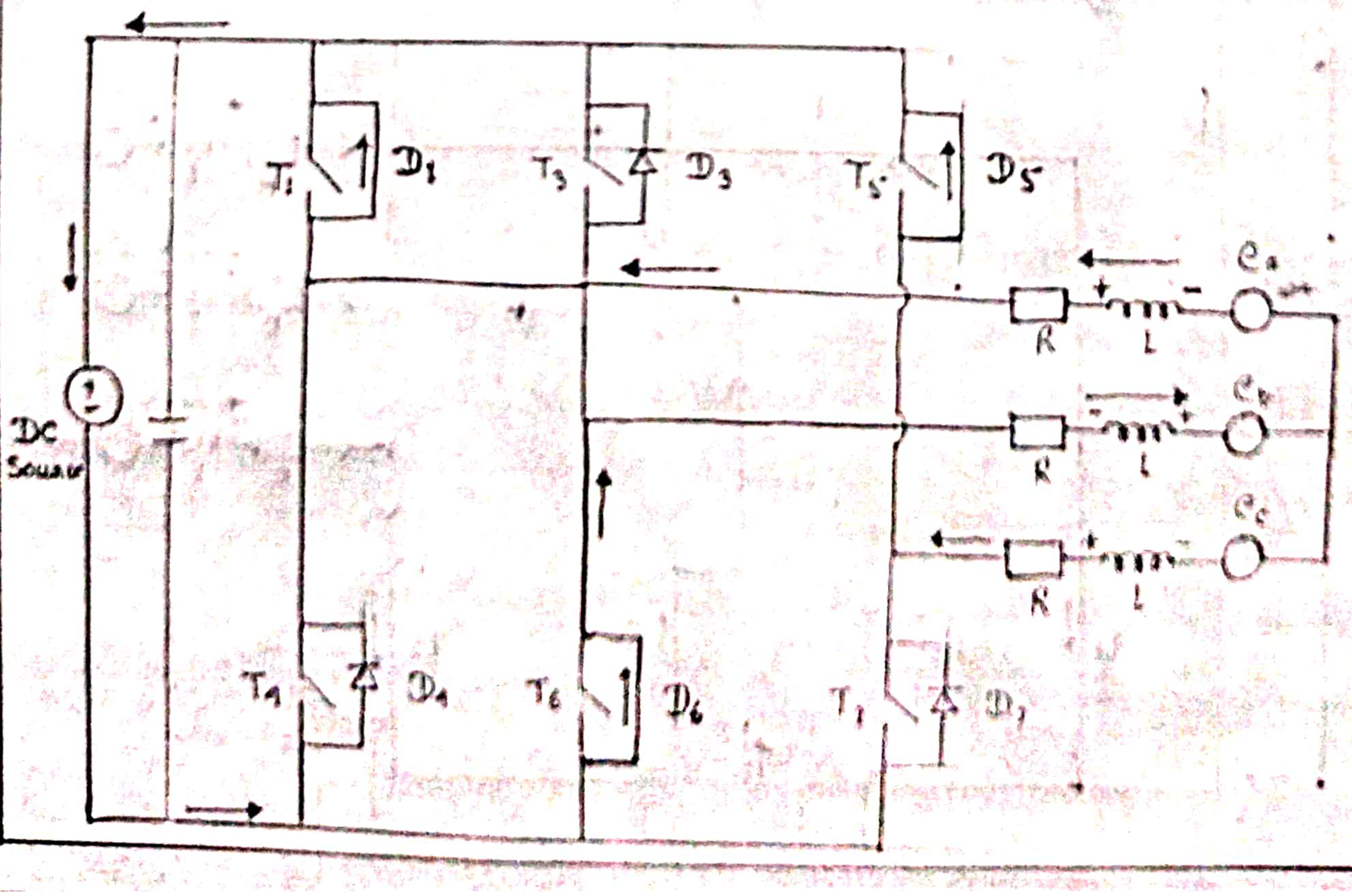
Regenerative braking

Power Converter circuit for regeneration



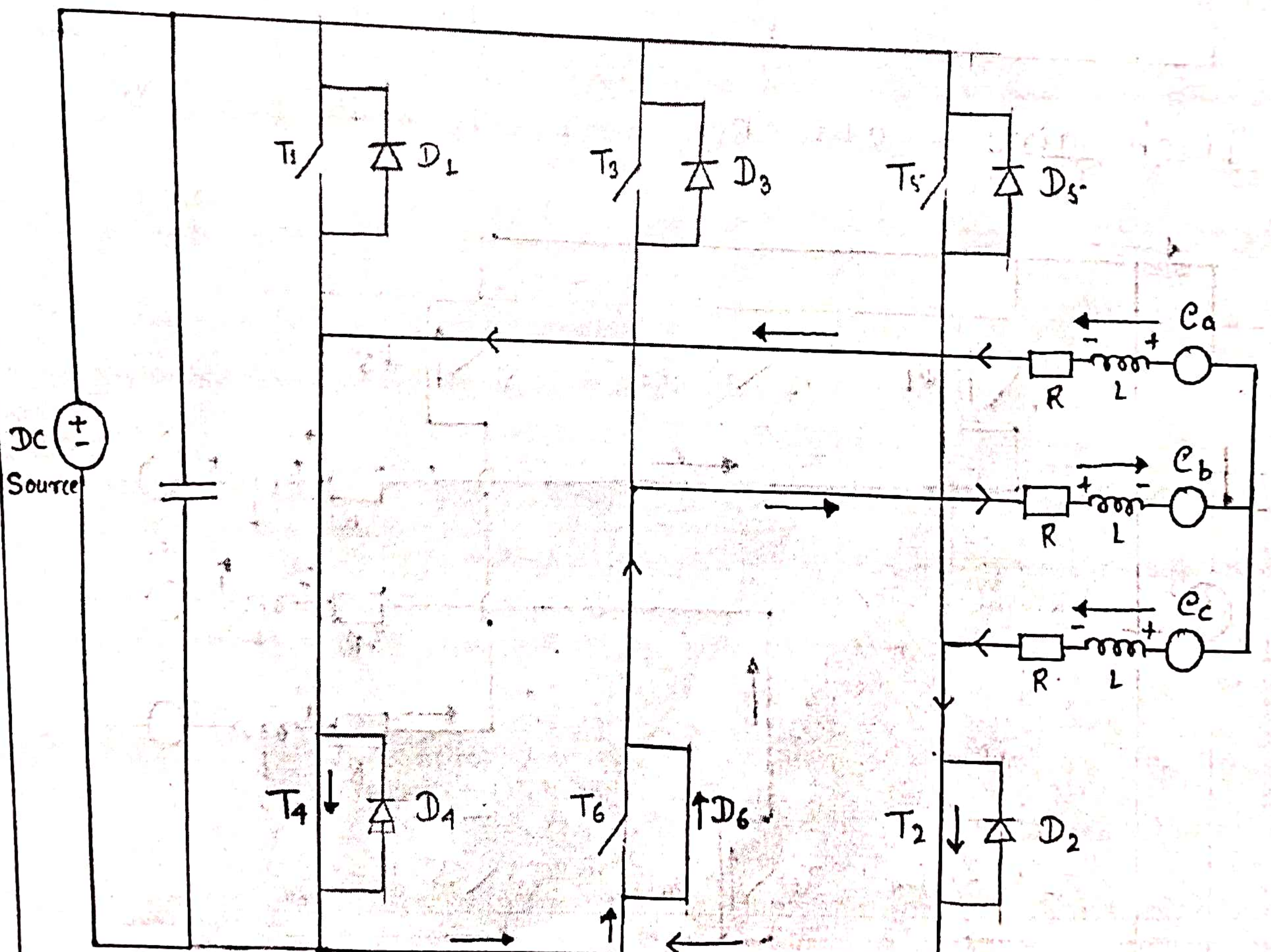
L-Discharging

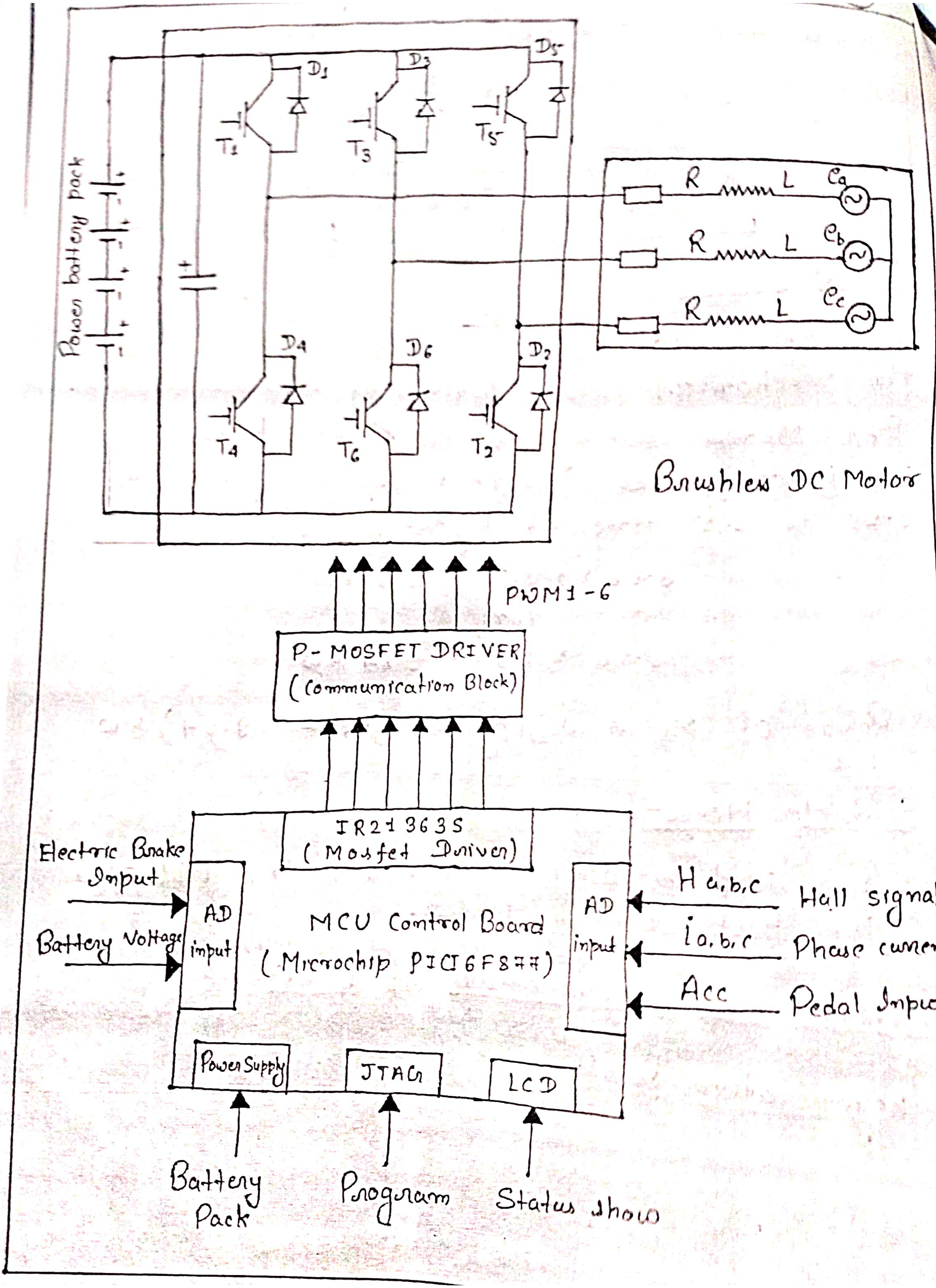
$a + c = b$ D_1, D_5 & D_6 - active



L-Charging

T_4, D_6 & T_2 - active





Power battery pack
D_1
D_3
D_5
T_1
T_3
T_5
D_4
D_6
D_2
T_4
T_6
T_2
R
L
e_a
R
L
e_b
R
L
e_c
Brushless DC Motor
PWM 1-6
P-MOSFET DRIVER
(Communication Block)
IR21363S
(Mosfet Driver)
Electric Brake Input
Battery Voltage
AD input
MCU Control Board
(Microchip PIC16F877)
AD input
H a,b,c
Hall signal
i a,b,c
Phase current
Acc
Pedal Input
Power Supply
JTAG
LCD
Battery Pack
Program
Status show

Power device rating :

→ Voltage rating = 240 V

It is 3-ϕ (there are two switches)

240V → connected with upper switch & lower switch .

$$\frac{240}{2} = 120V \rightarrow \text{each switch}$$

∴ Voltage rating for each switch is $\geq$ 120V

Current

→ Let us take 1.25 times of power rating

$6.56 \times 1.25 = 8.2$ KW

DC

→ Normal current is taken whatever we have calculated

AC

→ RMS current is taken

→ we have calculated peak current so $\sqrt{2}$ times of peak current should be taken

$\boxed{I_{rms} = \sqrt{2} \cdot I_{peak}}$

In this case, we can take directly because, it is DC

$$I = \frac{6.56 \times 1.25 \times 10^3}{240} A = 34.167 A$$

Current rating = 35 to 40 A

$I_{rating} \geq 34.167$ A

Problem - 3 : Design a light duty e-scooter to run 30 kmph with 25 Nm to lift 100 kg of weight (75 kg of body weight) with diameter of 8 inches. It should run at least 100 km for one shot charge when the friction coefficient factor is 0.9.

Solution :

given values :

$$\text{Mass} = (100 + 75)\ \text{kg} = 175\ \text{kg}$$

$$V = 30\ \text{Km/h}$$

$$T = 25\ \text{Nm}$$

$$D = 8\ \text{inches}$$

$$\mu = 0.9$$

$$S = 100\ \text{Km}$$

Calculations

$$D = 8 \times 2.54\ \text{cm} = 20.32\ \text{cm}$$

As we know

$$\text{Km/h} = \text{Diameter} \times \text{rpm} \times 1.885 \times 10^{-3}$$

$$\text{rpm} = \frac{\text{Km/h}}{\text{Diameter} \times 1.885 \times 10^{-3}}$$

$$= \frac{30 \times 1000}{20.32 \times 1.885}$$

$$= 783.2\ \text{rpm}$$

$$\boxed{N = 783.2\ \text{rpm}}$$

$$P = \frac{2\pi N T}{60} = \frac{2\pi \times 783.2 \times 25}{60} = 2050\ \text{Watt}$$

$$\boxed{P = 2.05\ kW}$$

$$P\,(Hp) = \frac{2050}{746} = 2.74\ Hp$$

$$\boxed{P = 2.74\ Hp}$$

$$\text{Time} = \frac{\text{Distance}}{\text{Speed}} = \frac{100\ km}{30\ Km/h} = 3.33\ h$$

KWh →

$$(2.05 \times 3.33)\ KWh = 6.82\ KWh$$

Assume $V = 24\ V$ → for light duty vehicle

$$Ah \rightarrow \frac{6.82 \times 10^3}{28\ V} = 243.57\ Ah$$

Standard value of Ah for light duty vehicle is assumed → 45 Ah

No. of batteries to run 3.33h $= \frac{243.57\ Ah}{45\ Ah}$

$= 5.41 \approx 6$

$$\boxed{6 \text{ batteries}}$$

<u>Motor Sizing</u>

In this case 2.05 kW is the requirement of the mechanical power.

So, Motor rating has to accept this much maxm power so that our design should be 1.25 to 1.5 times of higher than this one.

$$2.05 \times 1.25 = 2.56 \text{ KW}$$

(or)

$$2.05 \times 1.5 = 3.075 \text{ KW}$$

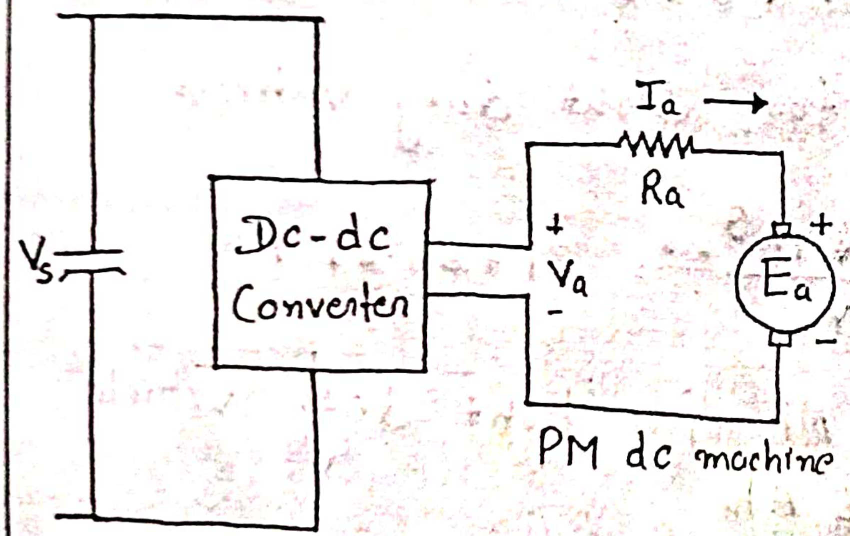
Take 1.25, $\boxed{\text{Motor sizing} = 2.56 \text{ KW}}$

Suitable Motor

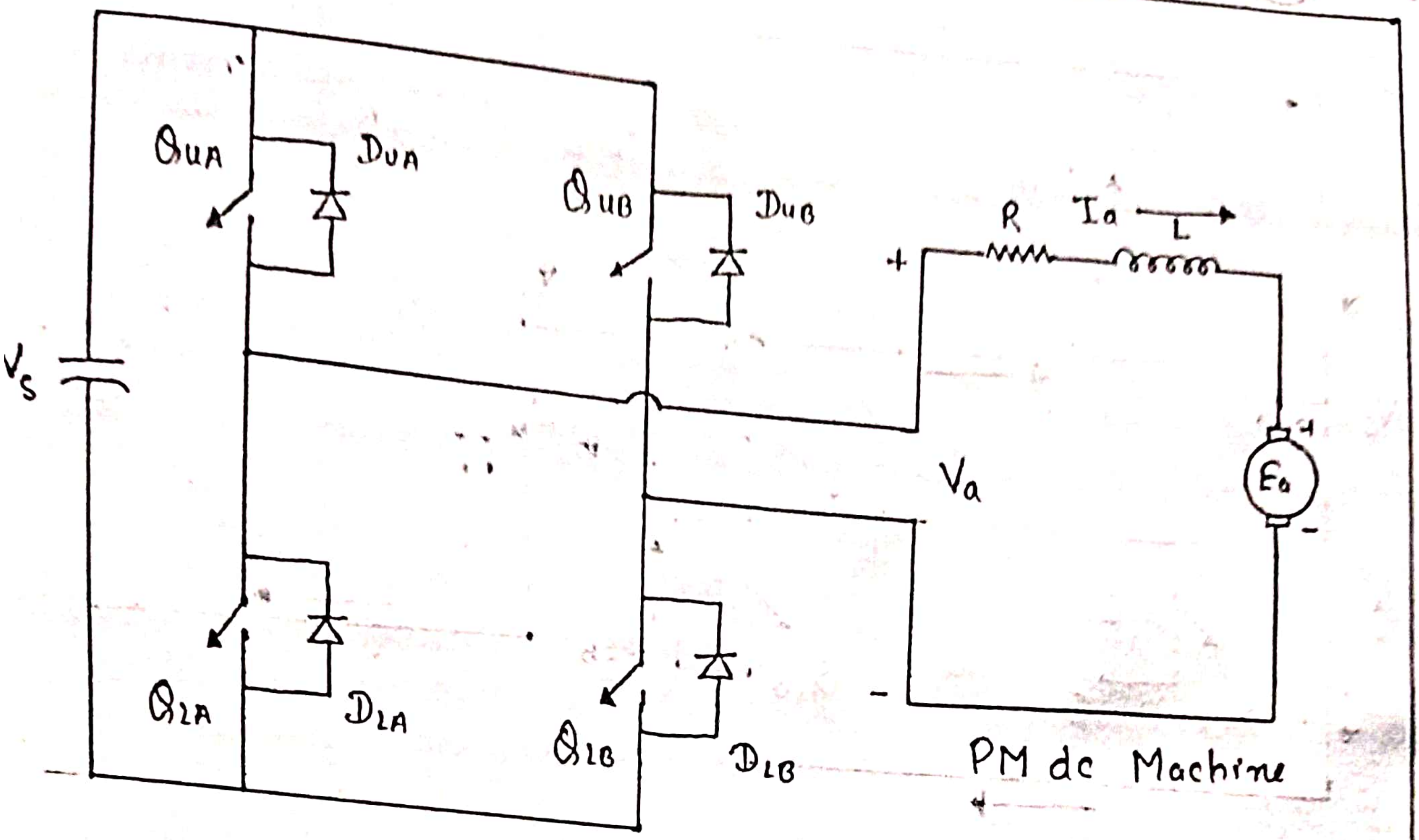
→ For light duty electric vehicle, PMDC is the best suitable Motor.

Circuit for regeneration of PMDC

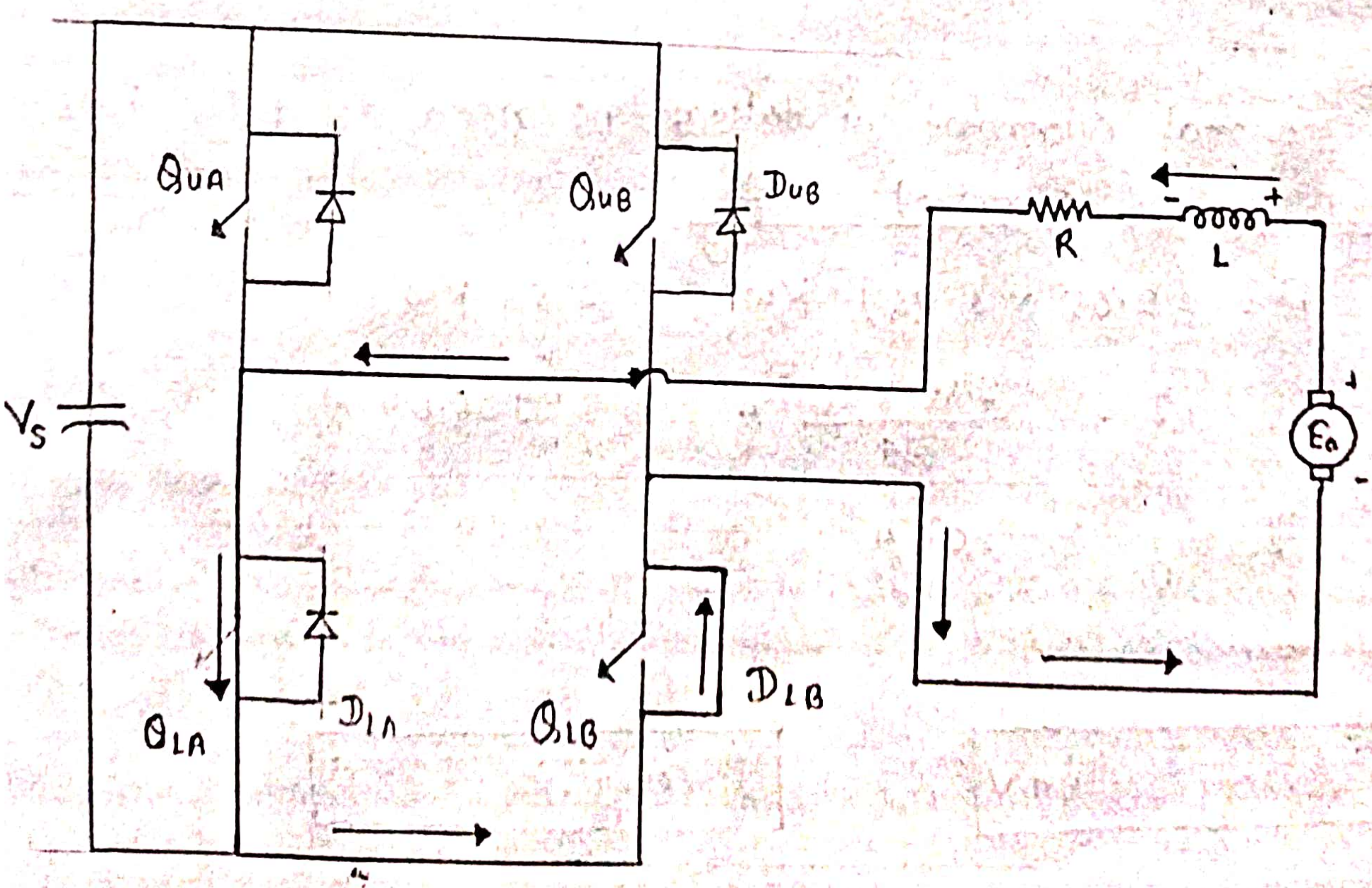
(a)



Forward Motoring

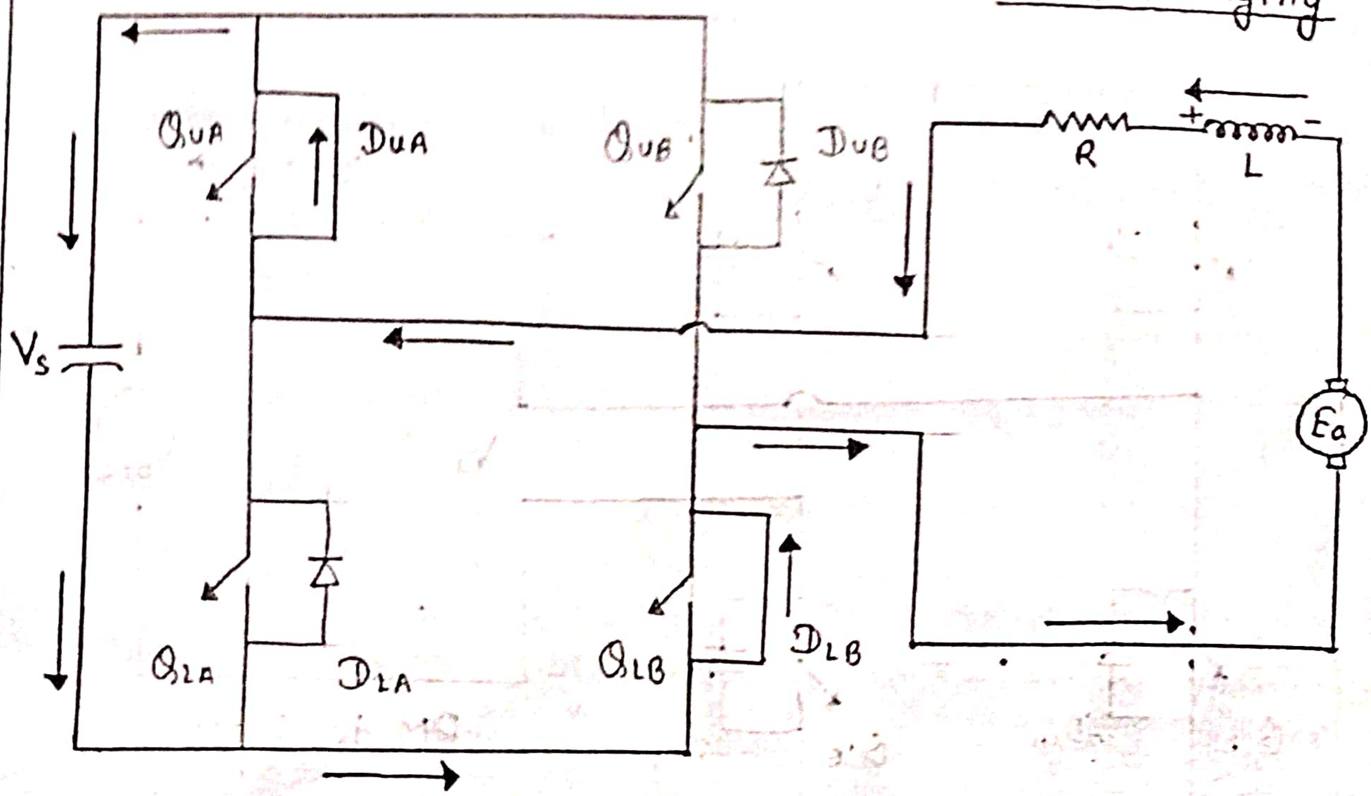


→ L - Charging   Q1A , D2B → active



D_{UA}, D_{LB} – active

L - Discharging



Power device rating

→ Voltage rating $\geq$ 24V (or) 24 V to 30 V

Current

DC

So, normal current is taken no need to take RMS.

Calculation of current rating

$$P = (2.05 \times 1.25)\ kW = 2.56\ kW$$

$$I = \frac{2.56 \times 10^3}{24}\ A = 106.67\ A$$

$$I_{rating} \geq 107\ A \quad (or) \quad 107\ A \text{ to } 110\ A$$

we have

$\boxed{V_{rating} \geq 24\ V}$ $\boxed{I_{rating} \geq 107\ A}$