LAMPIRAN

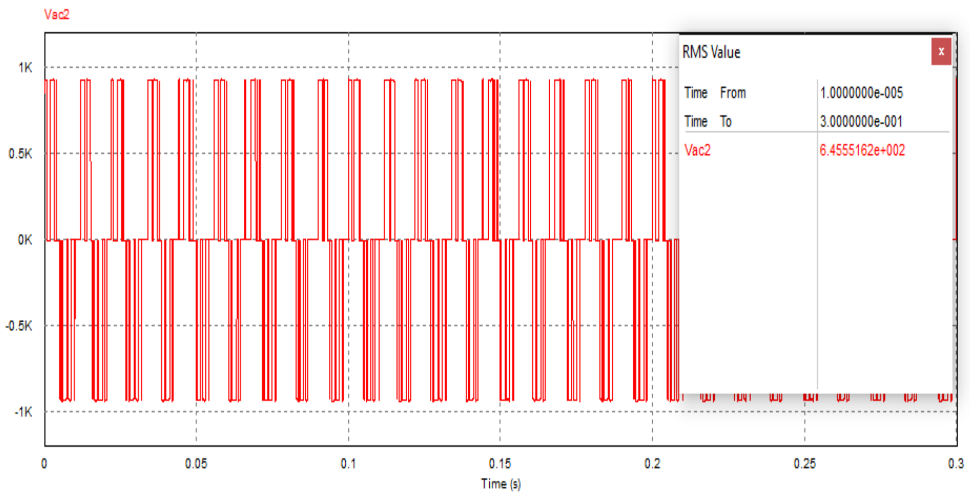
Lampiran 1. Perhitungan Rugi-rugi pada VVVF Inverter

a. Rugi-rugi dengan menggunakan f_{SW} 500 Hz.

Pada bagian ini akan dilakukan analisis terhadap rugi-rugi inverter tiga fasa dengan menggunakan frekuensi penyaklaran sebesar 500 Hz.

1) Keadaan pertama

Pada keadaan pertama keluaran inverter akan diatur untuk mendapatkan tegangan keluaran sebesar 645 volt dan frekuensi 90 Hz. Keluaran tersebut selanjutnya akan digunakan untuk memutar motor dengan kecepatan putaran 2634 rpm. Hasil simulasi sebagai berikut:



Untuk mendapatkan tegangan sebesar 645 volt pada keluaran inverter, maka rangkaian menggunakan indek modulati sebesar:

$$D = \frac{A_r}{A_c}$$

$$D = \frac{2,28}{4}$$

$$D = 0,57$$

Sehingga rugi-rugi yang terjadi pada VVVF Inverter sebagai berikut:

a) Rugi disipasi

$$P_{cond} = P_{cond} x D$$

$$P_{cond} = 1060x0,57$$

$$P_{cond} = 604,2 Watt$$

b) Rugi penyaklaran

$$P_{sw} = \frac{(E_{on} + E_{off}) x I_{pk} x f_{sw} x V_{dc}}{\pi x I_{nom} x V_{nom}}$$

$$P_{sw} = \frac{33,088x231,511x500x933,3}{\pi x290x1700}$$

$$P_{sw} = 2,308 KW$$

c) Rugi-rugi total

$$P_{igbt} = 6x(P_{cond} + P_{sw})$$

$$P_{igbt} = 6x(0,604 + 2,308)$$

$$P_{igbt} = 6x2,912$$

$$P_{igbt} = 17,472 KW$$

Maka,

$$P_{totloss} = P_{igbt} + P_{totdioda}$$

$$P_{totloss} = 17,472 + 2,52$$

$$P_{totloss} = 19,992 KW$$

d) Daya keluaran

$$P_{out} = P_{in} - P_{igbt}$$

$$P_{out} = 447,978 - 19,992$$

$$P_{out} = 427,506 KW$$

e) Efisiensi

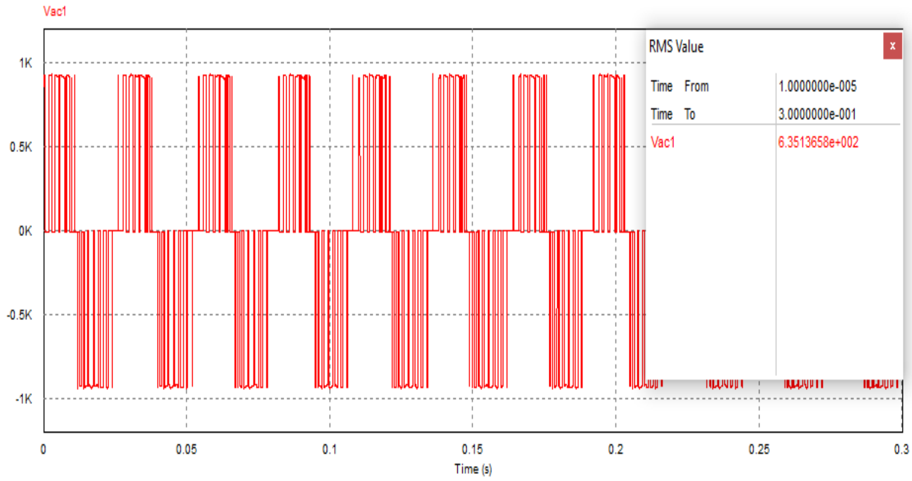
$$\eta = \frac{P_{out}}{P_{in}} x100\%$$

$$\eta = \frac{427,506}{447,978} x100\%$$

$$\eta = 95,43\%$$

2) Keadaan kedua

Pada keadaan pertama keluaran inverter akan diatur untuk mendapatkan tegangan keluaran sebesar 635 volt dan frekuensi 36,38 Hz. Keluaran tersebut selanjutnya akan digunakan untuk memutar motor dengan kecepatan putaran 1064 rpm. Hasil simulasi sebagai berikut:



Untuk mendapatkan tegangan sebesar 635 volt dan frekuensi pada keluaran inverter, maka rangkaian menggunakan indek modulati sebesar:

$$D = \frac{A_r}{A_c}$$

$$D = \frac{2{,}19}{4}$$

$$D = 0{,}547$$

Sehingga rugi-rugi yang terjadi pada VVVF Inverter sebagai berikut:

a) Rugi disipasi

$$P_{cond} = P_{cond} x D$$

$$P_{cond} = 1060 x 0{,}547$$

$$P_{cond} = 579{,}82 Watt$$

b) Rugi penyaklaran

$$P_{sw} = \frac{(E_{on} + E_{off}) x I_{pk} x f_{sw} x V_{dc}}{\pi x I_{nom} x V_{nom}}$$

$$P_{sw} = \frac{33{,}088 x 235{,}209 x 500 x 933{,}3}{\pi x 290 x 1700}$$

$$P_{sw} = 2{,}345 KW$$

c) Rugi-rugi total

$$P_{igbt} = 6x(P_{cond} + P_{sw})$$

$$P_{igbt} = 6x(0{,}58 + 2{,}345)$$

$$P_{igbt} = 6x2{,}925$$

$$P_{igbt} = 17{,}55 KW$$

Maka,

$$P_{totloss} = P_{igbt} + P_{totdioda}$$

$$P_{totloss} = 17,55 + 2,52$$

$$P_{totloss} = 20,07KW$$

d) Daya keluaran

$$P_{out} = P_{in} - P_{igbt}$$

$$P_{out} = 447,978 - 20,07$$

$$P_{out} = 427,908Watt$$

e) Efisiensi

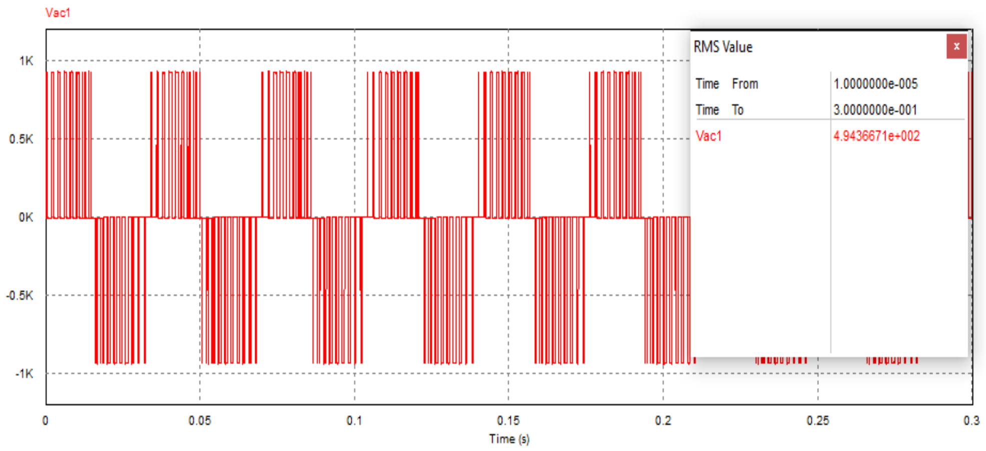
$$\eta = \frac{P_{out}}{P_{in}} x100\%$$

$$\eta = \frac{430,428}{447,978} x100\%$$

$$\eta = 96,08\%$$

3) Keadaan ketiga

Pada keadaan pertama keluaran inverter akan diatur untuk mendapatkan tegangan keluaran sebesar 494 volt volt dan frekuensi 28 Hz. Keluaran tersebut selanjutnya akan digunakan untuk memutar motor dengan kecepatan putaran 813 rpm. Hasil simulasi sebagai berikut:



Untuk mendapatkan tegangan sebesar 494 volt pada keluaran inverter, maka rangkaian menggunakan indek modulati sebesar:

$$D = \frac{A_r}{A_c}$$

$$D = \frac{1,02}{4}$$

$$D = 0.225$$

Sehingga rugi-rugi yang terjadi pada VVVF Inverter sebagai berikut:

a) Rugi disipasi

$$P_{cond} = P_{cond} x D$$

$$P_{cond} = 1060 x 0,225$$

$$P_{cond} = 238,5 Watt$$

b) Rugi penyaklaran

$$P_{sw} = \frac{(E_{on} + E_{off}) x I_{pk} x f_{sw} x V_{dc}}{\pi x I_{nom} x V_{nom}}$$

$$P_{sw} = \frac{33,088 x 302,285 x 500 x 933,3}{\pi x 290 x 1700}$$

$$P_{sw} = 3,013KW$$

c) Rugi-rugi total

$$P_{igbt} = 6x(P_{cond} + P_{sw})$$

$$P_{igbt} = 6x(0,238 + 3,013)$$

$$P_{igbt} = 6x3,251$$

$$P_{igbt} = 19,506KW$$

Maka,

$$P_{totloss} = P_{igbt} + P_{totdioda}$$

$$P_{totloss} = 19,506 + 2,52$$

$$P_{totloss} = 22,026KW$$

d) Daya keluaran

$$P_{out} = P_{in} - P_{igbt}$$

$$P_{out} = 447,978 - 22,026$$

$$P_{out} = 425,952KW$$

e) Efisiensi

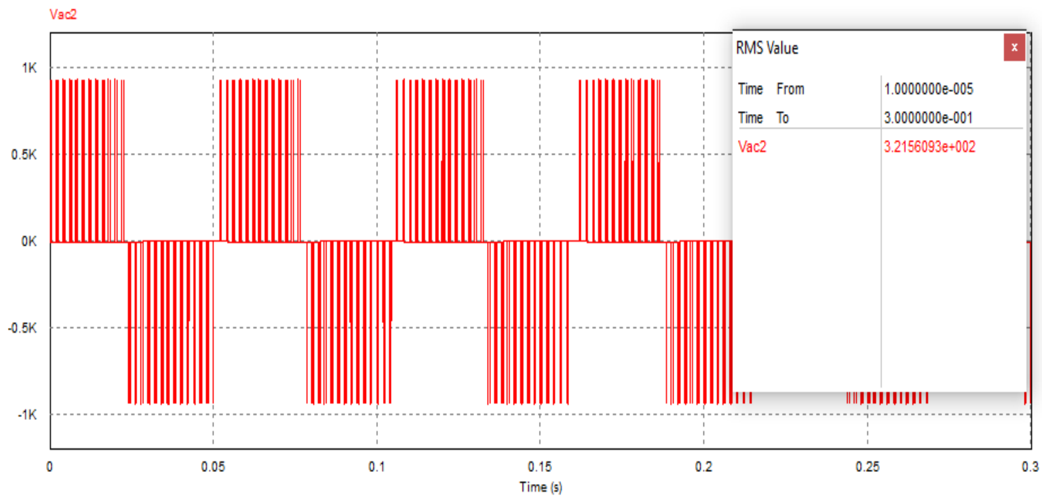
$$\eta = \frac{P_{out}}{P_{in}} x100\%$$

$$\eta = \frac{425,952}{447,978} x100\%$$

$$\eta = 95,083\%$$

4) Keadaan keempat

Pada keadaan pertama keluaran inverter akan diatur untuk mendapatkan tegangan keluaran sebesar 321 volt volt dan frekuensi 18,2 Hz. Keluaran tersebut selanjutnya akan digunakan untuk memutar motor dengan kecepatan putaran 518 rpm. Hasil simulasi sebagai berikut:



Untuk mendapatkan tegangan sebesar 321 volt pada keluaran inverter, maka rangkaian menggunakan indek modulati sebesar:

$$D = \frac{A_r}{A_c}$$

$$D = \frac{0,426}{4}$$

$$D = 0,1065$$

Sehingga rugi-rugi yang terjadi pada VVVF Inverter sebagai berikut:

a) Rugi disipasi

$$P_{cond} = P_{cond} x D$$

$$P_{cond} = 1060 x 0,1065$$

$$P_{cond} = 112,89 Watt$$

b) Rugi penyaklaran

$$P_{sw} = \frac{(E_{on} + E_{off}) x I_{pk} x f_{sw} x V_{dc}}{\pi x I_{nom} x V_{nom}}$$

$$P_{sw} = \frac{33,088 x 465,19 x 500 x 933,3}{\pi x 290 x 1700}$$

$$P_{sw} = 7,884 KW$$

c) Rugi-rugi total

$$P_{igbt} = 6x(P_{cond} + P_{sw})$$

$$P_{igbt} = 6x(0,113 + 7,884)$$

$$P_{igbt} = 6x7,997$$

$$P_{igbt} = 47,982 KW$$

Maka,

$$P_{totloss} = P_{igbt} + P_{totdioda}$$

$$P_{totloss} = 47,982 + 2,52$$

$$P_{totloss} = 50,502 KW$$

d) Daya keluaran

$$P_{out} = P_{in} - P_{igbt}$$

$$P_{out} = 447,978 - 50,502$$

$$P_{out} = 397,476 KW$$

e) Efisiensi

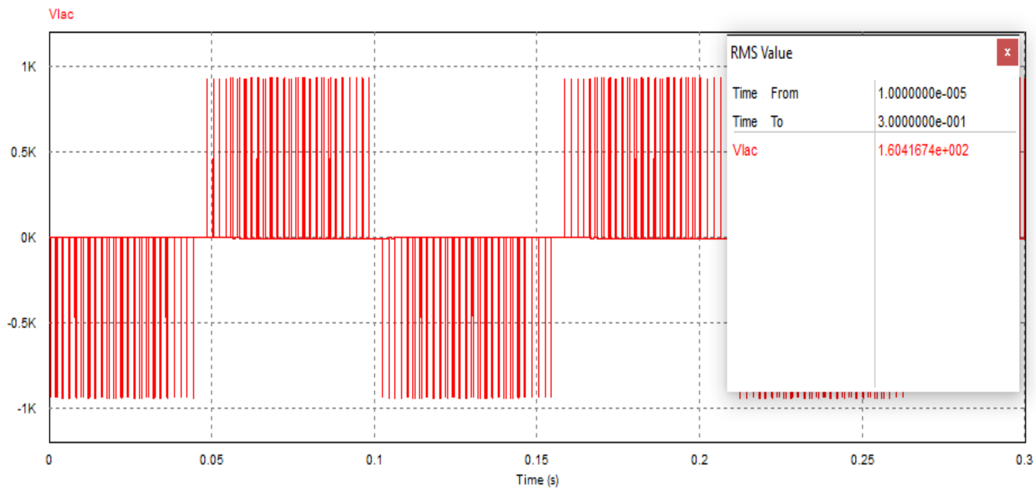
$$\eta = \frac{P_{out}}{P_{in}} x100\%$$

$$\eta = \frac{397,476}{447,978} x100\%$$

$$\eta = 88,727\%$$

5) Keadaan kelima

Pada keadaan pertama keluaran inverter akan diatur untuk mendapatkan tegangan keluaran sebesar 160,5 volt volt dan frekuensi 9,1 Hz. Keluaran tersebut selanjutnya akan digunakan untuk memutar motor dengan kecepatan putaran 238 rpm. Hasil simulasi sebagai berikut:



Untuk mendapatkan tegangan sebesar 160 volt pada keluaran inverter, maka rangkaian menggunakan indek modulati sebesar:

$$D = \frac{A_r}{A_c}$$

$$D = \frac{0{,}101}{4}$$

$$D = 0{,}025$$

Sehingga rugi-rugi yang terjadi pada VVVF Inverter sebagai berikut:

1) Rugi disipasi

$$P_{cond} = P_{cond} x D$$

$$P_{cond} = 1060 x 0{,}025$$

$$P_{cond} = 26{,}5 Watt$$

2) Rugi penyaklaran

$$P_{sw} = \frac{(E_{on} + E_{off}) x I_{pk} x f_{sw} x V_{dc}}{\pi x I_{nom} x V_{nom}}$$

$$P_{sw} = \frac{33,088x930x500x933,3}{\pi x290x1700}$$

$$P_{sw} = 9,271KW$$

3) Rugi-rugi total

$$P_{igbt} = 6x(P_{cond} + P_{sw})$$

$$P_{igbt} = 6x(0,026 + 9,271)$$

$$P_{igbt} = 6x9,297$$

$$P_{igbt} = 55,782KW$$

Maka,

$$P_{totloss} = P_{igbt} + P_{totdioda}$$

$$P_{totloss} = 55,782 + 2,52$$

$$P_{totloss} = 58,302KW$$

4) Daya keluaran

$$P_{out} = P_{in} - P_{igbt}$$

$$P_{out} = 447,978 - 58,302$$

$$P_{out} = 389,676Watt$$

5) Efisiensi

$$\eta = \frac{P_{out}}{P_{in}} x100\%$$

$$\eta = \frac{392,196}{447,978} x100\%$$

$$\eta = 87,548\%$$

Lampiran 2. Perhitungan Rugi-rugi Motor Induksi Tiga Fasa

4.6.1 Rugi-rugi Motor Induksi dengan variasi masukan

a. Keadaan pertama

Daerah Kerja	Nilai	Daerah Kerja	Nilai
Pshift	200 KW	X1	0,52286 Ohm
Tegangan	645 Volt	X2	0,24223 Ohm
Frekuensi	90 Hz	Xh	0,24223 Ohm
Arus	197,28 A	Φg	14,32132 mVs
Putaran	2634 rpm	L1	0,921 mH
Momen	740 Nm	L2	0,422mH
Cos Phi	0,87	Lh	25,326 mH
Efisiensi	93,44%	Rc	667,490 Ohm
Daya gesekan	2331,44 Watt	R1	0,04581 Ohm
I0	25,09 A	R2	0,04080 Ohm

Berdasarkan tabel keadaan diatas, maka rugi-rugi pada motor induksi sebagai berikut:

1) Daya input motor

$$P_{in} = \sqrt{3} x V x I x \cos\theta$$

$$P_{in} = \sqrt{3} x 645 x 197,28 x 0,87$$

$$P_{in} = 191,74 KW$$

2) Rugi-rugi tembaga stator

$$P_{ts} = 3xI_s{}^2 xR_s$$

$$P_{ts} = 3x197,28^2 x0,04581$$

$$P_{ts} = 5,349\ KW$$

3) Rugi-rugi inti stator

$$P_i = \frac{3xE^2{}_s}{R_c}$$

$$P_i = \frac{3x645^2}{667,490}$$

$$P_i = 1,870KW$$

Sehingga rugi-rugi total stator

$$P_s = P_{ts} + P_i$$

$$P_s = 5,349 + 1,870$$

$$P_s = 7,219KW$$

4) Daya rotor = daya celah udara

$$P_{cu} = P_{in} - P_s$$

$$P_{cu} = 191,74 - 7,219$$

$$P_{cu} = 184,521KW$$

5) Rugi-rugi rotor

$$N_s = \frac{120f}{p}$$

$$N_s = \frac{120x90}{4}$$

$$N_s = 2700$$

Maka besarnya slip

$$s = \frac{N_s - N_r}{N_s}$$

$$s = \frac{2700 - 2634}{2700}$$

$$s = 0,024$$

Sehingga rugi-rugi pada tembaga rotor

$$P_{tr} = sxP_{cu}$$

$$P_{tr} = 0,024x184,521$$

$$P_{tr} = 4,428KW$$

6) Daya mekanik

$$P_{mek} = P_{cu} - P_{tr}$$

$$P_{mek} = 184,521 - 4,428$$

$$P_{mek} = 180,093\,KW$$

7) Rugi gesekan

$$P_g = 2331,44\,W$$

8) Rugi stray

$$P_b = 1,5\%x(P_{mek} - P_g)$$

$$P_b = 1,5\%x(180,093 - 2,33144)$$

$$P_b = 2,666\,KW$$

9) Rugi-rugi total

$$P_{Losses} = P_{ts} + P_{i} + P_{tr} + P_{g} + P_{b}$$

$$P_{Losses} = 5,349 + 1,870 + 4,428 + 2,33144 + 2,666$$

$$P_{Losses} = 16,644 KW$$

10) Daya keluaran

$$P_{out} = P_{mek} - P_{g} - P_{b}$$

$$P_{out} = 180,093 - 2,33144 - 2,666$$

$$P_{out} = 175,096 KW$$

11) Efisiensi

$$\eta = \frac{P_{out}}{P_{in}} x100\%$$

$$\eta = \frac{175,096}{191,74} x100\%$$

$$\eta = 91,319\%$$

b. Keadaan kedua

Daerah Kerja	Nilai	Daerah Kerja	Nilai
Pshift	200 KW	X1	0,21332 Ohm
Tegangan	635 Volt	X2	0,10386 Ohm
Daerah Kerja	Nilai	Daerah Kerja	Nilai
Frekuensi	36,38 Hz	Xh	5,10502 Ohm
Arus	217,6 A	Φg	48,05 mVs

Putaran	1064 rpm	L1	0,921 mH
Momen	1800 Nm	L2	0.422 mH
Cos Phi	0,89	Lh	22,569 mH
Efisiensi	93,97%	Rc	365,442 Ohm
Daya gesekan	373,03 watt	R1	0,04581 Ohm
I0	68,9 A	R2	0,04080 Ohm

Berdasarkan tabel keadaan diatas, maka rugi-rugi pada motor induksi sebagai berikut:

1) Daya input motor

$$P_{in} = \sqrt{3} x V x I x \cos\theta$$

$$P_{in} = \sqrt{3} x 635 x 217,6 x 0,89$$

$$P_{in} = 212,4 KW$$

2) Rugi-rugi tembaga stator

$$P_{ts} = 3 x I_s^{2} x R_s$$

$$P_{ts} = 3 x 217,6^{2} x 0,04581$$

$$P_{ts} = 6,507 KW$$

3) Rugi-rugi inti stator

$$P_i = \frac{3 x E^2_s}{R_c}$$

$$P_i = \frac{3 x 635^2}{365,442}$$

$$P_i = 3,310 KW$$

Sehingga rugi-rugi total stator, sebagai berikut:

$$P_s = P_{ts} + P_i$$

$$P_s = 6,507 + 3,31$$

$$P_s = 9,817 KW$$

4) Daya rotor = Daya celah udara

$$P_{cu} = P_{in} - P_s$$

$$P_{cu} = 212,4 - 9,817$$

$$P_{cu} = 202,583$$

5) Rugi-rugi rotor

$$N_s = \frac{120f}{p}$$

$$N_s = \frac{120x36,38}{4}$$

$$N_s = 1091$$

Maka besarnya slip

$$s = \frac{N_s - N_r}{N_s}$$

$$s = \frac{1091 - 1064}{1091}$$

$$s = 0,025$$

Sehingga rugi-rugi pada tembaga rotor

$$P_{tr} = sxP_{cu}$$

$$P_{tr} = 0,025x202,583$$

$$P_{tr} = 5,064KW$$

6) Daya mekanik

$$P_{mek} = P_{cu} - P_{tr}$$

$$P_{mek} = 202,583 - 5,064$$

$$P_{mek} = 197,519KW$$

7) Rugi gesekan

$$P_g = 373,03\,W$$

8) Rugi stray

$$P_b = 1,5\%x(P_{mek} - P_g)$$

$$P_b = 1,5\%x(197,519 - 0.37303)$$

$$P_b = 2,957KW$$

9) Rugi-rugi total

$$P_{Losses} = P_{ts} + P_i + P_{tr} + P_g + P_b$$

$$P_{Losses} = 6,507 + 3,310 + 5,064 + 0,37303 + 2,957$$

$$P_{Losses} = 18,211KW$$

10) Daya keluaran

$$P_{out} = P_{mek} - P_g - P_s$$

$$P_{out} = 197,519 - 0,37303 - 2,957$$

$$P_{out} = 194,189KW$$

11) Efisiensi

$$\eta = \frac{P_{out}}{P_{in}} x100\%$$

$$\eta = \frac{194,189}{212,4} x100\%$$

$$\eta = 91,426\%$$

c. Keadaan ketiga

Tabel 10. Data teknis motor induksi tiga fasa pada keadaan kedua

Daerah Kerja	**Nilai**	**Daerah Kerja**	**Nilai**
Pshift	153 KW	X1	0,16839 Ohm
Tegangan	493,9 Volt	X2	0,08475 Ohm
Frekuensi	28 Hz	Xh	3,97066 Ohm
Arus	217,9 A	Φg	48,05 mVs
Putaran	813	L1	0,921 mH
Momen	1800	L2	0,422 mH
Cos Phi	0,89	Lh	22,570 mH
Daerah Kerja	Nilai	Daerah Kerja	Nilai
Efisiensi	92,47%	Rc	297,478 Ohm
Daya gesekan	225,66 Watt	R1	0,04581 Ohm
I0	68,9	R2	0,04080 Ohm

Berdasarkan tabel keadaan diatas, maka rugi-rugi pada motor induksi sebagai berikut:

1) Daya input motor

$$P_{in} = \sqrt{3} xVxIxcos\theta$$

$$P_{in} = \sqrt{3}x493,9x217,9x0,89$$

$$P_{in} = 165,900KW$$

2) Rugi-rugi tembaga stator

$$P_{ts} = 3xI_s^2xR_s$$

$$P_{ts} = 3x217,9^2 x0,04581$$

$$P_{ts} = 6,525KW$$

3) Rugi-rugi inti stator

$$P_i = \frac{3xE^2_s}{R_c}$$

$$P_i = \frac{3x493,9^2}{297,478}$$

$$P_i = 2,460KW$$

Sehingga rugi-rugi total stator

$$P_s = P_{ts} + P_i$$

$$P_s = 6,525 + 2,46$$

$$P_s = 8,985KW$$

4) Daya rotor = daya celah udara

$$P_{cu} = P_{in} - P_s$$

$$P_{cu} = 165,900 - 8.985$$

$$P_{cu} = 156,915KW$$

5) Rugi-rugi rotor

$$N_s = \frac{120f}{p}$$

$$N_s = \frac{120x28}{4}$$

$$N_s = 840$$

Maka besarnya slip

$$s = \frac{N_s - N_r}{N_s}$$

$$s = \frac{840 - 813}{840}$$

$$s = 0,032$$

Sehingga rugi-rugi pada tembaga rotor

$$P_{tr} = sxP_{cu}$$

$$P_{tr} = 0,032x156,915$$

$$P_{tr} = 5,021KW$$

6) Daya mekanik

$$P_{mek} = P_{cu} - P_{tr}$$

$$P_{mek} = 156,92 - 5,021$$

$$P_{mek} = 151,899KW$$

7) Rugi gesekan

$$P_g = 255,66\ W$$

8) Rugi stray

$$P_b = 1,5\%x(P_{mek} - P_g)$$

$$P_b = 1,5\% x (151,899 - 0,256)$$

$$P_b = 2,275 \text{ KW}$$

9) Rugi-rugi total

$$P_{Losses} = P_{ts} + P_i + P_{tr} + P_g + P_b$$

$$P_{Losses} = 6,525 + 2,460 + 5,021 + 0,25566 + 2,275$$

$$P_{Losses} = 16,537 \text{KW}$$

10) Daya keluaran

$$P_{out} = P_{mek} - P_g - P_b$$

$$P_{out} = 151,899 - 0,256 - 2,27$$

$$P_{out} = 149,363 \text{KW}$$

11) Efisiensi

$$\eta = \frac{P_{out}}{P_{in}} x100\%$$

$$\eta = \frac{149,605}{165,900} x100\%$$

$$\eta = 90,178\%$$

d. Keadaan keempat

Tabel 10. Data teknis motor induksi tiga fasa pada keadaan keempat

Daerah Kerja	Nilai	Daerah Kerja	Nilai
Pshift	98 KW	X1	0,11486 Ohm
Tegangan	321 Volt	X2	0,06321 Ohm
Frekuensi	18,2 Hz	Xh	2,58064 Ohm
Arus	224,4 A	Φg	48,05 mVs
Putaran	518 rpm	L1	0,921 mH
Momen	1800 Nm	L2	0,422 mH
Cos Phi	0,89	Lh	22,567 Ohm
Efisiensi	88,47%	Rc	205,036
Daya gesekan	23,84	R1	0,04581 Ohm
I0	95,34 A	R2	0,04080 Ohm

Berdasarkan tabel keadaan diatas, maka rugi-rugi pada motor induksi sebagai berikut:

1) Daya input motor

$$P_{in} = \sqrt{3} x V x I x \cos\theta$$

$$P_{in} = \sqrt{3} x 321 x 224,4 x 0,89$$

$$P_{in} = 111,040 KW$$

2) Rugi-rugi tembaga stator

$$P_{tr} = 3 x I_s^2 x R_s$$

$$P_{tr} = 3 x 224,4^2 x 0,04581$$

$$P_{tr} = 6,920\,KW$$

3) Rugi-rugi inti stator

$$P_i = \frac{3xE^2{}_s}{R_c}$$

$$P_i = \frac{3x321^2}{205,036}$$

$$P_i = 1,508KW$$

Sehingga rugi-rugi total stator

$$P_s = P_{ts} + P_i$$

$$P_s = 6,920 + 1,508$$

$$P_s = 8,428KW$$

4) Daya rotor = daya celah udara

$$P_{cu} = P_{in} - P_s$$

$$P_{cu} = 111,04 - 8.428$$

$$P_{cu} = 102,612KW$$

5) Rugi-rugi rotor

$$N_s = \frac{120f}{p}$$

$$N_s = \frac{120x18,2}{4}$$

$$N_s = 546$$

Maka besarnya slip

$$s = \frac{N_s - N_r}{N_s}$$

$$s = \frac{546 - 518}{546}$$

$$s = 0,05$$

Sehingga rugi-rugi pada tembaga rotor

$$P_{tr} = sxP_{cu}$$

$$P_{tr} = 0,05x102,612$$

$$P_{tr} = 5,131 KW$$

6) Daya mekanik

$$P_{mek} = P_{cu} - P_{tr}$$

$$P_{mek} = 102,612 - 5,131$$

$$P_{mek} = 97,481\,KW$$

7) Rugi gesekan

$$P_g = 88,47\ W$$

8) Rugi stray

$$P_b = 1,5\%x(P_{mek} - P_g)$$

$$P_b = 1,5\%x(97,481 - 0,088)$$

$$P_b = 1,461\,KW$$

9) Rugi-rugi total

$$P_{Losses} = P_{ts} + P_i + P_{tr} + P_g + P_b$$

$$P_{Losses} = 6,920 + 1,508 + 5,131 + 0,088 + 1,461$$

$$P_{Losses} = 15,108KW$$

10) Daya keluar

$$P_{out} = P_{mek} - P_g - P_b$$

$$P_{out} = 97,481 - 0,088 - 1,461$$

$$P_{out} = 95,932KW$$

11) Efisiensi

$$\eta = \frac{P_{out}}{P_{in}} x100\%$$

$$\eta = \frac{95,932}{111,040} x100\%$$

$$\eta = 86,394\%$$

e. Keadaan kelima

Tabel 9. Data teknis motor induksi tiga fasa pada keadaan pertama

Daerah Kerja	Nilai	Daerah Kerja	Nilai
Pshift	44,95 KW	X1	0,06980 Ohm
Tegangan	160,5 Volt	X2	0,04741 Ohm
Frekuensi	9,1	Xh	1,29032 Ohm
Arus	247,64 A	Φg	48,05 mVs
Putaran	238 rpm	L1	0,921 mH
Momen	1800 Nm	L2	0,422 mH
Cos Phi	0,87	Lh	22,567 Ohm
Efisiensi	74,76%	Rc	108,621 Ohm

Daya gesekan	23,84 Watt	R1	0,04581 Ohm
I0	68,9 A	R2	0,04080 Ohm

Berdasarkan tabel keadaan diatas, maka rugi-rugi pada motor induksi sebagai berikut:

1) Daya input motor

$$P_{in} = \sqrt{3} x V x I x \cos\theta$$

$$P_{in} = \sqrt{3} x 160,5 x 247,64 x 0,87$$

$$P_{in} = 59,893 KW$$

2) Rugi-rugi tembaga stator

$$P_{ts} = 3 x I_s^2 x R_s$$

$$P_{ts} = 3 x 247,64^2 x 0,04581$$

$$P_{ts} = 8,428 \, KW$$

3) Rugi-rugi inti stator

$$P_i = \frac{3 x E^2_s}{R_c}$$

$$P_i = \frac{3 x 160,5^2}{108,621}$$

$$P_i = 0,711 KW$$

Sehingga rugi-rugi total stator

$$P_s = P_{ts} + P_i$$

$$P_s = 8,428 + 0,711$$

$$P_s = 9{,}139KW$$

4) Daya rotor = daya celah udara

$$P_{cu} = P_{in} - P_s$$

$$P_{cu} = 59{,}893 - 9{,}139$$

$$P_{cu} = 50{,}754KW$$

5) Rugi-rugi rotor

$$N_s = \frac{120f}{p}$$

$$N_s = \frac{120x9{,}1}{4}$$

$$N_s = 273$$

Maka besarnya slip

$$s = \frac{N_s - N_r}{N_s}$$

$$s = \frac{273 - 238}{273}$$

$$s = 0{,}13$$

Sehingga rugi-rugi pada tembaga rotor

$$P_{tr} = sxP_{cu}$$

$$P_{tr} = 0{,}13x50{,}754$$

$$P_{tr} = 6{,}598KW$$

6) daya mekanik

$$P_{mek} = P_{cu} - P_{tr}$$

$$P_{mek} = 50,754 - 6,598$$

$$P_{mek} = 44,156 \text{ KW}$$

7) Rugi gesekan

$$P_{g} = 23,84 \text{ W}$$

8) Rugi stray

$$P_{b} = 1,5\% x (P_{mek} - P_{g})$$

$$P_{b} = 1,5\% x (44,156 - 0,024)$$

$$P_{b} = 0,662 \text{ KW}$$

9) Rugi-rugi total

$$P_{Losses} = P_{ts} + P_{i} + P_{tr} + P_{g} + P_{b}$$

$$P_{Losses} = 8,428 + 0,711 + 6,598 + 0,024 + 0,662$$

$$P_{Losses} = 16,423 \text{KW}$$

10) Daya keluar

$$P_{out} = P_{mek} - P_{g} - P_{b}$$

$$P_{out} = 44,156 - 0,024 - 0,662$$

$$P_{out} = 43,47 \text{KW}$$

11) Efisiensi

$$\eta = \frac{P_{out}}{P_{in}} \text{x}100\%$$

$$\eta = \frac{43,47}{59,893} x100\%$$

$$\eta = 72,579\%$$

Lampiran 3. Data Teknis Generator Sinkron Tiga Fasa

SPESIFIKASI TEKNIS 560 kVA

Daya keluaran	:	560 kVA
(*Output power*)	:	448 kW
Faktor daya	:	0,8
(*Power Factor*)		
Jumlah kutub	:	4
(*Poles Number*)		
Tegangan (V)	:	660 V
(*Voltage* (V))		
Arus (I)	:	489,87 A
(*Current* (I))		
Frekuensi (f)	:	60 Hz
(*Frequency* (f))		
Putaran (n)	:	1800 rpm
(*Speed* (n))		
Pendinginan	:	*open air cooling*
(*Cooling system*)		
Bearing	:	*double contact bearing*
IP	:	23

Eksitasi (*Excitation*)

Arus medan (*Field current*)	:	115 A
Tegangan eksitasi (*Exc. Voltage*)	:	167 V
Medan stator (*Stator field*)		
Hambatan stator eksiter (*Stator exciter resistant*)	:	1,09 Ω (1,49 Ω pada/*at* 115° C)

pada 85kVA, 600V, 800rpm (*at* 85kVA, 600V, 800rpm)		Pada 560kVA, 660V, 1800rpm (at 560kVA, 660V, 1800rpm)	
Arus medan eksitasi: (*Exc. field current*)	14,47 A	Arus medan eksitasi: (*Exc. field current*)	12,16 A

Lampiran 4. Data Teknis Motor Induksi Tiga Fasa

Daerah Kerja (*Operating area*)		S1	11	12	14	21
P_{shaft}	[kW]	200	44,95	98	153	200
Tegangan (*Voltage*)	[V]	635	160,5	321	493,9	645
Frekuensi (*Frequency*)	[Hz]	36,38	9,1	18,2	28	90
Arus (*Current*)	[A]	217,6	247,64	224,4	217,9	197,28
Putaran (*Speed*)	[rpm]	1064	238	518	813	2634
Momen (*Moment*)	[Nm]	1800	1800	1800	1800	740
Cos phi		0,89	0,87	0,89	0,89	0,87
Efisiensi (*Efficiency*)	[%]	93,97	74,76	88,47	92,47	93,44
P_{FW} Gesekan (*Friction*)	[W]	373,03	23,84	95,34	225,66	2331,44
I_0	[A]	68,9	68,9	68,9	68,9	25,09
X1σ	[Ω]	0,21332	0,06980	0,11486	0,16839	0,52286
X2'σ	[Ω]	0,10386	0,04741	0,06321	0,08475	0,24223
Xh	[Ω]	5,10502	1,29032	2,58064	3,97066	14,32132
Φg	mVs	48,05	48,05	48,05	48,05	19,52
L1σ	[mH]	0,921	0,921	0,921	0,921	0,921
L2'σ	[mH]	0,422	0,422	0,422	0,422	0,422
Lh	[mH]	22,569	22,567	22,567	22,570	25,326
Rc	[Ω]	365,442	108,621	205,036	297,478	667,490
R1 (115° C)	[Ω]	0,04581				
R2' (115° C)	[Ω]	0,04080				

Lampiran 5. *Datasheet* Dioda

General Purpose Plastic Rectifier

DO-201AD

FEATURES

- Low forward voltage drop
- Low leakage current
- High forward surge capability
- Solder dip 275 °C max. 10 s, per JESD 22-B106
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912

RoHS COMPLIANT

PRIMARY CHARACTERISTICS	
$I_{F(AV)}$	3.0 A
V_{RRM}	50 V, 100 V, 200 V, 300 V, 500 V, 600 V, 800 V, 1000 V
I_{FSM}	200 A
I_R	5.0 μA
V_F	1.2 V
T_J max.	150 °C
Package	DO-201AD
Diode variations	Single die

TYPICAL APPLICATIONS

For use in general purpose rectification of power supplies, inverters, converters and freewheeling diodes application.

Note

- These devices are not AEC-Q101 qualified.

MECHANICAL DATA

Case: DO-201AD, molded epoxy body
Molding compound meets UL 94 V-0 flammability rating
Base P/N-E3 - RoHS-compliant, commercial grade

Terminals: Matte tin plated leads, solderable per J-STD-002 and JESD 22-B102
E3 suffix meets JESD 201 class 1A whisker test

Polarity: Color band denotes cathode end

MAXIMUM RATINGS (T_A = 25 °C unless otherwise noted)

PARAMETER	SYMBOL	1N5400	1N5401	1N5402	1N5403	1N5404	1N5405	1N5406	1N5407	1N5408	UNIT
Maximum repetitive peak reverse voltage	V_{RRM}	50	100	200	300	400	500	600	800	1000	V
Maximum RMS voltage	V_{RMS}	35	70	140	210	280	350	420	560	700	V
Maximum DC blocking voltage	V_{DC}	50	100	200	300	400	500	600	800	1000	V
Maximum average forward rectified current 0.5" (12.5 mm) lead length at T_L = 105 °C	$I_{F(AV)}$	3.0									A
Peak forward surge current 8.3 ms single half sine-wave superimposed on rated load	I_{FSM}	200									A
Maximum full load reverse current, full cycle average 0.5" (12.5 mm) lead length at T_L = 105 °C	$I_{R(AV)}$	500									μA
Operating junction and storage temperature range	T_J, T_{STG}	- 50 to + 150									°C

ELECTRICAL CHARACTERISTICS (T_A = 25 °C unless otherwise noted)												
PARAMETER	**TEST CONDITIONS**	**SYMBOL**	**1N5400**	**1N5401**	**1N5402**	**1N5403**	**1N5404**	**1N5405**	**1N5406**	**1N5407**	**1N5408**	**UNIT**
Maximum instantaneous forward voltage	3.0 A	V_F	1.2									V
Maximum DC reverse current at rated DC blocking voltage	T_A = 25 °C	I_R	5.0									μA
	T_A = 150 °C		500									
Typical junction capacitance	4.0 V, 1 MHz	C_J	30									pF

THERMAL CHARACTERISTICS (T_A = 25 °C unless otherwise noted)											
PARAMETER	**SYMBOL**	**1N5400**	**1N5401**	**1N5402**	**1N5403**	**1N5404**	**1N5405**	**1N5406**	**1N5407**	**1N5408**	**UNIT**
Typical thermal resistance	$R_{\theta JA}$ (1)	20									°C/W

Note

(1) Thermal resistance from junction to ambient at 0.375" (9.5 mm) lead length, PCB mounted with 0.8" x 0.8" (20 mm x 20 mm) copper heatsinks

ORDERING INFORMATION (Example)				
PREFERRED P/N	**UNIT WEIGHT (g)**	**PREFERRED PACKAGE CODE**	**BASE QUANTITY**	**DELIVERY MODE**
1N5404-E3/54	1.1	54	1400	13" diameter paper tape and reel
1N5404-E3/73	1.1	73	1000	Ammo pack packaging

RATINGS AND CHARACTERISTICS CURVES (T_A = 25 °C unless otherwise noted)

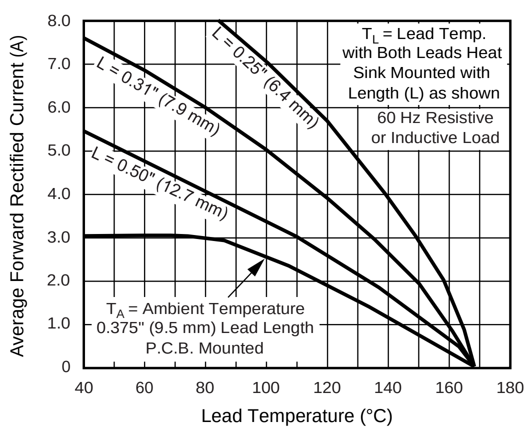


Fig. 1 - Forward Current Derating Curve

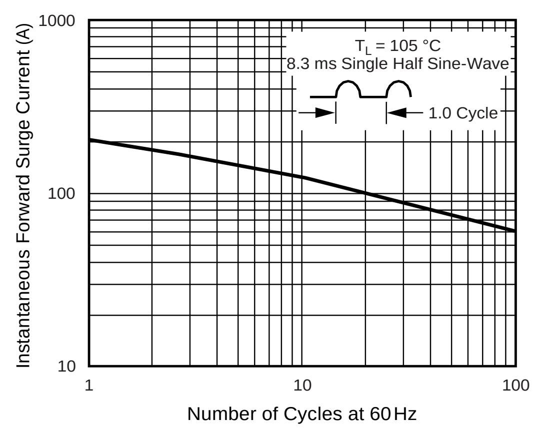


Fig. 2 - Maximum Non-Repetitive Peak Forward Surge Current

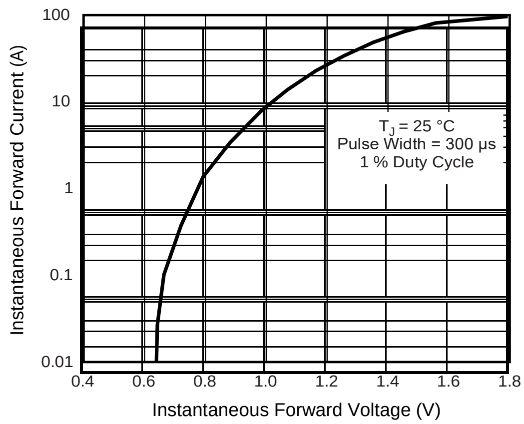


Fig. 3 - Typical Instantaneous Forward Characteristics

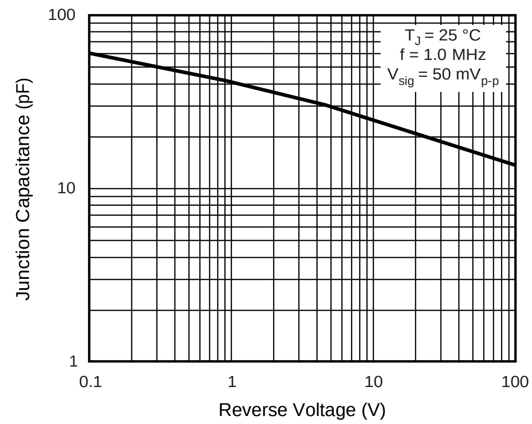


Fig. 5 - Typical Junction Capacitance

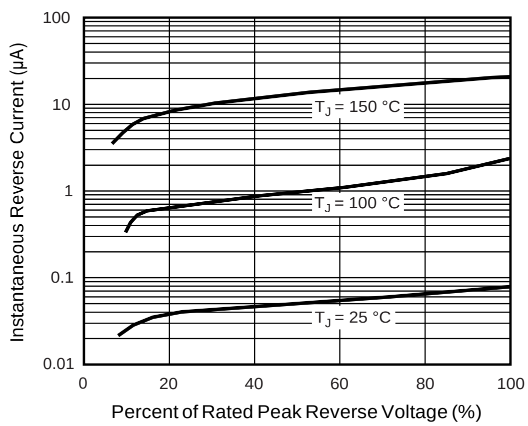


Fig. 4 - Typical Reverse Characteristics

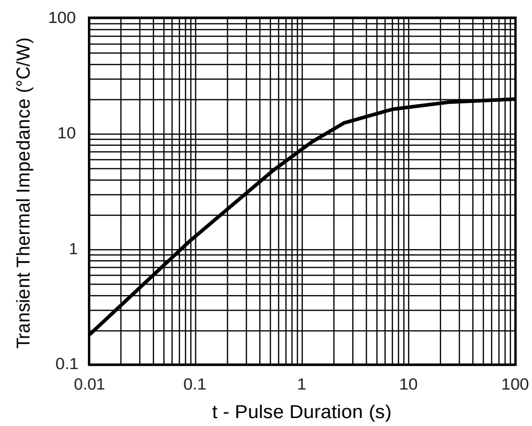
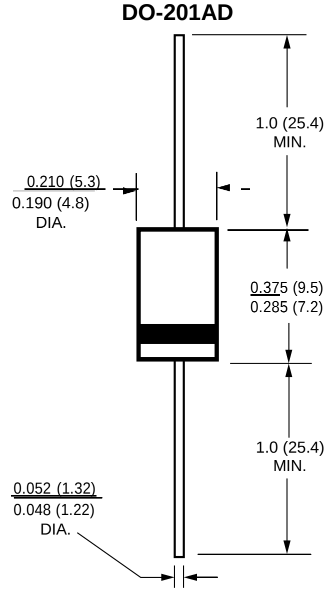


Fig. 6 - Typical Transient Thermal Impedance

PACKAGE OUTLINE DIMENSIONS in inches (millimeters)

DO-201AD



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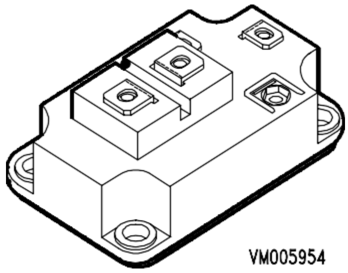
Lampiran 6. ***Datasheet*** **IGBT**

BSM 200 GA 170 DN2

IGBT Power Module



- Single switch
- Including fast free-wheeling diodes
- Package with insulated metal base plate
- $R_{G\ on,min}$ = 6.8 Ohm

Type	V_{CE}	I_C	Package	Ordering Code
BSM 200 GA 170 DN2	1700V	290A	SINGLE SWITCH 1	C67070-A2705-A67
BSM 200 GA 170 DN2 S	1700V	290A	SSW SENSE 1	C67070-A2707-A67

Maximum Ratings

Parameter	Symbol	Values	Unit
Collector-emitter voltage	V_{CE}	1700	V
Collector-gate voltage	V_{CGR}		
R_{GE} = 20 kΩ		1700	
Gate-emitter voltage	V_{GE}	± 20	
DC collector current	I_C		A
T_C = 25 °C		290	
T_C = 80 °C		200	
Pulsed collector current, t_p = 1 ms	I_{Cpuls}		
T_C = 25 °C		580	
T_C = 80 °C		400	
Power dissipation per IGBT	P_{tot}		W
T_C = 25 °C		1750	
Chip temperature	T_j	+ 150	°C
Storage temperature	T_{stg}	-40 ... + 125	

Thermal resistance, chip case	R_{thJC}	≤ 0.07	K/W
Diode thermal resistance, chip case	$R_{thJC\mathbf{D}}$	≤ 0.21	
Insulation test voltage, *t* = 1min.	V_{is}	4000	Vac
Creepage distance	-	20	mm
Clearance	-	11	
DIN humidity category, DIN 40 040	-	F	sec
IEC climatic category, DIN IEC 68-1	-	40 / 125 / 56	

Electrical Characteristics, at T_j = 25 °C, unless otherwise specified

Parameter	Symbol	Values			Unit
		min.	typ.	max.	
Static Characteristics					
Gate threshold voltage $V_{GE} = V_{CE}$, I_C = 16 mA	$V_{GE(th)}$	4.8	5.5	6.2	V
Collector-emitter saturation voltage V_{GE} = 15 V, I_C = 200 A, T_j = 25 °C V_{GE} = 15 V, I_C = 200 A, T_j = 125 °C	$V_{CE(sat)}$	- -	3.4 4.6	3.9 5.3	
Zero gate voltage collector current V_{CE} = 1700 V, V_{GE} = 0 V, T_j = 25 °C V_{CE} = 1700 V, V_{GE} = 0 V, T_j = 125 °C	I_{CES}	- -	1.6 6.4	2 -	mA
Gate-emitter leakage current V_{GE} = 20 V, V_{CE} = 0 V	I_{GES}	-	-	320	nA
AC Characteristics					
Transconductance V_{CE} = 20 V, I_C = 200 A	g_{fs}	72	-	-	S
Input capacitance V_{CE} = 25 V, V_{GE} = 0 V, f = 1 MHz	C_{iss}	-	32	-	nF
Output capacitance V_{CE} = 25 V, V_{GE} = 0 V, f = 1 MHz	C_{oss}	-	2.5	-	
Reverse transfer capacitance V_{CE} = 25 V, V_{GE} = 0 V, f = 1 MHz	C_{rss}	-	1	-	

Electrical Characteristics, at T_j = 25 °C, unless otherwise specified

Parameter	Symbol	Values			Unit
		min.	typ.	max.	
Switching Characteristics, Inductive Load at T_j = 125 °C					
Turn-on delay time V_{CC} = 1200 V, V_{GE} = 15 V, I_C = 200 A R_{Gon} = 6.8 Ω	$t_{d(on)}$	-	530	1000	ns
Rise time V_{CC} = 1200 V, V_{GE} = 15 V, I_C = 200 A R_{Gon} = 6.8 Ω	t_r	-	200	400	
Turn-off delay time V_{CC} = 1200 V, V_{GE} = -15 V, I_C = 200 A R_{Goff} = 6.8 Ω	$t_{d(off)}$	-	1250	1800	
Fall time V_{CC} = 1200 V, V_{GE} = -15 V, I_C = 200 A R_{Goff} = 6.8 Ω	t_f	-	110	160	

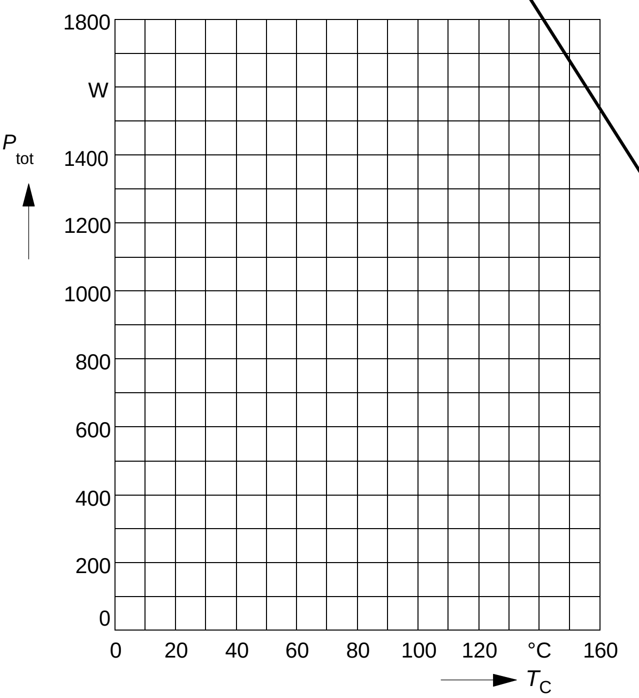
Free-Wheel Diode

Parameter	Symbol	min.	typ.	max.	Unit
Diode forward voltage I_F = 200 A, V_{GE} = 0 V, T_j = 25 °C I_F = 200 A, V_{GE} = 0 V, T_j = 125 °C	V_F	 - -	 2.3 2.1	 2.8 -	V
Reverse recovery time I_F = 200 A, V_R = -1200 V, V_{GE} = 0 V di_F/dt = -1400 A/µs, T_j = 125 °C	t_{rr}	-	0.8	-	µs
Reverse recovery charge I_F = 200 A, V_R = -1200 V, V_{GE} = 0 V di_F/dt = -1400 A/µs T_j = 25 °C T_j = 125 °C	Q_{rr}	 - -	 14 50	 - -	µC

Power dissipation

$P_{tot} = f(T_C)$

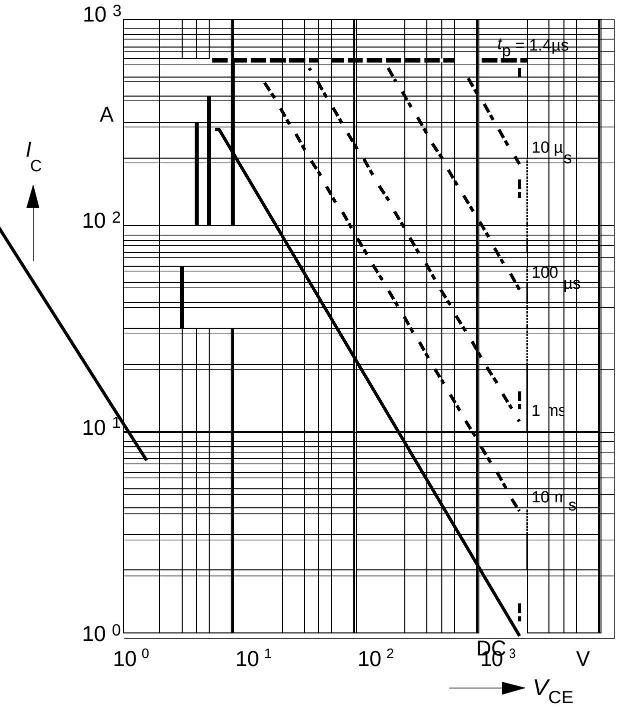
parameter: $T_j \leq 150$ °C



Safe operating area

$I_C = f(V_{CE})$

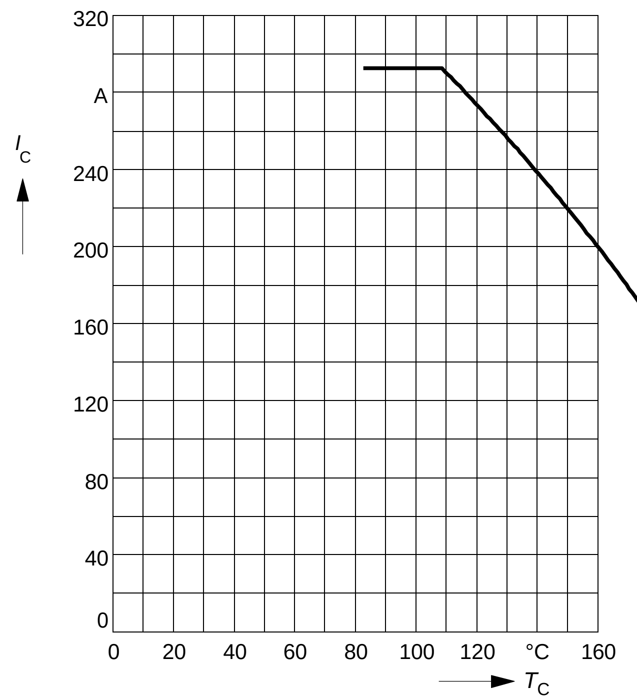
parameter: $D = 0$, $T_C = 25$°C , $T_j \leq 150$ °C



Collector current

$I_C = f(T_C)$

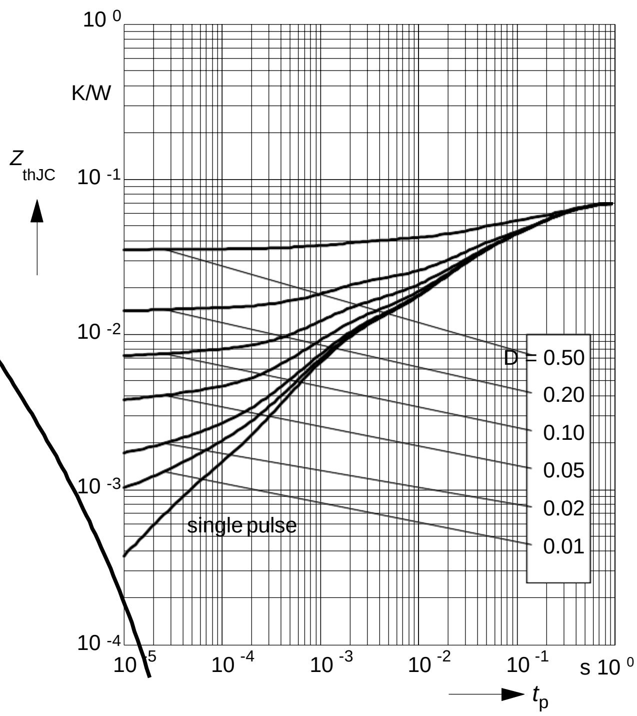
parameter: $V_{GE} \geq 15$ V , $T_j \leq 150$ °C



Transient thermal impedance IGBT

$Z_{th\ JC} = f(t_p)$

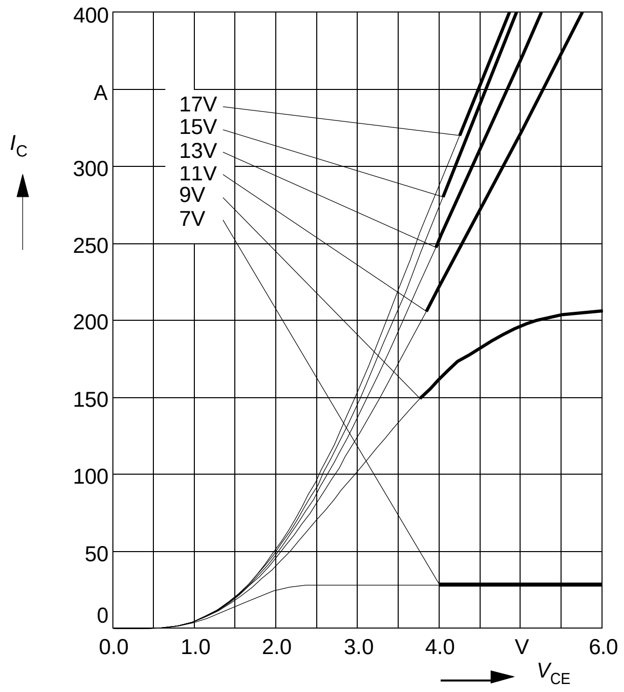
parameter: $D = t_p / T$



Typ. output characteristics

$I_C = f(V_{CE})$

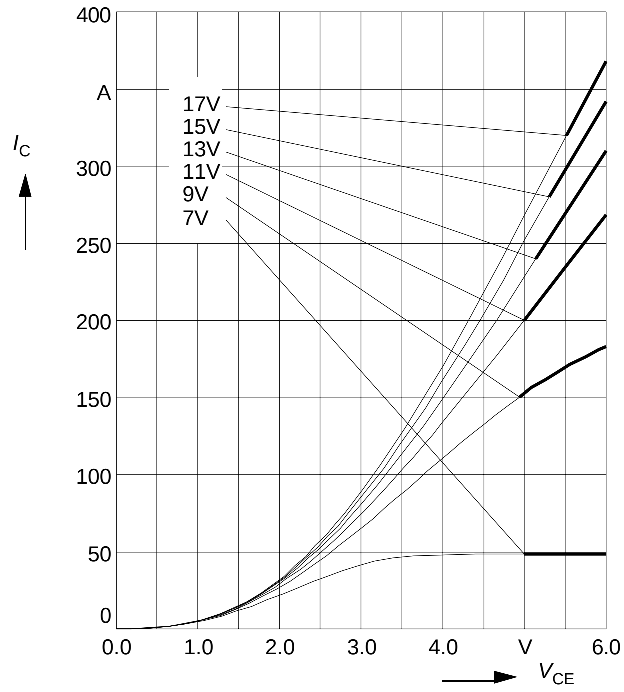
parameter: t_p = 80 µs, T_j = 25 °C



Typ. output characteristics

$I_C = f(V_{CE})$

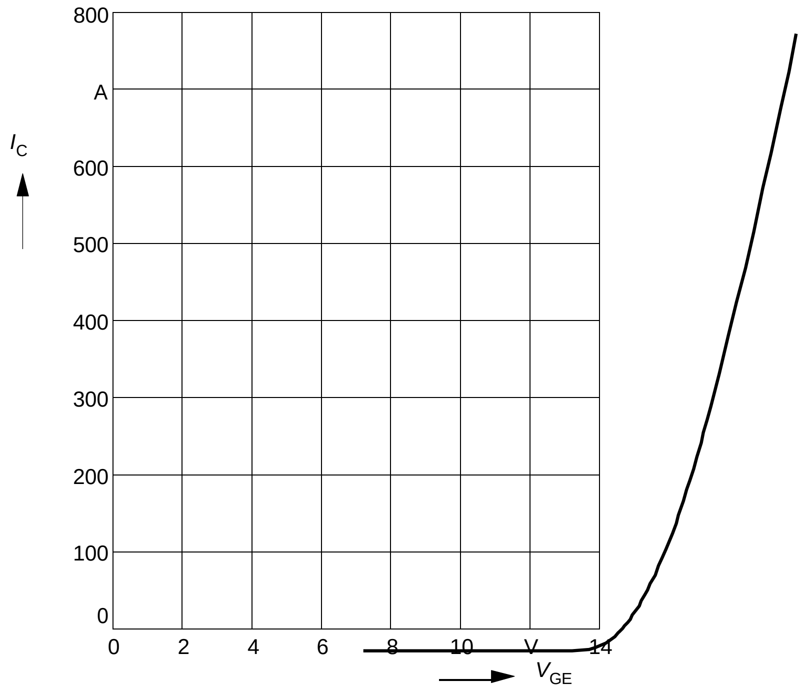
parameter: t_p = 80 µs, T_j = 125 °C



Typ. transfer characteristics

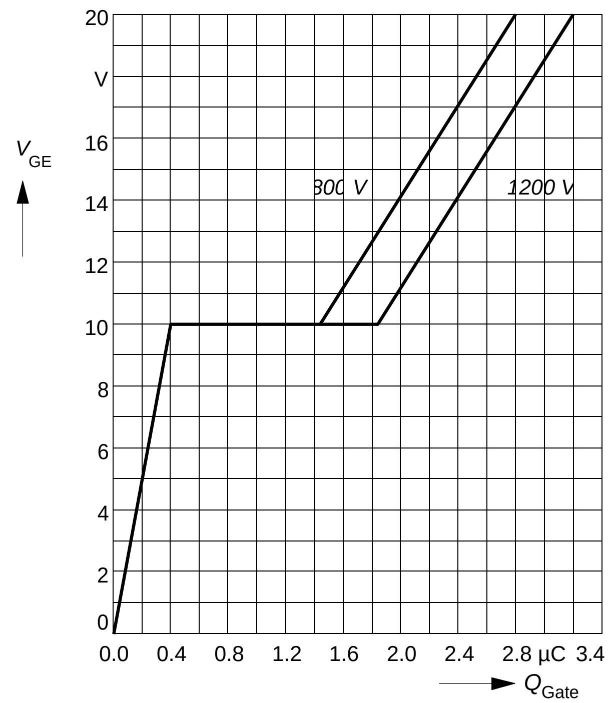
$I_C = f(V_{GE})$

parameter: t_p = 80 µs, V_{CE} = 20 V



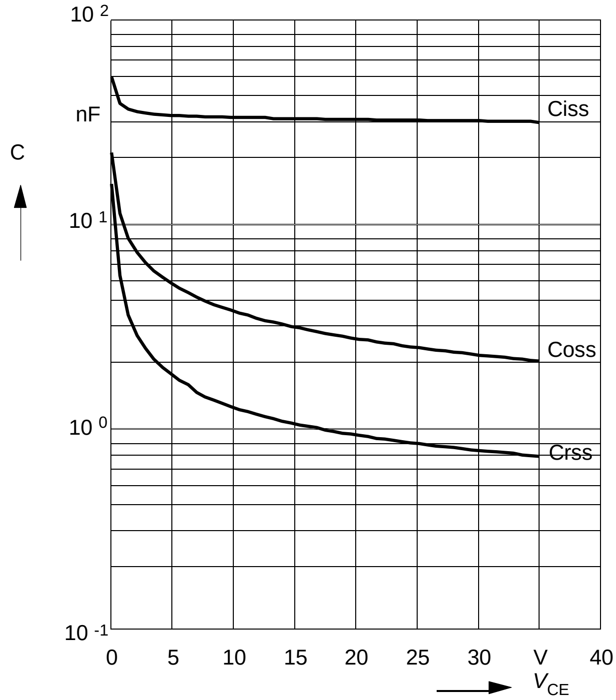
Typ. gate charge

$V_{GE} = f(Q_{Gate})$
parameter: $I_{C\ puls}$ = 200 A



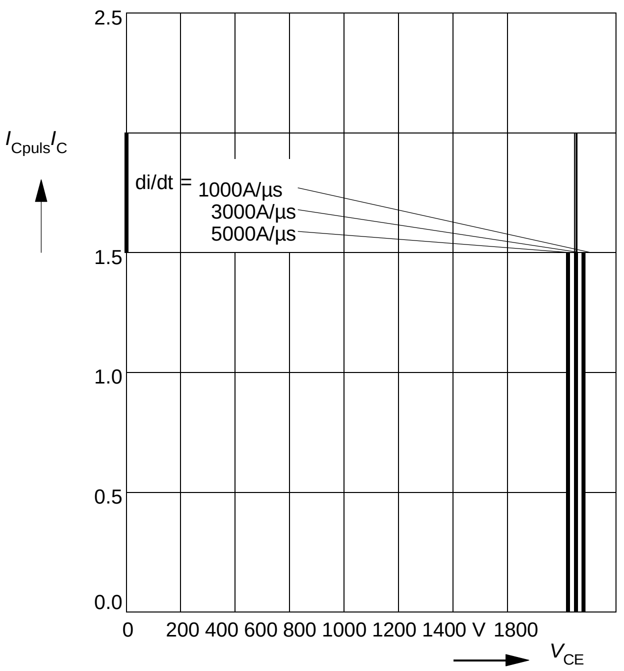
Typ. capacitances

$C = f(V_{CE})$
parameter: V_{GE} = 0, f = 1 MHz



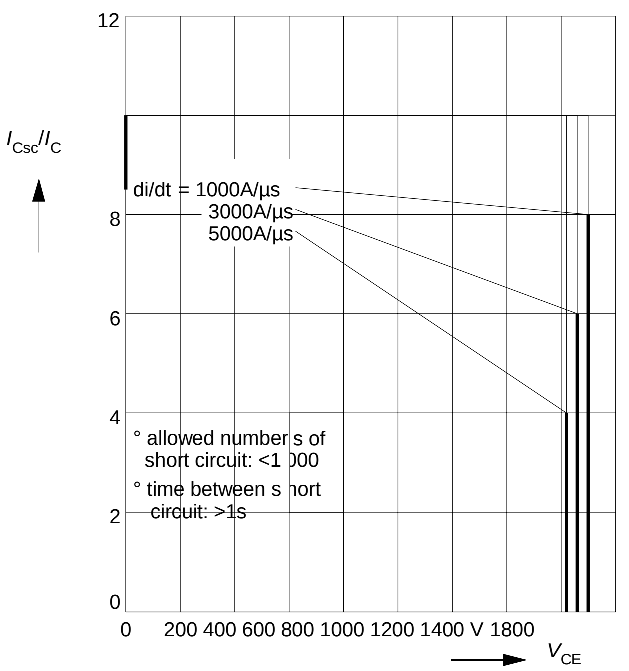
Reverse biased safe operating area

$I_{Cpuls} = f(V_{CE})$, T_j = 150°C
parameter: V_{GE} = ± 15 V, $t_p \leq$ 1 ms, L < 20 nH



Short circuit safe operating area

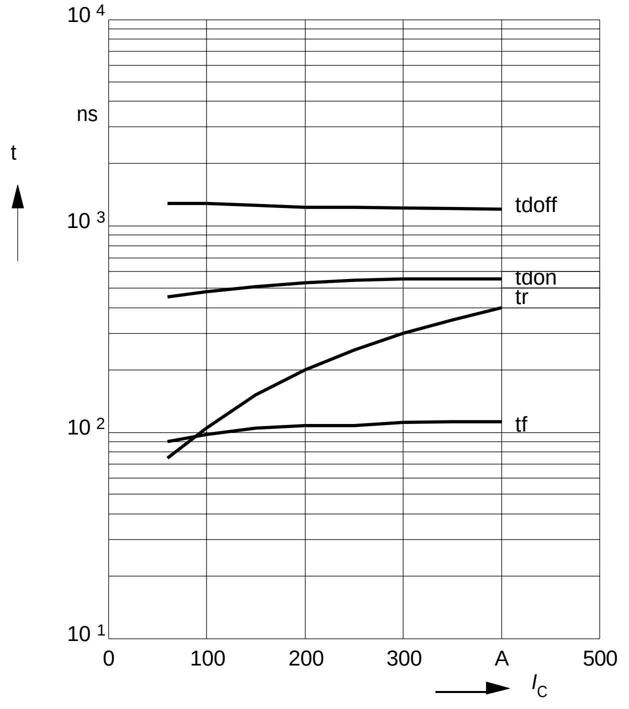
$I_{Csc} = f(V_{CE})$, T_j = 150°C
parameter: V_{GE} = ± 15 V, $t_{SC} \leq$ 10 µs, L < 20 nH



Typ. switching time

$t = f(I_C)$, inductive load , T_j = 125°C

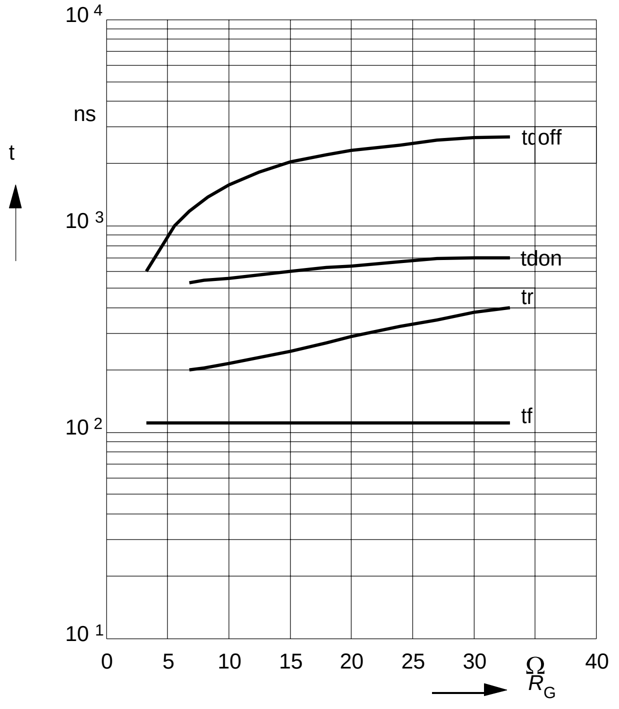
par.: V_{CE} = 1200 V, V_{GE} = ± 15 V, R_G = 6.8 Ω



Typ. switching time

$t = f(R_G)$, inductive load , T_j = 125°C

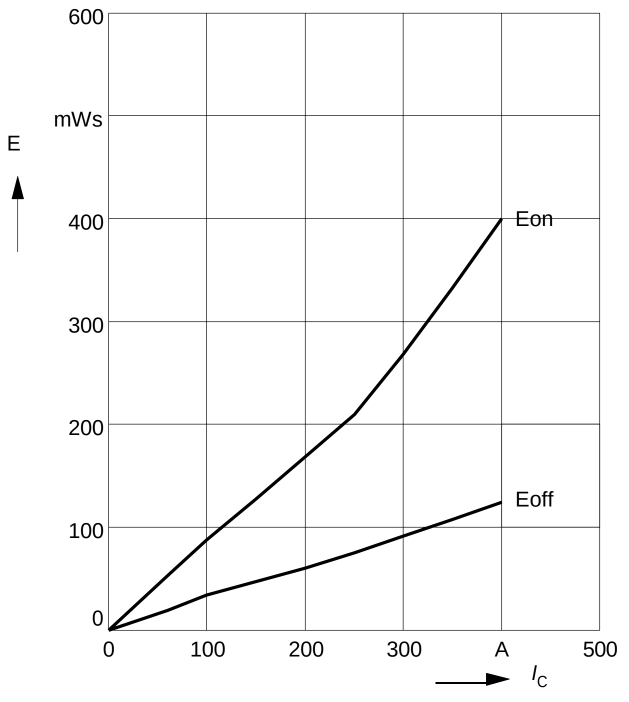
par.: V_{CE} = 1200 V, V_{GE} = ± 15 V, I_C = 200 A



Typ. switching losses

$E = f(I_C)$, inductive load , T_j = 125°C

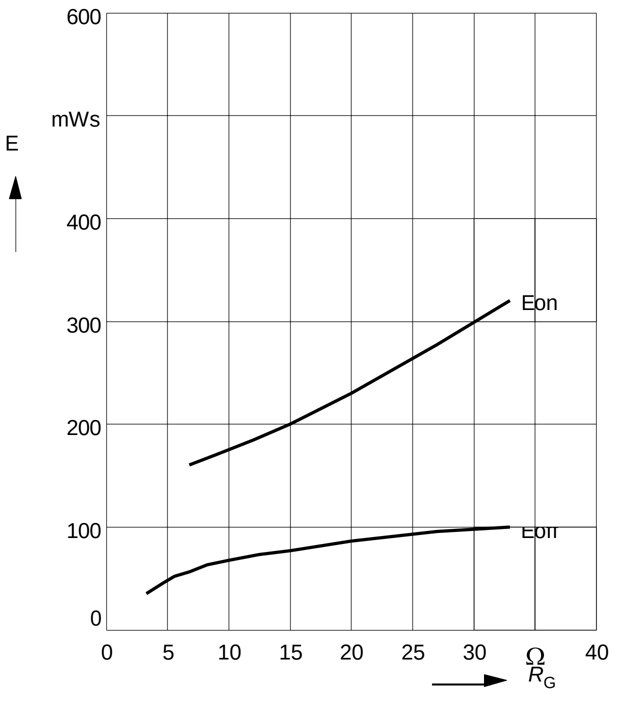
par.: V_{CE} = 1200 V, V_{GE} = ± 15 V, R_G = 6.8 Ω



Typ. switching losses

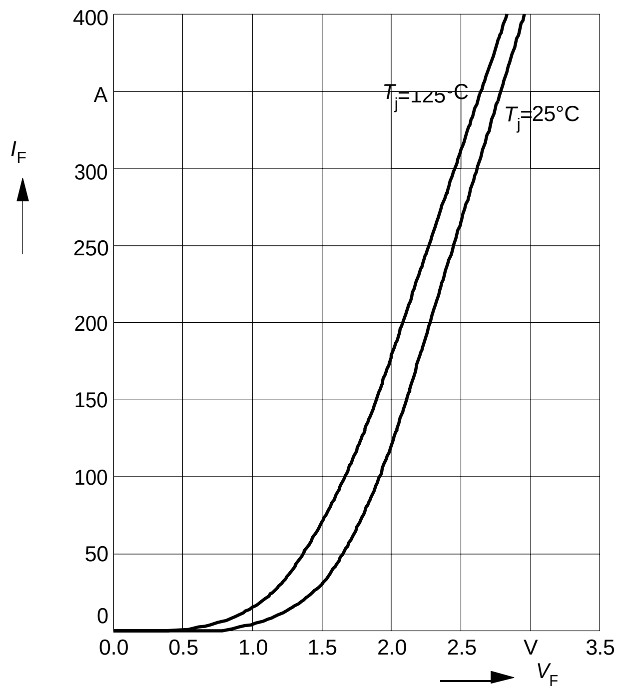
$E = f(R_G)$, inductive load , T_j = 125°C

par.: V_{CE} = 1200 V, V_{GE} = ± 15 V, I_C = 200 A



Forward characteristics of fast recovery reverse diode $I_F = f(V_F)$

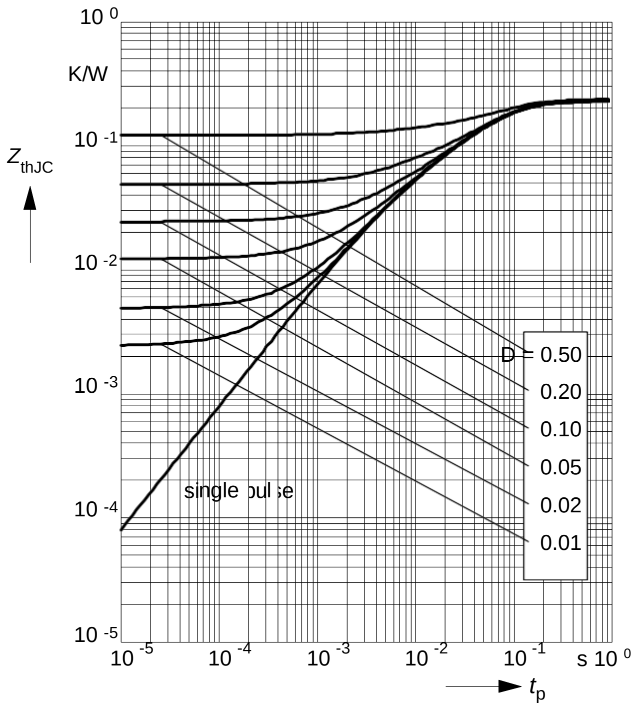
parameter: T_j



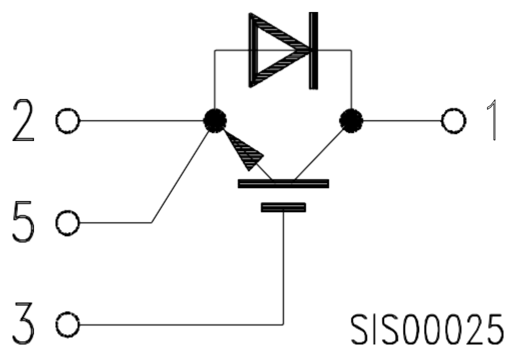
Transient thermal impedance Diode

$Z_{th\ JC} = f(t_p)$

parameter: $D = t_p / T$



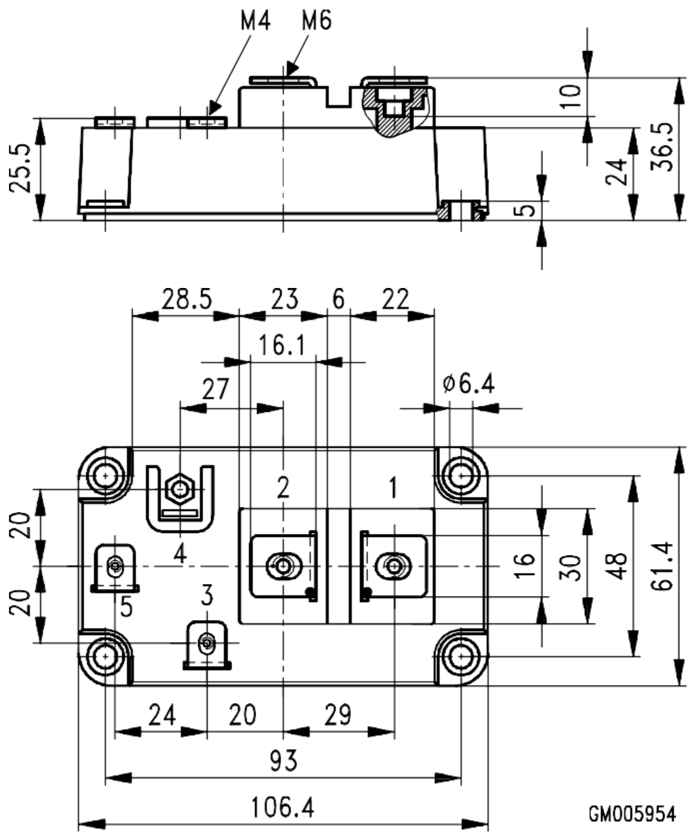
Circuit Diagram



Package Outlines

Dimensions in mm

Weight: 420 g



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