OLLSCOIL NA hÉIREANN, CORCAIGH
THE NATIONAL UNIVERSITY OF IRELAND, CORK

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

SUMMER EXAMINATIONS, 2010

B.E. DEGREE (ELECTRICAL)

POWER ELECTRONICS, DRIVES AND ENERGY CONVERSION
EE4001

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Time allowed: *3 hours*

Answer *four* out of six questions.
All questions carry an equal weighting of 20 marks.

The use of departmental-approved non-programmable calculators is permitted.

1. Induction Motor Characterization

(a) The specification table for Westinghouse induction motors is provided as an attachment. Consider the 75 kW, **four**-pole machine with 400 V (line-line), 50 Hz applied in the delta configuration.
Estimate the per-phase equivalent circuit parameters: R_R', P_{CFW}, L_{LS}, L_{LR}', and L_M. Assume $R_S = 117$ mΩ and L_{LS} equals L_{LR}' for this class of machine.

[10 *marks*]

(b) A four-pole star-connected induction motor used in an electric vehicle application has the following per-phase equivalent circuit parameters:
$R_S = 11.8$ mΩ, $L_{LS} = 0.0972$ mH, $L_M = 2.0$ mH, $L_{LR}' = 0.0772$ mH, and $R_R' = 12.9$ mΩ.
When supplied by a current-controlled inverter outputting 93 A at 200 Hz, the motor generates an output torque of 40 Nm at 5945 rpm. Core, friction and windage losses are estimated at 2.3 kW at this speed. Determine approximate values for the input per-phase voltage, power factor, and efficiency at this operating point.

[10 *marks*]

2. Induction Motor Inrush and Speed Control

(a) Sketch the wiring diagram for the volts/hertz control of the induction machine.

[4 *marks*]

(b) The specification table for the Westinghouse 22 kW, 8-pole induction motor, with 400 V (line-line), 50 Hz applied in the delta configuration, is provided as an attachment.

(i) What are the initial starting line current and torque for a direct-on-line start?

A volts/hertz controller with voltage boost is integrated into the delta-wired drive. The series resistance is estimated to be 0.43 Ω.

(ii) Determine approximate values for the starting frequency, current, and voltage in order to supply the specified starting torque.

(iii) Maintaining rated airgap flux, what are the electrical line voltage, current, frequency, and power factor sourced from the inverter, when developing 50 % of the rated torque at 75 % of the rated speed?

Use the formula $slope = \dfrac{V_{ph,rated} - R_S \cdot I'_{R,rated}}{f_{rated}}$ for low-voltage boost.

[16 *marks*]

3. AC Machines Space Vectors and Vector Control of the Induction Motor

A four-pole star-connected induction motor used in a servo application has the following per-phase equivalent circuit parameters:

$R_S = 1.77\ \Omega$, $L_{LS} = 14$ mH, $L_M = 369$ mH, $L'_{LR} = 12$ mH, and $R'_R = 1.34\ \Omega$.

At the rated condition of 460 V line-line, 60 Hz, the machine pulls 3.753 A at a lagging power factor of 0.822. At time $t = 0$, the machine is in steady state.

(i) Taking the per-phase input voltage as the reference, calculate the per-phase rotor current phasor and the per-phase rotor flux-linkage phasor.

(ii) Align the d-axis with the rotating rotor flux linkage state vector and calculate the rotor current and the rotor flux-linkage space vectors.

(iii) Calculate λ_{rd} and i_{rq} and the resulting electromagnetic torque and slip.

(iv) Calculate the three phase currents at time $t = 0$.

Note the following equations:

$$\vec{i}_s = \frac{3}{2}\sqrt{2}I_s\angle\theta_{Is} = \sqrt{\frac{3}{2}}\left(i_{sd} + ji_{sq}\right)$$

$$\vec{\lambda}_r(t) = -L_r\vec{i}_r(t) + L_m\vec{i}_s(t)$$

$$T_{em} = \frac{P}{2}\lambda_{rd}i_{rq} \text{ and } \omega_{slip} = \frac{2}{P}\frac{R'_r i_{rq}}{\lambda_{rd}}$$

$$\begin{pmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{pmatrix} = \sqrt{\frac{2}{3}}\begin{pmatrix} \cos\theta_{da} & -\sin\theta_{da} \\ \cos\left(\theta_{da} + 240^o\right) & -\sin\left(\theta_{da} + 240^o\right) \\ \cos\left(\theta_{da} + 120^o\right) & -\sin\left(\theta_{da} + 120^o\right) \end{pmatrix}\begin{pmatrix} i_{sd} \\ i_{sq} \end{pmatrix}$$

$$\theta_{da} = \omega t + \theta_{\lambda r}$$

[20 *marks*]

4. Power Electronics Converters

(a) In a regulated flyback converter with a 1:1 turns ratio, $V_O = 12$ V, V_I is 12-24 V, P_{load} is 6-60 W and the switching frequency is 200 kHz.

(i) Calculate the maximum value of the magnetizing inductance L_m that can be used if the converter is always required to operate in a complete demagnetization (equivalent to a discontinuous-conduction) mode. Assume ideal components.

(ii) Sketch to scale the transformer primary and secondary current waveforms at full power and low input voltage.

(iii) Determine the maximum voltage across the switch at full power and high input voltage

[6 *marks*]

(b) The Toyota Prius uses a 20 kW bidirectional converter to generate a 500 V dc link voltage from the 200 V NiMH battery. This higher voltage allows the efficiency, range, and emissions of the vehicle to be optimized. The bidirectional converter has an inductance of 435 uH and switches at 10 kHz.

The vehicle is operating in motoring mode and the bi-directional converter is required to act as a boost and provide a **half power level of 10 kW**. For this 10 kW condition:

(i) Calculate the rms currents in the inductor and in the output and input capacitors.

(ii) Calculate the switch average and rms currents.

[6 *marks*]

(c) The system parameters of a permanent-magnet dc motor supplied by a switch-mode PWM dc-dc converter are as follows: armature resistance $R_a = 0.1\,\Omega$, armature inductance $L_a = 1$ mH, motor constant $k = 0.07$ V/(rad/s), dc bus voltage $V_d = 12$ V, switching frequency $f_s = 20$ kHz, and amplitude of triangular waveform control voltage $V_{tri} = 5$ V. The motor is spinning forward at a speed of 750 rpm and acts as a **generator** supplied by a full-load torque of -0.7 Nm.

(i) Calculate the following: (a) the applied armature voltage V_{AB}; (b) duty ratios for the overall converter, pole A, and pole B; (c) the control voltage, and (d) the peak-to-peak ripple on the armature current.

(ii) Calculate the rms currents in the upper and lower MOSFET switches of pole A.

[8 *marks*]

5. DC Machines

(a) A 100 kW compound generator, of terminal ratings 250 V and 400 A, has an armature resistance (including brushes) of 0.025 Ω and the attached magnetization curve. There are 1000 shunt-field turns per pole and 3 series-field turns per pole. Compute the shunt field current required at full load when the generator speed is 1100 rpm. Include the effects of armature reaction.

[6 *marks*]

(b) The specification sheet for the Maxon 250 W, 48 V, 6500 rpm, EC dc motor is attached. Compute the armature current, applied voltage, and machine efficiency for the condition shown in line 10 of motor data. What are the amplitude of per-phase back emf and the rms per-phase current?

[6 *marks*]

(c) The specification sheet for the TK 164-110-04 permanent magnet motor is attached. Estimate the no-load core, friction and windage losses and determine the per-phase no-load current. Under full-load determine the applied per-phase current and voltage, power factor for the full power condition under water cooling: 6.41 kW output power at 173.29 rad/s. Note that the specified winding parameters are twice the per-phase parameters.
Apply the following formulae:

$$T_{EM} = 3 \cdot k \cdot I_{ph(rms)} \text{ and } E_{ph(rms)} = k \cdot \omega$$

[8 *marks*]

6. Power Semiconductors

(a) The IRFPS40N60K power MOSFET (see attached specification sheets) from International Rectifier operates in a boost converter with a dc link voltage $V_d = 480$ V, and load current $I_o = 20$ A. The MOSFET is driven by a gate drive IC outputting a square-wave voltage v_{GG}, of amplitude 0 V to +10 V, in series with an external gate resistance $R_G = 4.3\ \Omega$. Assume the diode has a 1V forward drop and no reverse recovery.

Useful formula: RC discharge time $t = -RC \ln\left[\frac{v_c - (-V_{GG})}{V_{ci} - (-V_{GG})}\right]$

(i) Determine the following parameters from the data sheet at a junction temperature of 100°C: maximum threshold voltage, minimum forward transconductance, gate-source capacitance, gate-drain capacitance, maximum on-state resistance, maximum gate voltage at the 20 A load current, and maximum conduction drop across MOSFET at 20 A.

(ii) Sketch $v_{GG}(t)$, $v_{GS}(t)$, $v_{DS}(t)$, and $i_D(t)$ during turn-off of the MOSFET. Note the approximate voltage levels on waveforms.

(iii) Calculate the following (a) turn-off delay time t_{doff}, (b) voltage rise time t_{vr}, and (c) current fall time t_{fv} at a junction temperature of 100°C. Sketch the basic switching circuit under analysis in each case.

[12 *marks*]

(b) The 2003 Toyota Prius uses a 20 kW bidirectional converter to generate a 500 V dc link voltage from the 200 V NiMH battery. The bidirectional converter has an inductance of 435 uH and switches at 10 kHz.

At full power in generating (buck) mode, the inductor carries 100 Adc with a peak-to-peak ripple of 27.6 A , and the rms/average currents in the IGBT and diode are 63.4 A/40 A and 77 A/60 A, respectively. Determine the typical power loss at 125 C due to conduction and switching in the upper IGBT and lower diode for this full-power condition when using the SEMiX252GB126HDs as the half-bridge module (see attached specification sheets on pages 12 to 14).

[8 *marks*]

22kW-315kW TEFC, CLASS F, S1 (MCR) DUTY

kW	Full Speed (RPM)	Frame No.	Rated Torque (Nm)	Current (amp) at volts			Efficiency (%) at load			Power Factor at load			D.O.L. Starting current (%FLC)	D.O.L. Starting Torque (%FLT)	Pull out Torque (%FLT)	Rotor inertia mr² (kg.m²)	Max load inertia mr² (kg.m²)	Sound pressure (dB(A)) (avg no-load@1m)
				380	400	415	100%	75%	50%	100%	75%	50%						
22	2945	D180M	71.3	40.3	38.3	36.9	90.6	90.4	88.9	0.92	0.90	0.84	770	250	344	0.071	0.50	76
22	1465	D180L	143	41.6	39.5	38.1	91.3	91.6	91.0	0.89	0.84		710	220	309	0.14	1.4	63
22	975	D200L	215	43.9	41.7	40.2	89.9	90.3	89.1	0.85	0.81	0.72	670	217	316	0.34	4.1	63
22	730	D225M	288	47.9	45.5	43.9	90.6	90.7	89.4	0.77	0.72	0.62	770	210	301	0.53	8.0	60
30	2950	D200L	97.1	54.9	52.2	50.3	91.4	91.3	89.6	0.91	0.89	0.82	750	260	346	0.12	0.83	79
30	1465	D200L	196	55.8	53.1	51.1	91.8	92	91.4	0.89	0.85	0.74	700	230	303	0.25	2.5	68
30	980	D225M	292	58.3	55.4	53.4	91.8	92.0	90.6	0.85	0.82	0.75	620	235	284	0.53	6.3	76
30	730	D250M	392	61.0	57.9	55.9	90.8	90.8	89.2	0.82	0.77	0.65	582	198	298	0.81	12	61
37	2950	D200L	120	66.9	63.6	61.3	92.1	92.0	91.0	0.91	0.89	0.87	750	220	298	0.13	0.93	79
37	1475	D225S	240	69.8	66.3	63.9	92.1	92.7	91.2	0.88	0.86	0.78	660	220	306	0.39	3.9	69
37	980	D250M	360	70.8	67.2	64.8	91.5	91.4	89.9	0.87	0.83	0.75	690	212	323	0.81	9.68	64
37	735	D280S	481	77.8	73.9	71.2	91.5	91.5	89.5	0.79	0.71	0.65	660	200	240	1.4	21	62
45	2960	D225M	145	81.8	77.7	74.9	92.5	92.1	91.0	0.90	0.88	0.82	790	270	369	0.22	1.5	79
45	1475	D225M	291	84.1	79.9	77.0	92.5	92.3	91.5	0.88	0.85	0.77	750	200	314	0.45	4.5	68
45	980	D280S	438	85.9	81.7	78.7	92.5	92.3	90.0	0.86	0.83	0.75	700	230	270	1	16	66
45	735	D280M	585	94.1	89.4	86.1	92.0	91.8	89.5	0.79	0.71	0.65	660	200	240	1.7	26	62
55	2965	D250M	177	101	95.7	92.2	93.0	92.1	90.3	0.89	0.86	0.80	770	190	368	0.31	2.1	79
55	1475	D250M	356	101	96.0	92.6	93.0	92.8	91.3	0.90	0.86	0.79	700	220	316	0.64	6.4	69
55	980	D280M	536	105	99.5	95.9	92.8	92.5	90.5	0.86	0.83	0.75	700	230	270	1.6	19	66
55	735	D315S	714	111	106	102	92.8	92.7	90.0	0.81	0.71	0.65	660	180	220	4.6	69	67
75	2971	D280S	241	134	128	123	93.3	92.9	91.2	0.91	0.89	0.86	640	220	250	0.58	2.9	80
75	1485	D280S	482	137	130	126	94.2	94.2	93.2	0.88	0.86	0.79	730	250	240	1.0	7.3	72
75	935	D315S	766	142	135	130	93.5	93.2	91.0	0.86	0.83	0.75	700	200	240	3.9	39	70
75	735	D315M	974	151	144	139	93.0	92.8	90.2	0.81	0.72	0.65	660	180	220	5.4	64	67
90	2965	D280M	290	159	152	146	93.7	93.5	92.7	0.92	0.90	0.86	700	230	250	0.67	3.3	80
90	1484	D280M	579	162	154	148	94.4	94.2	93.0	0.89	0.88	0.81	720	240	240	1.4	9.77	72
90	935	D315M	919	170	161	155	93.8	93.5	91.2	0.86	0.83	0.76	700	200	240	4.6	45.8	70
90	735	D315L	1169	178	169	163	93.8	93.5	90.3	0.82	0.72	0.65	660	180	230	6.1	73	67
110	2975	D315S	353	195	186	179	94.0	93.5	91.9	0.91	0.89	0.86	640	180	240	1.1	5.7	81
110	1485	D315S	707	201	191	184	94.5	94.2	93.0	0.88	0.85	0.80	580	190	270	3.0	21	78
110	935	D315L	1123	207	196	189	94.0	93.7	91.4	0.86	0.83	0.76	700	210	240	5.2	52	85
110	735	D315L	1429	217	206	199	94.0	93.8	90.4	0.82	0.72	0.66	660	190	230	6.6	79	67
132	2975	D315M	424	233	222	214	94.5	94.5	93.4	0.91	0.89	0.87	590	170	240	1.8	8.8	81
132	1485	D315M	849	240	228	220	94.8	94.5	93.1	0.88	0.86	0.81	560	180	260	3.5	24	78
132	935	D315L	1348	245	232	224	94.2	93.9	91.5	0.87	0.83	0.76	700	210	230	5.5	55	70
132	745	D355M	1692	262	249	240	93.5	93.2	90.4	0.82	0.73	0.66	650	190	200	10	125	75
160	2975	D315L	514	279	265	256	95.2	94.9	93.7	0.92	0.89	0.86	700	220	250	2.0	10	84
160	1485	D315L	1029	288	273	264	94.9	94.6	93.6	0.89	0.86	0.82	520	170	240	4.0	28	82
160	990	D355M	1543	291	277	267	94.8	94.5	91.7	0.88	0.84	0.76	700	200	200	8.8	88	70
160	745	D355M	2051	313	298	287	93.5	93.2	90.4	0.83	0.73	0.66	650	190	200	12	140	75
200	2975	D315L	642	348	331	319	95.0	94.9	93.8	0.92	0.89	0.87	590	170	250	2.3	11	84
200	1485	D315L	1286	359	341	329	95.2	95.2	94.5	0.89	0.86	0.81	600	220	240	4.5	31	82
200	990	D355M	1929	363	345	333	95.0	94.5	91.8	0.88	0.84	0.76	700	200	200	9.6	96	77
200	745	D355L	2563	386	367	354	94.8	94.5	91.0	0.83	0.74	0.67	650	190	200	13	154	75
250	2970	D355M	804	432	411	396	95.5	95.0	94.5	0.92	0.90	0.86	730	160	220	3.0	15	88
250	1490	D355M	1602	437	415	400	95.5	95.2	91.8	0.91	0.87	0.77	680	230	230	5.8	40	86
250	990	D355L	2411	449	427	411	95.0	94.5	91.0	0.89	0.84	0.67	700	230	250	11	105	77
315	2970	D355L	1013	543	516	497	95.8	95.3	94.8	0.92	0.90	0.86	730	160	220	4.2	21	88
315	1490	D355L	2019	549	522	503	95.8	95.5	92.0	0.91	0.88	0.77	680	230	230	6.8	48	86

NOTES

1. Data is based on tests to EN60034.
2. Tolerance: EN60034.
3. All data is subject to change without prior notification. Not to be used for installation purposes without referring to TECO Electric Europe Limited.

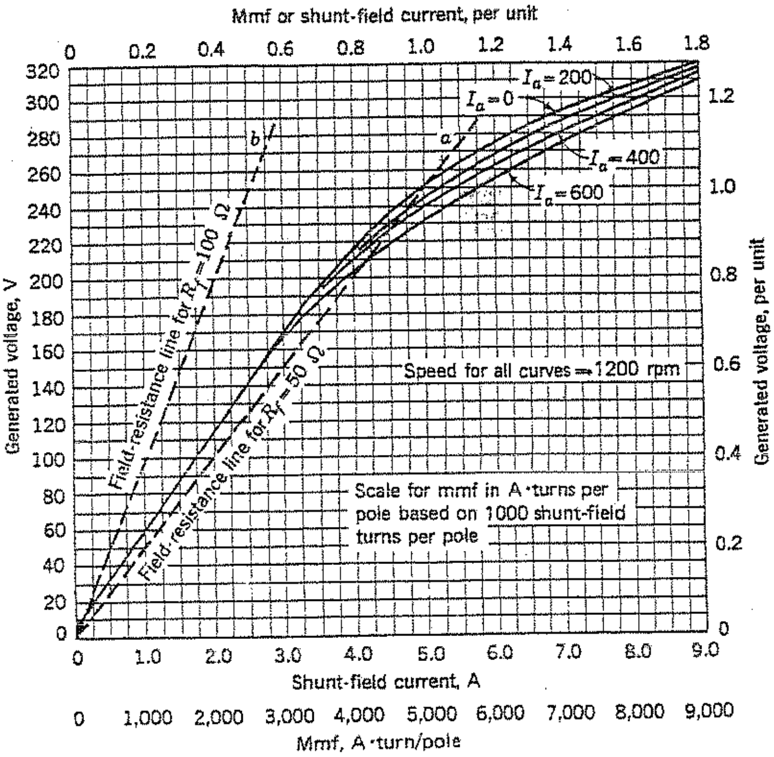
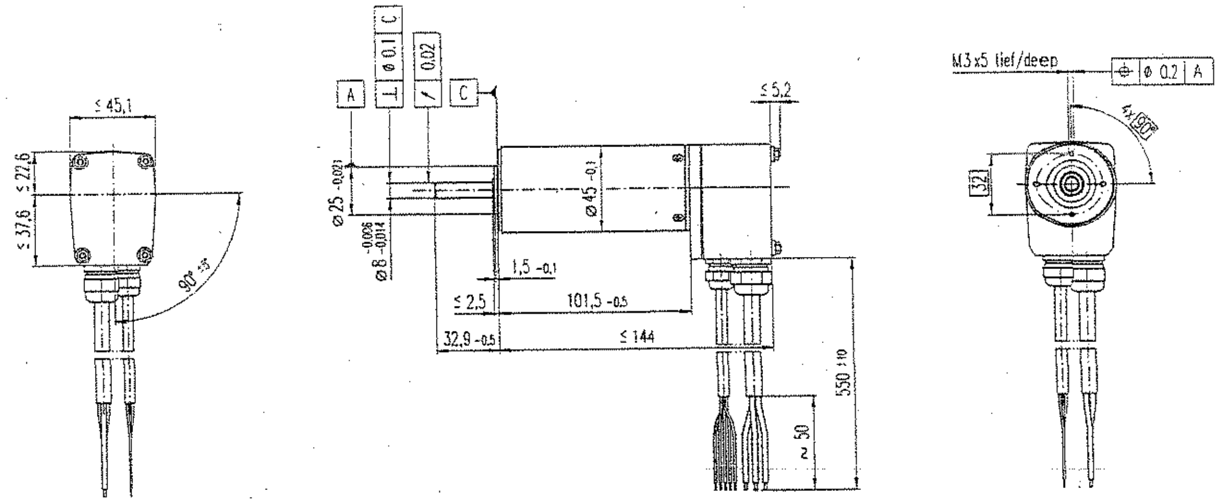


Fig. 9-14. Magnetization curves for a 250-V 1200-r/min dc machine.



M 1:4

Stock program
Standard program
Special program (on request!)

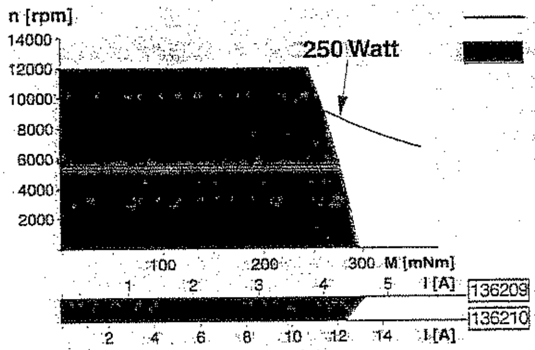
		Order Number					
	Y-circuit	136207	136208	136209			
	Δ-circuit				136210	136211	136212
Motor Data							
Assigned power rating	W	250	250	250	250	250	250
Nominal voltage	Volt	24.0	36.0	48.0	24.0	36.0	48.0
3 No load speed	rpm	5300	6300	6500	9100	11000	11100
4 Stall torque	mNm	2250	3000	3250	3910	5260	5670
5 Speed / torque gradient	rpm / mNm	2.40	2.10	2.00	2.34	2.10	1.97
6 No load current	mA	435	370	290	1139	1062	818
7 Terminal resistance phase to phase	Ohm	0.46	0.64	1.04	0.15	0.21	0.35
8 Max. permissible speed	rpm	12000	12000	12000	12000	12000	12000
9 Max. continuous current at 5000 rpm	A	7.10	6.00	4.70	12.50	10.60	8.20
10 Max. continuous torque at 5000 rpm	mNm	283	300	306	286	303	304
11 Max. efficiency	%	83	85	85	84	85	86
12 Torque constant	mNm / A	43.3	54.0	71.0	25.0	31.2	41.0
13 Speed constant	rpm / V	220	175	135	382	306	233
14 Mechanical time constant	ms	5	5	5	5	5	5
15 Rotor inertia	gcm²	209	209	209	209	209	209
16 Terminal inductance phase to phase	mH	0.170	0.260	0.440	0.060	0.090	0.150
17 Thermal resistance housing-ambient	K / W	1.7	1.7	1.7	1.7	1.7	1.7
18 Thermal resistance winding-housing	K / W	1.1	1.1	1.1	1.1	1.1	1.1
19 Thermal time constant winding	s	16	16	16	16	16	16
20 Thermal time constant stator	s	850	850	850	850	850	850

Specifications

- Motor connections — Screw fitting for cable PG7
- Axial play at axial load < 20 N — 0 mm
  > 20 N — max. 0.14 mm
- Preloaded ball bearing
- Max. ball bearing loads
  - axial (dynamic) — 20 N
  - radial (5 mm from flange) — 180 N
  - Force for press fits (static) — 170 N
  - (static, shaft supported) — 5000 N
- Radial play ball bearing — 0.02 mm
- Ambient temperature range — -20 ... +125°C
- Max. permissible winding temperature — +125°C
- Weight of motor — 1150 g
- Protection — IP54
- 2 pole permanent magnet
- Values listed in the table are nominal.
- Connection (Cable AWG 16)
  - Cable 1 — Motor winding 1
  - Cable 2 — Motor winding 2
  - Cable 3 — Motor winding 3
- Connection (Cable AWG 24)
  - Cable white — Hall sensor 3
  - Cable brown — Hall sensor 2
  - Cable green — Hall sensor 1
  - Cable yellow — GND
  - Cable grey — V_{Hall} 4.5 ... 24 VDC
- Options: Temperature monitoring
  PTC resistance micropille 110°C
  - R 25°C — < 0.5 kΩ
  - R 105°C — = 1.2 ... 1.5 kΩ
  - R 115°C — = 7 ... 13 kΩ
  - R 120°C — = 18 ... 35 kΩ
- For wiring diagram for Hall sensors, see p. 26
- Options: motor connection with plug

Operating Range

Comments — Details on page 149



Curve of constant assigned power rating

Continuous operation
In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit

Short term operation
The motor may be briefly overloaded (recurring).

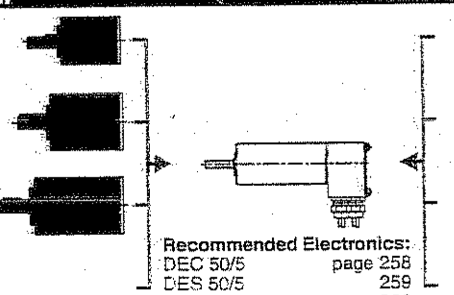
maxon Modular System

Overview on page 17 - 21

Planetary Gearhead
Ø42 mm
3 - 15 Nm
Details page 219

Planetary Gearhead
Ø52 mm
4 - 30 Nm
Details page 221

Planetary Gearhead
Ø62 mm
8 - 50 Nm
Details page 223



Recommended Electronics:

DEC 50/5	page 258
DES 50/5	259
DES 70/10	260
EPOS 70/10	263
MIP 50, MIP 100	265
Notes	17

Digital Encoder HP HEDL 9140
500 CPT, 3 channels
Details page 241

Resolver
Ø26 mm
10 V
Details page 247

Brake
Ø28 mm, 24 VDC
0.4 Nm
Details page 270

Page 8

Technical Data Summary TK 164

High power medium speed spindle motors
Applications:
Direct drive lathes
Swiss type lathes
Speed up to 5000 rpm, 40-200 Nm
Short duty constant power

	Symbol	TK 164-60-04	TK 164-110-03	TK 164-250-09	Units
Reference data (winding independent)					
Nominal torque, S1,0 speed, conduction+convection cooled IC 418 1)	Tnc	19	40	106	*Nmrms*
Nominal torque, S1, 0 speed, water cooled 2)	Tnw	37	80	209	*Nmrms*
Peak torque, S6 10% 1)	Tpk	54	114	302	*Nmrms*
Maximum torque 3)	Tul	93	171	389	*Nm*
Maximum structural speed	Pn	500	500	500	*rad/sec*
Critical flux control torque 4)	Pf	86	157	366	*Nm*
Motor constant	Tw	2,33	3,63	6,31	*Nm/sqrt(W)*
Pole number	PN	12	12	12	
Connection		Y	Y	Y	
Physical data (winding independent)					
Rotor inertia	Jm	4,30	7,30	16	*mkgm2*
Acceleration at maximum torque	apk	12576	15595	18855	*rad/s2*
Outer diameter	Dout	164	164	164	*mm*
Rotor hole diameter	Din	96	96	96	*mm*
Overall stator length	Stkout	102	152	292	*mm*
Stack length	Stk	60	110	250	*mm*
Stator mass	Msta	4,8	8	17	*kg*
Rotor mass	Mrot	1,3	2,4	5,5	*kg*
Insulation		Class H - F	Class H - F	Class H - F	
Protection		IP 00	IP 00	IP 00	
Thermal data (winding independent)					
Thermal imp. assumed for cond. Cooling 1)	Rthc	0,390	0,214	0,093	*K/W*
Thermal impedance, motor to cooling frame 2)	Rthw	0,092	0,050	0,021	*K/W*
Thermal capacity	Cth	2.016	3.360	7.140	*J/K*
Thermal time constant cond cooling 1)	Tc	786	719	664	*sec*
Thermal time constant, water cooled 2)	Tw	185	168	150	*sec*
Loss at Tnc	LOc	267	491	1.120	*W*
Loss at Tnw	LOw	1.030	1.880	4.380	*W*
Coolant flow, 5 C temp rise, 35 C inlet	Cfl	3,0	5,4	12,6	*lit/min*
Treshold of built-in PTC	PTCt	130	130	130	*oC*
Electrical data (winding dependent)					
Nominal speed (knee speed) 5)	wn	173,29	173,99	52,40	*rad/sec*
Nominal power, water cooling, knee speed 6)	Pnw	6,41	13,92	10,95	*kW*
Back E.M.F. between phases	Ke	1,80	1,76	5,13	*Vs*
Torque constant	Kt	3,13	3,05	8,89	*Nm/Arms*
Temp.coeff. of E.M.F. and Kt	dKe/dT	-0,09	-0,09	-0,09	*%/oC*
Winding resistance, 20oC	Rw	2,69	1,06	2,98	*Ohm*
Winding inductance	Lw	12,63	6,58	24,00	*mH*
Nominal current, zero speed 1)	In0	6,08	13,12	11,92	*Arms*
Nominal current, zero speed, 2)	In	12,46	27,62	24,74	*Arms*
Maximum current 3)	Ipk	37,19	70,12	54,69	*Arms*
Frequency	fn	166	166	50	*Hz*
Efficiency at rated power 6)	n	0,86	0,88	0,71	

Definitions:
1) Motor assembled in light alloy case with outer surface = 500% of
2) Water cooled motor, water inlet temperature = 35 C, copper temp, 120
3) Torque at which magnetic saturation prevents further overloading
4) Knee torque corresponding to unlimited constant power operation
5) Limit of constant torque operation with 400 Vac supply

International
IOR Rectifier

SMPS MOSFET

PD - 94384A

IRFPS40N60K

HEXFET® Power MOSFET

V_{DSS}	$R_{DS(on)}$ typ.	I_D
600V	0.110 Ω	40A

SUPER TO-247AC

Applications

- Hard Switching Primary or PFC Switch
- Switch Mode Power Supply (SMPS)
- Uninterruptible Power Supply
- High Speed Power Switching
- Motor Drive

Benefits

- Low Gate Charge Qg results in Simple Drive Requirement
- Improved Gate, Avalanche and Dynamic dv/dt Ruggedness
- Fully Characterized Capacitance and Avalanche Voltage and Current
- Enhanced Body Diode dv/dt Capability

Absolute Maximum Ratings

	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	40	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	24	
I_{DM}	Pulsed Drain Current ①	160	
P_D @T_C = 25°C	Power Dissipation	570	W
	Linear Derating Factor	4.5	W/°C
V_{GS}	Gate-to-Source Voltage	± 30	V
dv/dt	Peak Diode Recovery dv/dt ③	7.5	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 150	°C
	Soldering Temperature, for 10 seconds (1.6mm from case)	300	

Avalanche Characteristics

Symbol	Parameter	Typ.	Max.	Units
E_{AS}	Single Pulse Avalanche Energy②	——	600	mJ
I_{AR}	Avalanche Current①	——	40	A
E_{AR}	Repetitive Avalanche Energy①	——	57	mJ

Thermal Resistance

Symbol	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case⑤	——	0.22	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.24	——	
$R_{\theta JA}$	Junction-to-Ambient⑤	——	40	

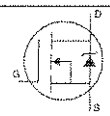
Static @ T_J = 25°C (unless otherwise specified)

Symbol	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	600	—	—	V	V_{GS} = 0V, I_D = 250μA
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	—	0.63	—	V/°C	Reference to 25°C, I_D = 1mA⑥
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	—	0.110	0.130	Ω	V_{GS} = 10V, I_D = 24A ④
$V_{GS(th)}$	Gate Threshold Voltage	3.0	—	5.0	V	V_{DS} = V_{GS}, I_D = 250μA
I_{DSS}	Drain-to-Source Leakage Current	—	—	50	μA	V_{DS} = 600V, V_{GS} = 0V
		—	—	250		V_{DS} = 480V, V_{GS} = 0V, T_J = 125°C
I_{GSS}	Gate-to-Source Forward Leakage	—	—	100	nA	V_{GS} = 30V
	Gate-to-Source Reverse Leakage	—	—	-100		V_{GS} = -30V

Dynamic @ T_J = 25°C (unless otherwise specified)

Symbol	Parameter	Min.	Typ.	Max.	Units	Conditions
g_{fs}	Forward Transconductance	21	—	—	S	V_{DS} = 50V, I_D = 24A
Q_g	Total Gate Charge	—	—	330	nC	I_D = 38A
Q_{gs}	Gate-to-Source Charge	—	—	84		V_{DS} = 480V
Q_{gd}	Gate-to-Drain ("Miller") Charge	—	—	150		V_{GS} = 10V, See Fig. 6 and 13 ④
$t_{d(on)}$	Turn-On Delay Time	—	47	—	ns	V_{DD} = 300V
t_r	Rise Time	—	110	—		I_D = 38A
$t_{d(off)}$	Turn-Off Delay Time	—	97	—		R_G = 4.3Ω
t_f	Fall Time	—	60	—		V_{GS} = 10V,See Fig. 10 ④
C_{iss}	Input Capacitance	—	7970	—	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	—	750	—		V_{DS} = 25V
C_{rss}	Reverse Transfer Capacitance	—	75	—		f = 1.0MHz, See Fig. 5
C_{oss}	Output Capacitance	—	9440	—		V_{GS} = 0V, V_{DS} = 1.0V, f = 1.0MHz
C_{oss}	Output Capacitance	—	200	—		V_{GS} = 0V, V_{DS} = 480V, f = 1.0MHz
C_{oss} eff.	Effective Output Capacitance	—	260	—		V_{GS} = 0V, V_{DS} = 0V to 480V ⑤

Diode Characteristics

Symbol	Parameter	Min.	Typ.	Max.	Units	Conditions
I_S	Continuous Source Current (Body Diode)	—	—	40	A	MOSFET symbol showing the integral reverse p-n junction diode. 
I_{SM}	Pulsed Source Current (Body Diode) ①	—	—	160		
V_{SD}	Diode Forward Voltage	—	—	1.5	V	T_J = 25°C, I_S = 38A, V_{GS} = 0V ④
t_{rr}	Reverse Recovery Time	—	630	950	ns	T_J = 25°C I_F = 38A
		—	730	1090		T_J = 125°C di/dt = 100A/μs ④
Q_{rr}	Reverse Recovery Charge	—	14	20	μC	T_J = 25°C
		—	17	25		T_J = 125°C
I_{RRM}	Reverse Recovery Current	—	39	58	A	T_J = 25°C
t_{on}	Forward Turn-On Time	Intrinsic turn-on time is negligible (turn-on is dominated by L_S+L_D)				

Notes:

① Repetitive rating; pulse width limited by max. junction temperature.(See Fig. 11)

② Starting T_J = 25°C, L = 0.84mH, R_G = 25Ω, I_{AS} = 38A, (See Figure 12a)

③ $I_{SD} \le$ 38A, di/dt ≤ 224A/μs, $V_{DD} \le V_{(BR)DSS}$, $T_J \le$ 150°C

④ Pulse width ≤ 300μs; duty cycle ≤ 2%.

⑤ C_{oss} eff. is a fixed capacitance that gives the same charging time as C_{oss} while V_{DS} is rising from 0 to 80% V_{DSS}

⑥ R_θ is measured at T_J approximately 90°C

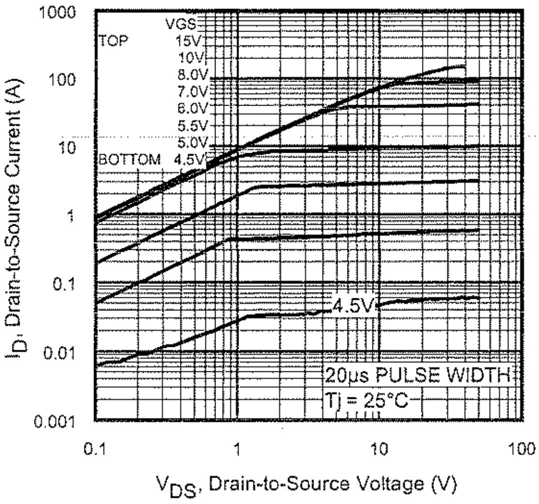


Fig 1. Typical Output Characteristics

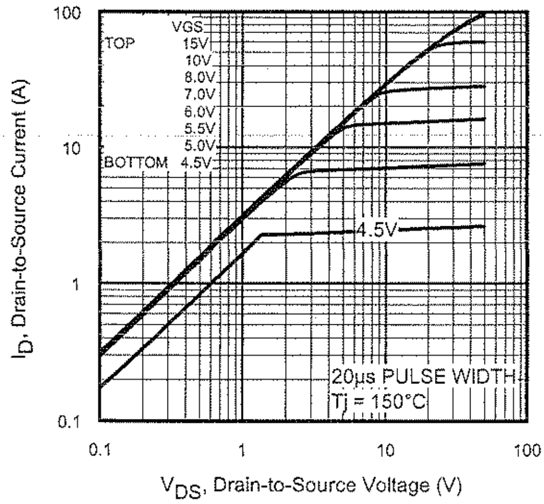


Fig 2. Typical Output Characteristics

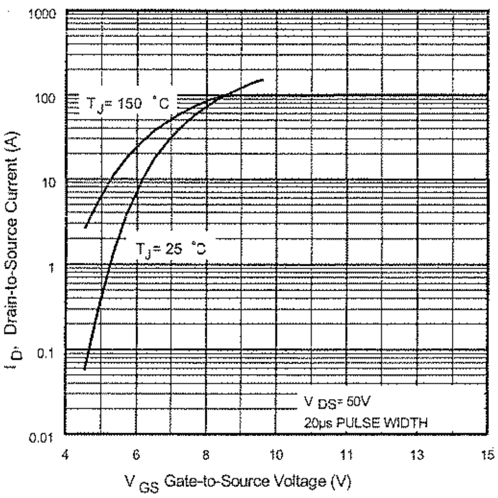


Fig 3. Typical Transfer Characteristics

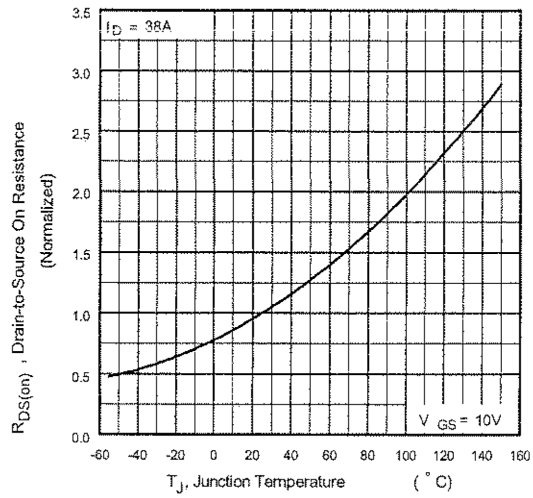


Fig 4. Normalized On-Resistance
Vs. Temperature

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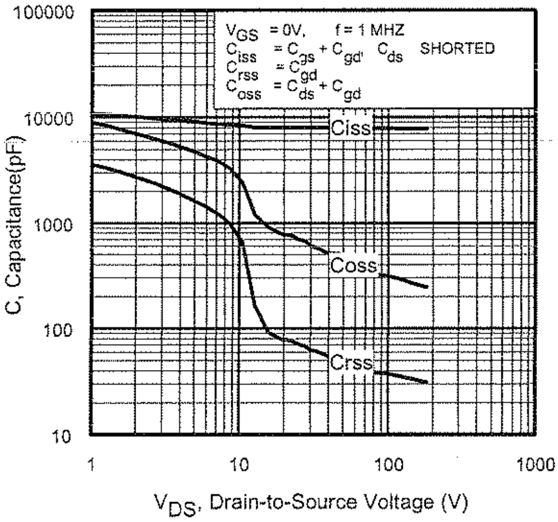


Fig 5. Typical Capacitance Vs. Drain-to-Source Voltage

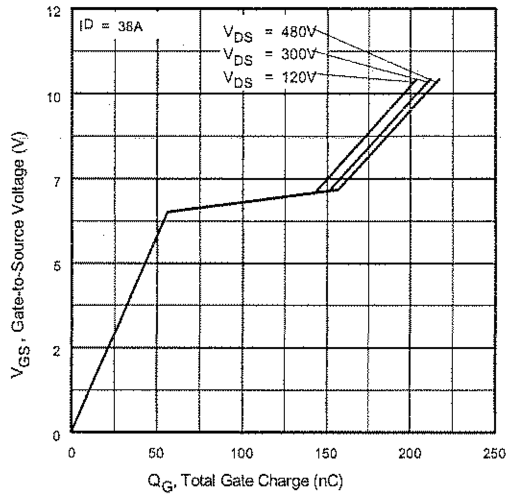


Fig 6. Typical Gate Charge Vs. Gate-to-Source Voltage

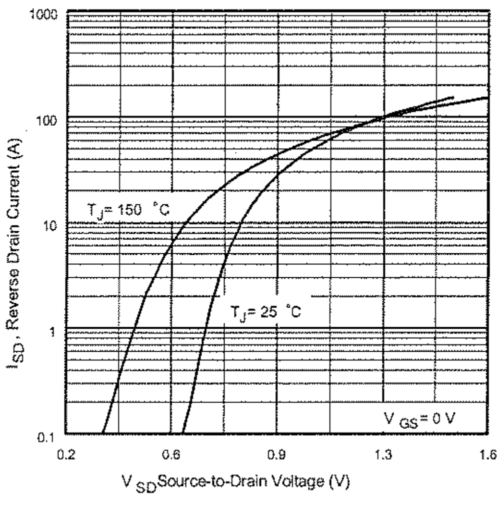


Fig 7. Typical Source-Drain Diode Forward Voltage

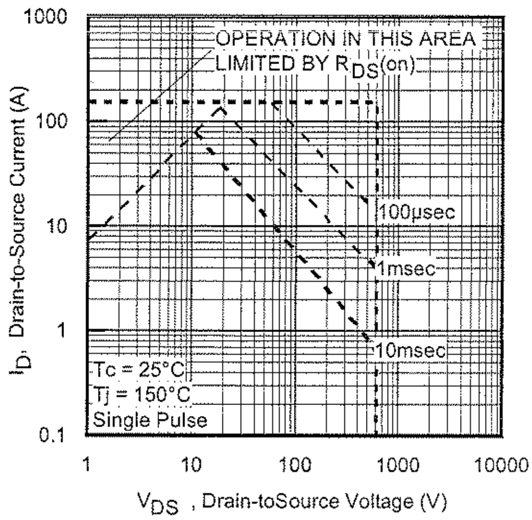
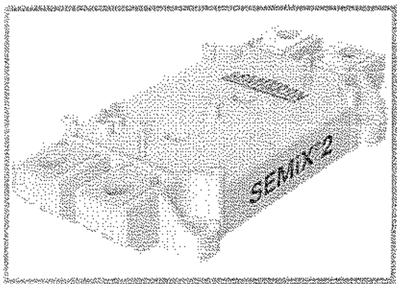


Fig 8. Maximum Safe Operating Area

SEMiX 252GB126HDs



SEMiX®2s

Trench IGBT Modules

SEMiX 252GB126HDs

Preliminary Data

Features

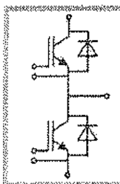
- Homogeneous Si
- Trench = Trenchgate technology
- $V_{CE(sat)}$ with positive temperature coefficient
- High short circuit capability

Typical Applications

- AC inverter drives
- UPS
- Electronic Welding

Remarks

- Case temperatur limited to T_C=125°C max.



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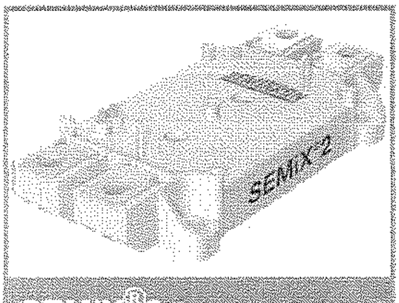
Absolute Maximum Ratings		T_{case} = 25°C, unless otherwise specified		
Symbol	**Conditions**		**Values**	**Units**
IGBT				
V_{CES}	T_j = 25 °C		1200	V
I_C	T_j = 150 °C	T_c = 25 °C	270	A
		T_c = 80 °C	200	A
I_{CRM}	I_{CRM}=2xI_{Cnom}		400	A
V_{GES}			± 20	V
t_{psc}	V_{CC} = 600 V; $V_{GE} \leq$ 20 V; V_{CES} < 1200 V	T_j = 125 °C	10	µs
Inverse Diode				
I_F	T_j = 150 °C	T_c = 25 °C	210	A
		T_c = 80 °C	160	A
I_{FRM}	I_{FRM} = 2xI_{Fnom}		400	A
I_{FSM}	t_p = 10 ms; sin.	T_j = 25 °C	1000	A
Freewheeling Diode				
I_F	T_j = °C	T_{case} = °C	10	A
I_{FRM}	I_{FRM} = 2xI_{Fnom}, t_p = ms			A
Module				
$I_{t(RMS)}$			600	A
T_{vj}			- 40 ... + 150	°C
T_{stg}			- 40 ... + 125	°C
V_{isol}	AC, 1 min.		4000	V

Characteristics		T_{case} = 25°C, unless otherwise specified				
Symbol	**Conditions**		**min.**	**typ.**	**max.**	**Units**
IGBT						
$V_{GE(th)}$	V_{GE} = V_{CE}, I_C = 6,4 mA		5	5,8	6,5	V
I_{CES}	V_{GE} = 0 V, V_{CE} = V_{CES}	T_j = 25 °C			1	mA
V_{CE0}		T_j = 25 °C		1	1,2	V
		T_j = 125 °C		0,9	1,1	V
r_{CE}	V_{GE} = 15 V	T_j = 25°C		4,7	6,3	mΩ
		T_j = 125°C		7,3	9	mΩ
$V_{CE(sat)}$	I_{Cnom} = 150 A, V_{GE} = 15 V	T_j = 25°$C_{chiplev.}$		1,7	2,15	V
		T_j = 125°$C_{chiplev.}$		2	2,45	V
C_{ies}				10,7		nF
C_{oes}	V_{CE} = 25, V_{GE} = 0 V	f = 1 MHz		0,6		nF
C_{res}				0,5		nF
Q_G	V_{GE} = -8 ... +15V			1050		nC
$t_{d(on)}$	R_{Gon} = 3 Ω	V_{CC} = 600V		300		ns
t_r		I_{Cnom}= 150A		45		ns
E_{on}		T_j = 125 °C		20		mJ
$t_{d(off)}$	R_{Goff} = 3 Ω			570		ns
t_f				110		ns
E_{off}				21		mJ
$R_{th(j-c)}$	per IGBT				0,15	K/W



SEMiX®2s

Trench IGBT Modules

SEMiX 252GB126HDs

Preliminary Data

Features

- Homogeneous Si
- Trench = Trenchgate technology
- $V_{CE(sat)}$ with positive temperature coefficient
- High short circuit capability

Typical Applications

- AC inverter drives
- UPS
- Electronic Welding

Remarks

- Case temperatur limited to T_C=125°C max.

Characteristics						
Symbol	**Conditions**		**min.**	**typ.**	**max.**	**Units**
Inverse Diode						
$V_F = V_{EC}$	I_{Fnom} = 150 A; V_{GE} = 0 V	T_j = 25 °$C_{chiplev.}$		1,6	1,8	V
		T_j = 125 °$C_{chiplev.}$		1,6	1,8	V
V_{F0}		T_j = 25 °C		1	1,1	V
		T_j = 125 °C		0,8	0,9	V
r_F		T_j = 25 °C		4	4,7	mΩ
		T_j = 125 °C		5,3	6	mΩ
I_{RRM}	I_{Fnom} = 150 A	T_j = 125 °C		265		A
Q_{rr}	di/dt = 4600 A/µs			43		µC
E_{off}	V_{GE} = -15 V; V_{CC} = 600 V			18		mJ
$R_{th(j-c)D}$	per diode				0,3	K/W
Freewheeling Diode						
$V_F = V_{EC}$	I_{Fnom} = A; V_{GE} = V	T_j = °$C_{chiplev.}$				V
V_{F0}		T_j = °C				V
r_F		T_j = °C				V
I_{RRM}	I_{Fnom} = A	T_j = °C				A
Q_{rr}						µC
E_{off}	V_{GE} = 0 V; V_{CC} = 300 V					mJ
	per diode					K/W
Module						
L_{CE}				18		nH
$R_{CC'+EE'}$	res., terminal-chip	T_{case}= 25 °C		0,7		mΩ
		T_{case}= 125 °C		1		mΩ
$R_{th(c-s)}$	per module			0,045		K/W
M_s	to heat sink (M5)		3		5	Nm
M_t	to terminals (M6)		2,5		5	Nm
w				290	250	g
Temperature sensor						
R_{100}	T_c=100°C (R_{25}=5 kΩ)			0,493±5%		kΩ
$B_{100/125}$	$R(T)=R_{100}\exp[B_{100/125}(1/T-1/T_{100})]$; T[K]; B			3550±2%		K

This is an electrostatic discharge sensitive device (ESDS), international standard IEC 60747-1, Chapter IX.

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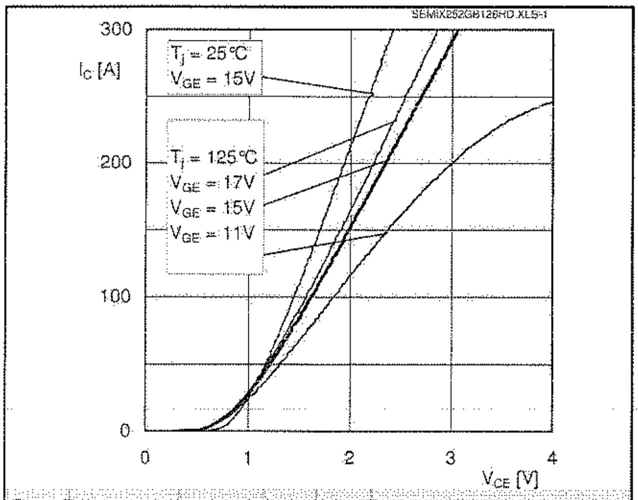

Fig. 1 Typ. output characteristic, inclusive $R_{CC'+EE'}$

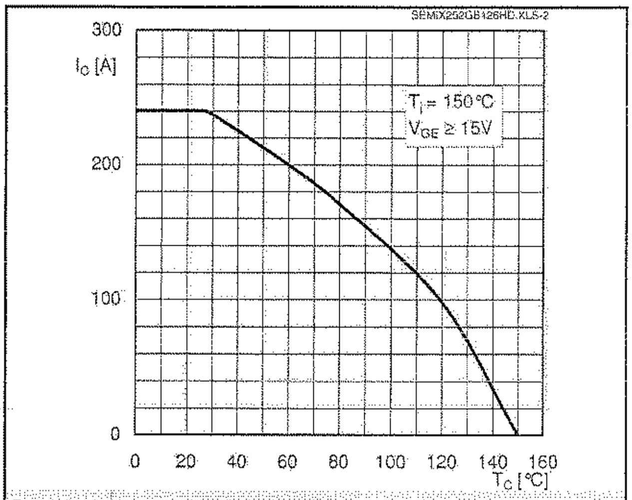

Fig. 2 Rated current vs. temperature $I_C = f(T_C)$

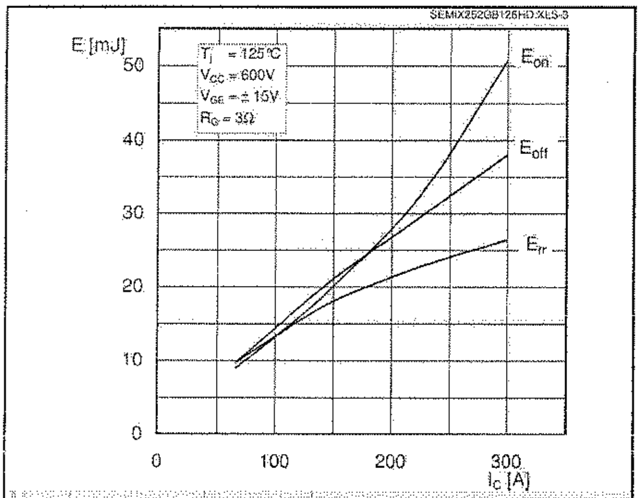

Fig. 3 Typ. turn-on /-off energy = f (I_C)

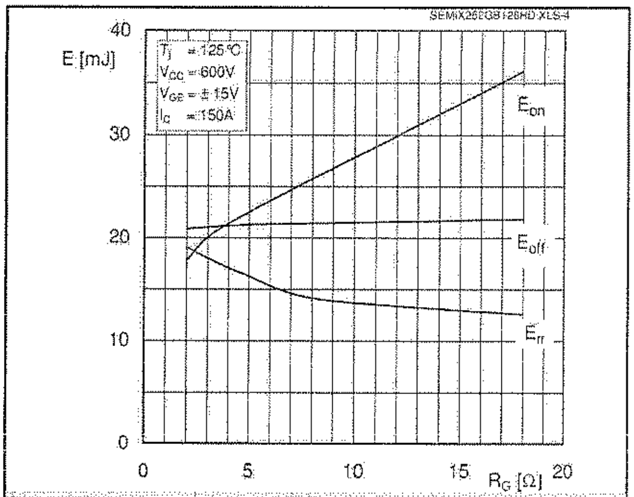

Fig. 4 Typ. turn-on /-off energy = f (R_G)

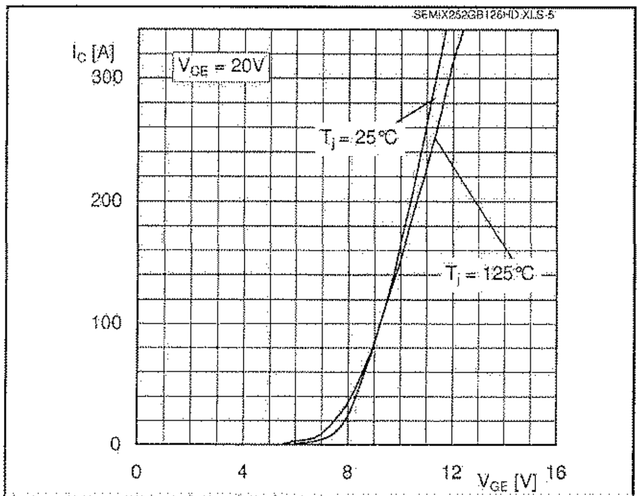

Fig. 5 Typ. transfer characteristic

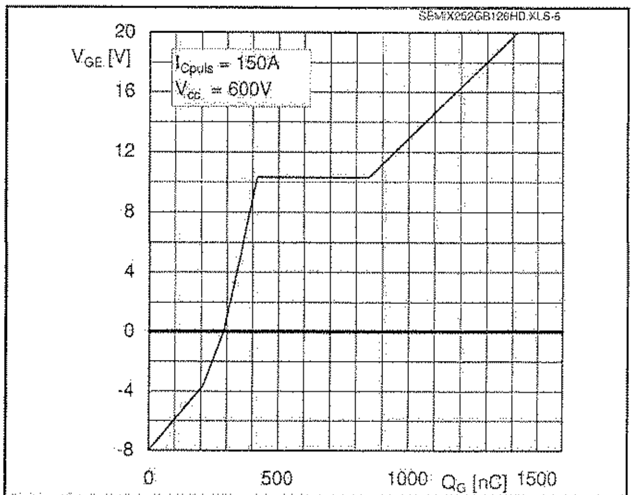

Fig. 6 Typ. gate charge characteristic

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