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Determination of Thermal Rating Of Power Semiconductor Devices For Different Motor Duty Cycle

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ABSTRACT

This paper determines the thermal rating of power semiconductor devices such as thyristors for different motor duty cycles under given ambient temperature. The ability to generate thermal simulations of systems and to accurately predict a system's response becomes essential in order to increase reliability, quantify the accuracy of the estimated thermal rating of thyristor module and predicts the maximum peak value current without violating thermal limits. The different motor duty cycles leads to different current carrying capacity of specific device and for each duty class current carrying capacity of the device is determined without violating its thermal limits. Computer simulation: Simulation is performed in MATLAB to find out peak continuous current of thyristor (SKT 100). For the hardware implementation, different duty classes are made to pass through the thyristor. This leads to different currents in the thyristor. The junction temperature of the thyristor cannot be calculated easily, hence we find out the temperature of
a heat sink which on which the thyristor is drilled.

I.INTRODUCTION

Power electronics involves the processing of electrical power (voltage, current and frequency) by means of solid-state electronics. It is used in a wide range of applications, from mobile phones to space shuttle power supply systems. A major design limit for modules of power electronic devices, such as solid-state power switches, is the device temperature; an estimated 55% of electronic component failures are related to temperature. The semiconductor industry is driven to decreasing the size of semiconductor devices. Coupled with the continuing increase in power rating [1], the power density of devices are rising which puts pressure on cooling technologies.

A solid-state power switches experience increased heat dissipation due to the voltage drop across them. Effective management of this heat generation is required in order to increase the operating lifetime of the devices. In particular, short duration transient heat losses are key issue which need to be considered when designing thermal management systems.Power electronic devices must be designed to handle the largest power dissipation to which they may be subjected. Short surges can occur due to over-current fault, which dissipates heat within devices. In some applications it may be adequate to switch devices off during such transients, but in the aerospace industry it is preferred that aircraft equipment is not switched off unnecessarily. Devices are required to ride through these transients to allow time for faults to be diagnosed and unnecessary shut downs to be avoided. The objective of the paper is to determine the thermal rating of power semiconductor devices such as thyristors for different motor duty cycles under given ambient temperature [2]. Methods opted to find out current carrying capacity of device for different duty classes are: -

Mathematical calculation: From device characteristics maximum allowable average current is determined and for each duty class's peak continuous current in determined under given ambient temperature.

Computer simulation: Simulation is performed in MATLAB to find out peak continuous current of thyristor (SKT 100).

SKT 100- THYRISTOR CHARACTERISTICS

Device characteristic provided by the manufacturer- SEMIKRON SKT 100C 16E

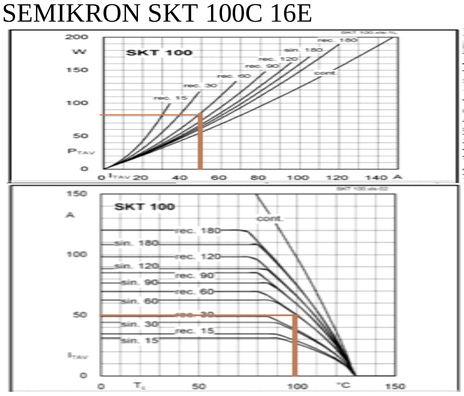

Fig 1 (a) Power dissipation Vs average current

(b) Average current Vs case temperature

For different conduction angle, there is different r.m.s value of the current for which variable current pass through the device and correspondingly average power is dissipated across the device for which junction temperature will be different. From the fig 1 (a) for 50A average current maximum forward power dissipation is 81 W (approx.) and corresponding case temperature can be read from fig 4.1 (b). Case temperature for 50 A average current is $100\ ^0$ C.

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II. THERMAL RESISTANCE

Thermal resistance denoted by R, if power loss P_{av} in watts causes the temperature of two points to be at T_1 ^{0}C and T_2 ^{0}C where $T_1 > T_2$ then thermal resistance is given by:- $R = (T_1 - T_2)/ P_{av}$ ^{0}C/W

From junction to thyristor case, thermal resistance R_{jc} From thyristor case to heat sink, thermal resistance R_{cs} and from the heat sink to corresponding ambient fluid (air or water), thermal resistance R_{sa}

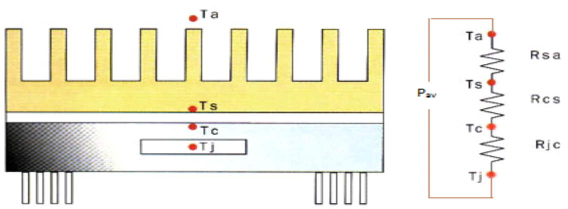


Fig 1(b) Thermal Resistance

III. CALCULATION BASED ON DEVICE CHARACTERISTICS

Maximum average power dissipation is calculated from the relation between thermal resistances and keeping junction temperature to be maximum under given ambient temperature. From device characteristics maximum allowable current is determined corresponding to max power dissipation [3]. By keeping max allowable average current in mind current carrying capacity of the device is calculated for different motor duty.

SEMIKRON SKT 100

Stud type thyristor having 100A, 1600 V rating is taken for the calculation. Following thermal resistances are provided by the manufacturer:

R_{jc}=0.36 K/W R_{CS}=0.1 K/W R_{sa}=1 K/W

We have taken ambient temperature to be: T_{amb} = 40 ^{0}C, now we calculate the value of maximum power dissipation so that junction temperature of the given device not exceeds its limiting value i.e. 125 ^{0}C. Junction temperature is T_J = 125 ^{0}C.The mathematical relations are:

$T_J = T_{amb} + P_{diss} (R_{jc} + R_{CS} + R_{sa})$ P_{diss}=75.86 W

From the characteristics curve between power dissipation and average continuous current we will obtained the maximum allowable average current [4].

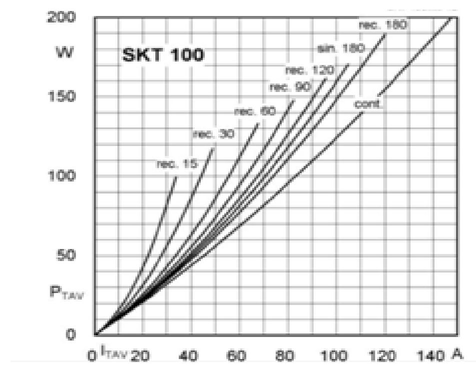
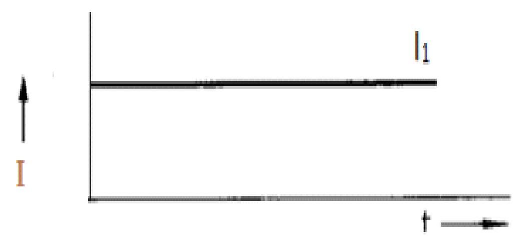


Fig 1(c) Power dissipation v/s current

FOR 30^0 CONDUCTION ANGLE

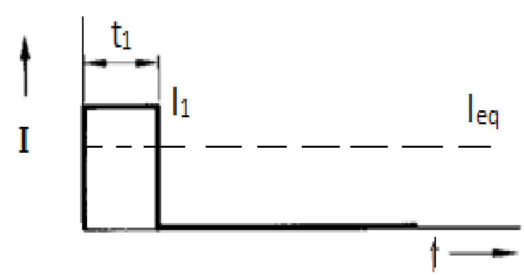
Now average current obtained from the graph are 32A (approx). We will calculate the value of continuous equivalent current and peak value current for different motor duty classes [5].

FOR S1 DUTY



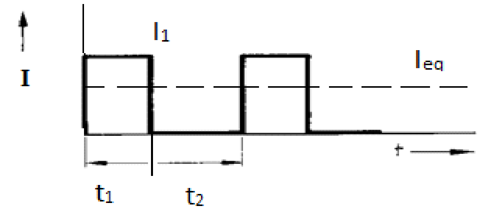
In this duty continuous current (I_1) is flowing through the device and equivalent current is same as the max allowable continuous current i.e. 32A

FOR S2 DUTY



In this duty for short duration, peak value of current is I_1, and the value of it depends on the load and time duration.

FOR S3 DUTY

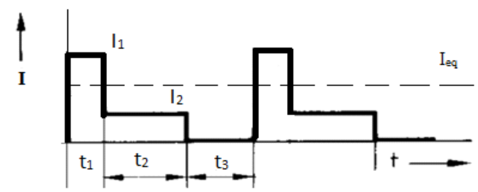


Equivalent continuous current for given duty is

$$I_{eq} = \sqrt{\frac{I_1^2 t_1}{t_1+t_2}}$$

Take $t_1 = t_2 = 20$ sec $I_{eq} = I_1/$ and by comparing it with maximum allowable current we get $I_1 = 45.25$ A. If we decreased the value of $t_1 = 10$ sec then peak current carrying capacity of the device will increase to 55.42 A.

FOR S4 DUTY



Equivalent continuous current for given duty is given by:

$$I_{eq} = \sqrt{\frac{I_1^2 t_1 + I_2^2 t_2}{t_1+t_2+t_3}}$$

Take $t_1 = t_2 = t_3 = 20$ sec and $I_2 = I$, $I_1 = 2I$

After putting all values in given equation we get: $I_{eq} = 1.29I$ and compare it with max allowable average current. I = 24.78 A $I_1 = 49.57$ A $I_2 = 24.78$ A

Now for $t_1 = t_2 = 10$, we get $I_{eq} = 1.118$ I A, so

$I_1 = 57.24$ A $I_2 = 28.62$ A

So by decreasing the value running time peak value of current or current carrying capacity of device is increased.

RESULT

Similarly peak value current is calculated for different conduction angle [6].

CONDUCTION ANGLES	DUTY CLASSES (I1)							
	S1	S2	S3	S4	S5	S6	S7	S8
30	32	50	45.25	49.57	64	40.5	48.48	48.48
60	41	60	57.98	63.57	82	51.89	62.12	62.12
90	43	65	60.8	66.66	74.78	54.43	65.15	65.15
120	49	70	69.29	75.96	85.21	62.02	82.35	82.35

Table 1: current rating for different duty cycle

IV. METHODS TO GET EQUATION FROM GIVEN CURVE

By seeing on the characteristics curve we can say that that it looks like 3rd or higher degree equation, we are going to generate polynomial equation which can fit the curve. Few methods are discussed below:

FOR 'N' POINTS ONE CAN FIT (N-1) TH DEGREE POLYNOMIAL

$$y = a * x^{n-1} + b * x^{n-2} + c * x^{n-3} \dots\dots\dots + f * x + g$$

Where a, b, c……g is coefficients of x and determined by putting all points in the given equation.

CALCULATION FOR 30^0 CONDUCTION ANGLE

From the characteristics curve between power dissipation and average current five set of points are taken, that's: (0, 0) (10, 18) (20, 46) (30, 80) & (33, 100) So the equation will be order four:

$$y = ax^4 + bx^3 + cx^2 + dx + e$$

Where y = power dissipation x = average current For (0, 0) e = 0

For (10, 18) 18 = 10000a+1000b+100c+10d -- (1)

Or, d = 1.8 – 1000a – 100b – 10c

For (20, 46) 46 = 160000a + 8000b + 400c + 20d

Or,10 = 140000a + 6000b + 200c (from 1)

For (30, 80) 80 = 810000a + 27000b + 900c + 30d

Or 26 = 780000a + 24000b + 600c (from 1)

For (33, 100) 100 = 1185921a + 35937b + 1089c + 33d Or, 40.7 = 1152921a + 32637b +759c (from 1)

Now by solving all equation we get:

a = 3.1512*10^(-4)

b = -0.01957

c = 0.41663

Put all values in 1 we get d= -0.72442

Hence the equation for 30^0 will be

$$y = 3.1512 * 10^{-4} x^4 - 0.01957x^3 + 0.41663x^2 - 0.72442x$$

LAGRANGE INTERPOLATING FORMULA

The Lagrange interpolating [7] polynomial is the polynomial of degree that passes through the points and is given by Where Written explicitly,

V. SIMULATION USING MATLAB

All equation that has been obtained from the device characteristics is simulated in MATLAB and peak value current is calculated for different duty classes.

VI. RESULT

Peak value current (I_1) is estimated for different duty classes under given ambient temperature [8].

MANUAL AND SIMULATION RESULT COMPARISON

Peak value current is determined manually and by using simulation in matlab, their results are compared below.

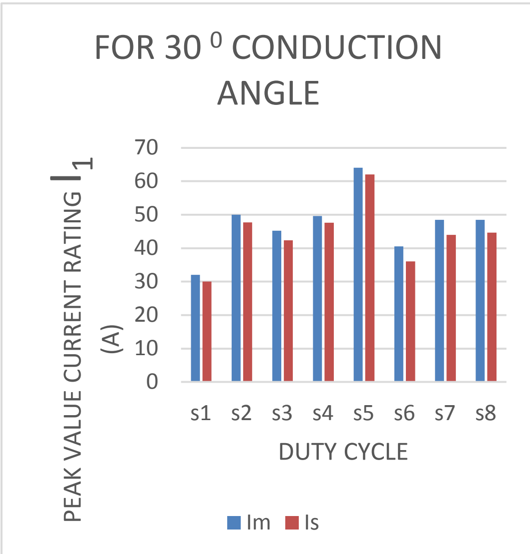


Fig 1(d) Conduction v/s Duty cycle

Blue line shows for manual results and red for computer simulation output. It can be observed that simulated result is 9.04% low in comparison to manually calculated result.

VII. CONCLUSION

In practical applications, there is a variable load which leads to variable current passing through the device and the corresponding temperature rise across the junction will be different. Thermal limiting value of the device is much smaller than that of a motor. Hence our main focus remains not allowing the junction temperature of the device to exceed its thermal limit for different motor duty classes. Conduction angle of the device depends upon the drive operational requirement, because for different conduction angle r.m.s voltage is different so speed of the motor will be different for variable voltages [9].

Simulation with proper inputs provides quick solution to manual calculation. Manual calculations are much more tedious as compared to computer simulation. Accuracy is less in manual calculations than in computer simulations [10]. Also, in simulations we can get a plot of peak current in a few seconds. This would take a much longer time in manual calculations and hence, analysis would become tougher.

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