Threshold Voltage (V_{TO}) and Slope Resistance (R_T) for Power Diodes and Thyristors

Summary

The mean forward power loss produced by current through diodes and thyristors is commonly presented by manufacturers in graphical form. These losses have usually been calculated from a mathematical expression which, in part, describes the forward voltage characteristic in terms of a logarithmic function and three or so constants.

The increasing use of computers to perform calculations for power semiconductor ratings has led to a need to provide data sheet parameters which can facilitate power loss calculations being made directly and simply from average current values.

This article explains how these calculations may be made, involving V_{TO} and R_T parameters and a simple power loss expression. It will also be demonstrated that adequate accuracy can be achieved, even for a high level of power loss, when two sets of V_{TO}, R_T values are available.

Mean Forward Power Loss in Diodes and Thyristors

The mean power loss produced in any circuit element with a repetitive waveform is given by the following equation:

$$P_M = \frac{1}{T} \int_{X1}^{X2} vi \, dt \qquad (1)$$

where:

P_M = mean power loss
v = instantaneous value of voltage across the element
i = instantaneous value of current through the element
X1,X2 = limits of conduction of the current
T = the waveform period

To determine the complete power loss curve for a diode or thyristor, it is essential to be able to accurately relate the instantaneous forward voltage to the instantaneous forward current, that is, to be able to accurately describe the mathematical shape of the forward characteristics of the device.

Data Sheet Power Loss Graphs

The power loss graphs which appear on International Rectifier data sheets have been produced from information which first assumes a forward voltage characteristic of the form:

$$v = \frac{1}{A} \log \left(\frac{i}{B} + 1 \right) iC \qquad (2)$$

where:
A, B, and C are constants

This expression, which very closely describes the shape of most power diode and thyristor forward voltage characteristics, involves the establishment of three constants (A, B, and C) for an optimum curve fit. With these constants secured, power loss expressions for sinusoidal and rectangular waves, incorporating expression (2), are used to calculate the data sheet mean power loss curves.

Calculation of Mean Forward Power Loss Using V_{TO} and R_T Parameters

An alternative equation to expression (2) for describing the forward characteristics may be obtained by considering the curves as consisting of two straight lines.
v may be described as:

$$v = iR_T + V_{TO} \qquad (3)$$

where:

V_{TO} = threshold voltage (v)
R_T = slope resistance (Ω)

Expression (1) gives

$$P_M = \frac{1}{T}\int_{X1}^{X2} vi\,dt$$

$$P_M = \frac{1}{T}\int_{X1}^{X2} i^2 R_T + V_{TO}\, i\,dt$$

hence,

$$P_M = R_T I_{RMS}^2 + V_{TO} I_{AV}$$

or

$$P_M = V_{TO} \cdot I_{AV} + R_T \cdot F^2 \cdot I_{AV}^2 \qquad (4)$$

where F = Form Factor = $\frac{I_{RMS}}{I_{AV}}$

Expression (4) may be used to calculate average power loss for sinusoidal or square waves at any conduction angle and average current.

Production of R_T, V_{TO} Parameters

The major problem in producing R_T, V_{TO} values for a forward voltage characteristic over a wide range of current values is that unacceptable power loss errors will occur where the straight line approximation deviates too much from the measured curve. A solution which International Rectifier has adopted is to provide two sets of R_T, V_{TO} parameters, a low level set and a high level set.

The low level R_T, V_{TO} parameters are generated from a series of evenly spaced points taken from the measured forward voltage characteristic of the device over the range 16% to 100% rated average current.

The high level R_T, V_{TO} parameters are generated in a similar way, but here, the chosen range is 100% to 2000% rated average current.

For both low and high level parameters "best fit" lines are determined by a process of linear regression.

Use of Low Level and High Level R_T, V_{TO} Parameters

Low level: These values should be used only up to average device current rating.

High level: These values may be used from around the average device rating to at least 20 times this level.

Example of Use of R_T, V_{TO} Values

For example, take the IRKE236-10 single diode in the INT-A-pak power module range (refer to Section D, page 233).

Calculate mean forward power loss using R_T, V_{TO} parameter @:

1: 150A average for 180° sine wave conduction and 120° square wave conduction.

2: 300A average for 120° square wave conduction.

Note: Since this is a 230A rated device, use low level R_T, V_{TO} parameters for 150A and high level values for 300A.

Using expression 4 and published R_T, V_{TO} parameters:

1:

Mean Power loss @ 150A, 180°C Sine Wave:

$0.79 \times 150 + 0.64 \times 10^{-3} \times 1.57^2 \times 150^2 = 157W$

Mean Power loss @ 150A, 120°C Square Wave:

$0.79 \times 150 + 0.64 \times 10^{-3} \times 1.73^2 \times 150^2 = 161.6W$

2:

Mean Power loss @ 300A, 120°C Square Wave:

$0.79 \times 300 + 0.64 \times 10^{-3} \times 1.73^2 \times 300^2 = 409W$

These values show a good correlation with the curves (Figures 25 & 26 page D241).

Conclusion

Threshold voltage and slope resistance parameters can provide a useful and simple method of

calculating mean forward power loss for power diodes and thyristors. Their use obviates the need for data sheet graph reading which will often make the operation easier and quicker.

It should be remembered that the principle underlying the determination of R_T, V_{TO} involves an approximation procedure, though good correlation with data curves can be achieved.

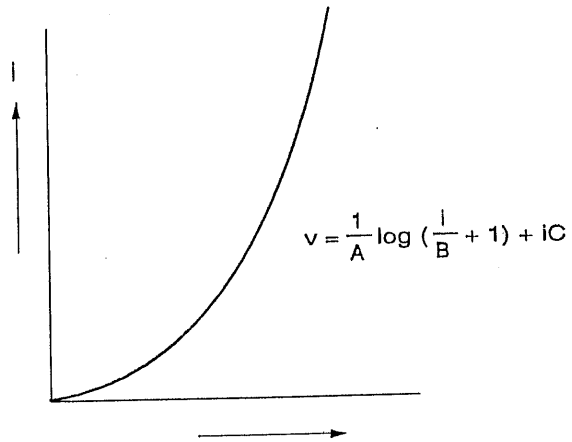

Fig. A - Typical shape of diode / thyristor forward voltage characteristic.

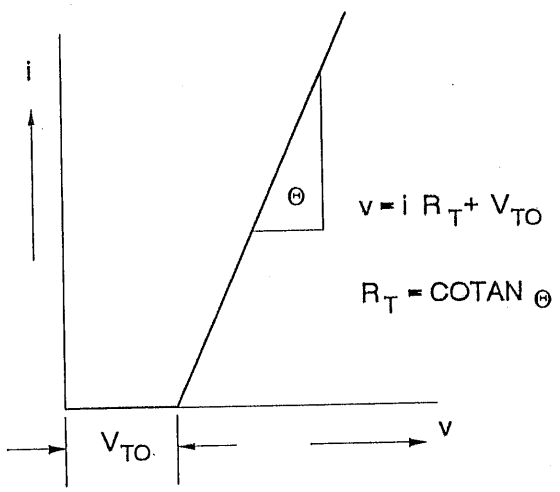

Fig. B - Forward voltage characteristics reduced to two straight lines.