AN5951

Estimation of Turn-off Losses in a Thyristor due to Reverse Recovery

Replaces AN5951-2

AN5951-3 January 2010 (LN27002)

Introduction:

The total power losses in a thyristor are comprised of off-state losses, switching losses and conduction losses. The off-state losses are the steady state losses as a result of blocking voltage and current (leakage current). The switching losses are the dynamic losses encountered during the turn-on and the reverse recovery phases of the thyristor. The conduction losses are the steady state on-state losses during the conduction phase of the thyristor. In the majority of the phase control thyristor applications the conduction losses are the dominant power losses compared to others. Therefore it is often sufficient to design thermal circuit using just the conduction losses with some safety margin. To help towards this process Dynex i^2 phase control thyristor datasheets give charts of power dissipation under the commonly encountered waveforms such as sine wave and the rectangular wave for different conduction angles.

The switching power losses are the function of the repetition frequency and the commutating di/dt. Therefore these losses become significant at higher frequencies and for high di/dt. For high voltage applications the contribution made by the reverse recovery losses can no longer be ignored. The reverse recovery energy is given by:

$$E_{rec} = \int I_{rec}(t) \times V_R\,(t)dt \quad (1)$$

To calculate the energy loss as per equation (1), detailed knowledge of the reverse recovery current and voltage waveforms is required. This is usually acquired through actual measurements in the real circuit. However for initial design purposes and dimensioning of the device, a quick method of estimating the recovery losses is desirable. In this Application Note a method of estimating power losses due to reverse recovery is outlined.

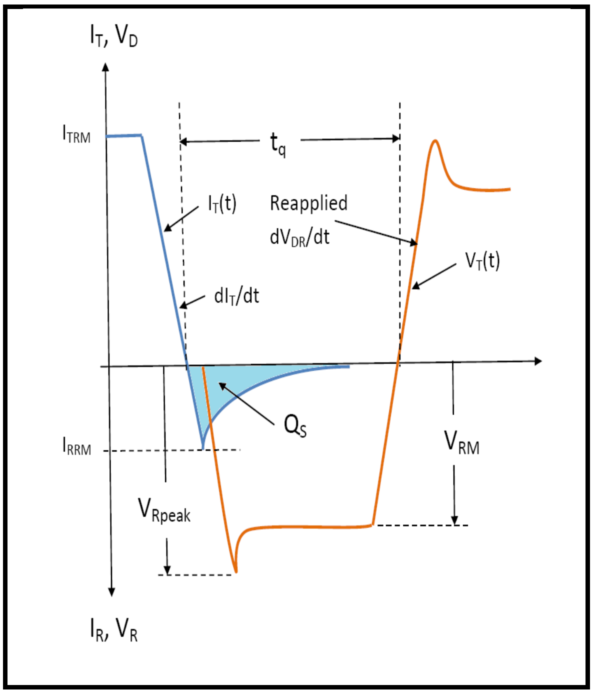

Fig. 1 Thyristor Turn-off waveforms

Approximation of reverse recovery waveforms:

Fig. 1 shows the current and voltage waveforms observed during the turn-off phase of a thyristor. The charge stored during the conduction phase is extracted as reverse recovery current when a thyristor undergoes turn-off. The reverse recovery phase is characterised by the peak reverse recovery current I_{RR} and the recovered charge Q_S. Q_S is given by the integral of the reverse recovery current.

$$Q_S = \int I_{rec}(t)dt$$
(2)

This is the shaded area in Fig. 1. For practical reason the datasheet value of Q_S is integrated for 150μs by which time the reverse recovery current is virtually zero.

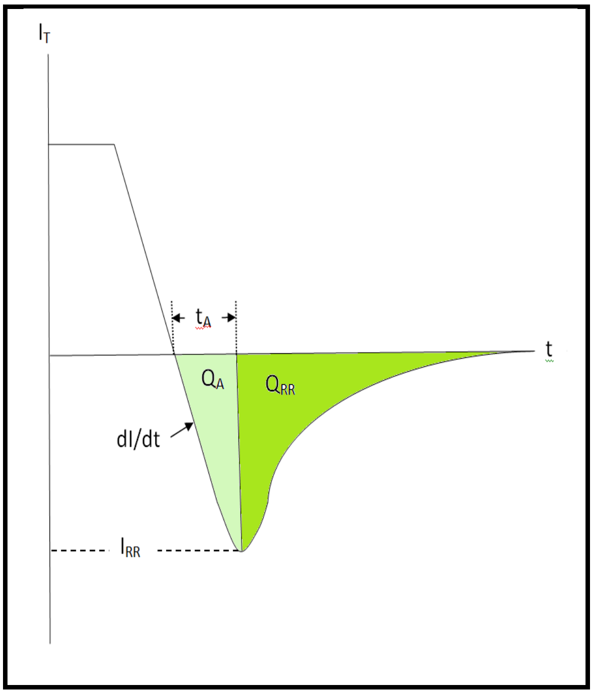

Fig. 2 Triangular Approximation

In Fig. 2 the total charge Q_S is divided into two regions, Q_A and Q_{RR} respectively; where

$$Q_A = \int_0^{t_A} I_{rec}(t)dt$$
(3)

$$Q_{RR} = \int_{t_A}^{\infty} I_{rec}(t)dt$$
(4)

The reverse voltage during the time interval t_A is negligible (Fig. 1) and hence energy contribution during the period t_A can be approximated to zero. Then from (1 and 4),

$$E_{rec} \approx V_R \int_{t_A}^{\infty} I_{rec}(t)dt$$
(5)

where V_R is assumed to be quasi constant and equal to applied peak reverse voltage V_{Rpeak} .

And from (5),

$$E_{rec} \approx 0.5 \times V_{Rpeak} \times Q_{RR}$$
(6)

Also,

$$E_{rec} \approx 0.5 \times V_{Rpeak} \times (Q_S - Q_A)$$
(7)

The charge Q_A can be approximated by the area of a triangle formed by I_{RR} and t_A. Thus

$$Q_A = 0.5 \times I_{RR} \times t_A$$
(8)

But

$$t_A = {I_{RR}}/{dI/dt}$$
(9)

Thus

$$Q_A = \frac{0.5 \times I_{RR}^2}{dI/dt}$$
(10)

Substituting in (7) we get,

$$E_{rec} \approx 0.5 \times V_{Rpeak} \times \left(Q_S - \frac{0.5 \times I_{RR}^2}{\frac{dI}{dt}}\right)$$
(11)

Worked example:

For illustration purpose, thyristor part number DCR3030V42 is chosen and the charts of stored charge and reverse recovery current from the datasheets are reproduced in the Fig. 3 and Fig. 4 respectively.

The calculation begins with known parameters of the circuit the V_{RM}(line voltage), V_{Rpeak} (controlled by the snubber circuit) and the dI/dt. The dI/dt of the turn-off current is usually controlled by the commutation inductance L_C.

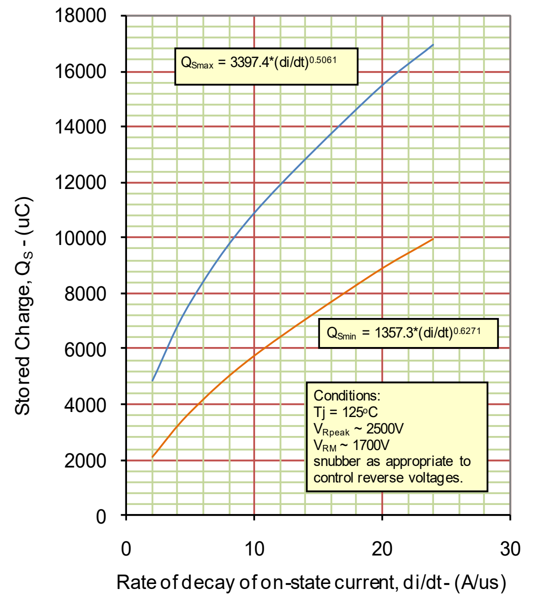

Fig. 3 Stored Charge

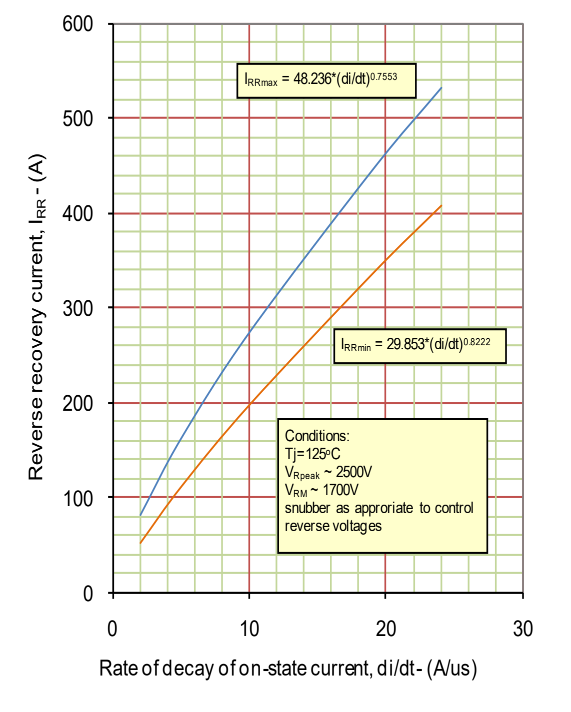

Fig. 4 Reverse Recovery Current

Thus

$dI/dt = V_{RM}/L_C$

If we assume dI/dt =10A/us, the value of Qs is given by using the equation on the chart of Fig. 3; $Q_{Smax} = 3397.4 \times (10)^{0.5061} = 10895\mu C$ and $Q_{Smin} = 1357.3 \times (10)^{0.6271} = 5751\mu C$. Similarly from chart of Fig. 4 the I_{RRmax} = 275A and I_{RRmin} =198A. V_{Rpeak} is 2500V.

Using the equation (11),

$E_{rec(max)}$ = 8.89J and $E_{rec(min)}$ = 4.74J per pulse.

If the repetition frequency is say 50Hz, then the power losses are:

$P_{rec(max)} = 8.89 \times 50 = 444.5W$ and

$P_{rec(min)} = 4.74 \times 50 = 237W$.

It should be noted that the minimum recovery losses correspond to the maximum conduction losses and vice a versa. Ideally both the conditions should be calculated and the worst case value should be used to design the thermal circuit (heat sink etc). Using both the maximum conduction losses and maximum recovery losses will lead to over dimensioning of the heatsink.

Measurement Method:

In this method the reverse recovery energy is determined by the measurement of the reverse recovery current and voltage using stored charge test equipment. The thyristor part tested was DCR2400B85. Fig.5 shows the oscillogram of the measured waveforms.

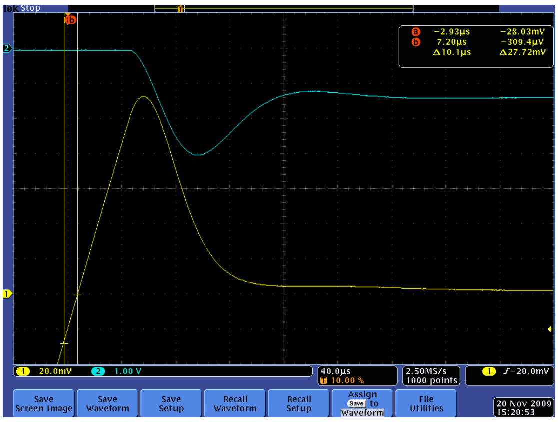

Fig.5 Reverse recovery waveforms

The test conditions are:
T_j = 125°C
V_{Rpeak} = 3030V
Snubber setting: 14Ω and 12µF

Test equipment readings:
Q_S = 15610µC integrated over 500µs
I_{rr} = 225.1A
dI/dt = 5.5 A/µs

Fig. 6 shows the digitised reverse recovery current and voltage waveforms plotted in an Excel chart. The Excel spreadsheet is used to multiply the digitised voltage and current waveforms to obtain the instantaneous power waveform as shown in Fig.7. Finally integrating this power waveform gives the energy per pulse. Again numerical integration was performed within the spreadsheet using the trapezium rule. The result of this integration gave the measured value of the reverse recovery energy:
E_{meas} = 17.8 J.
Using the approximation method (Eqn. 11) for the test results thus:
$E_{rec} = 0.5x3030x(15610-(0.5x(225.1)^2/5.5))$
$= 16.7$ J.
The approximation result is within 10% of the measured value.
Using the datasheet curves for DCR2400B85, the maximum and minimum values of recovery energy per pulse are 21.7 J and 15.9 J respectively.

Conclusion:

A method for estimating reverse recovery losses in a thyristor using datasheet curves is presented and verified with actual measurement. The approximated value lies within 10% of the measured value.

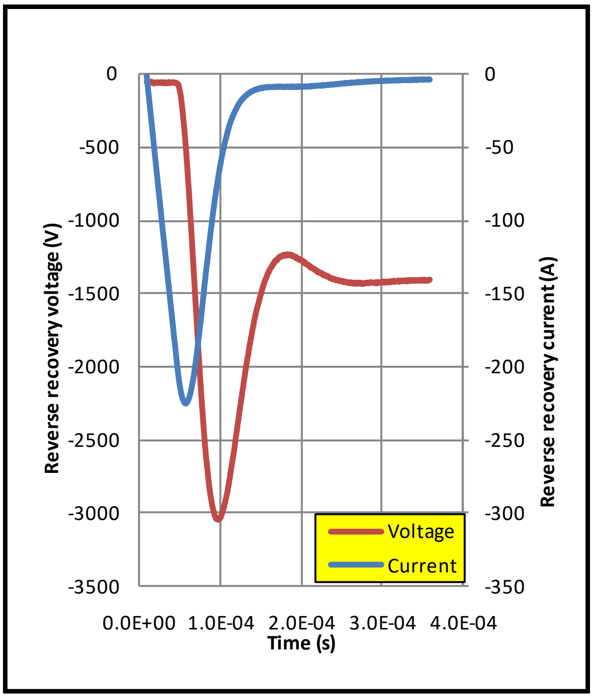

Fig. 6 Reverse recovery current and voltage

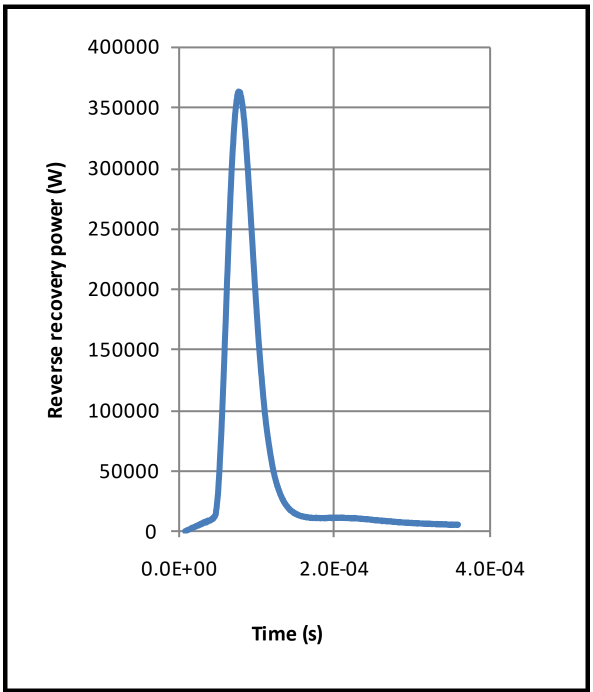

Fig. 7 Reverse recovery instantaneous power

IMPORTANT INFORMATION:

This publication is provided for information only and not for resale.

The products and information in this publication are intended for use by appropriately trained technical personnel.

Due to the diversity of product applications, the information contained herein is provided as a general guide only and does not constitute any guarantee of suitability for use in a specific application.The user must evaluate the suitability of the product and the completeness of the product data for the application. The user is responsible for product selection and ensuring all safety and any warning requirements are met. Should additional product information be needed please contact Customer Service.

Although we have endeavoured to carefully compile the information in this publication it may contain inaccuracies or typographical errors. The information is provided without any warranty or guarantee of any kind.

This publication is an uncontrolled document and is subject to change without notice. When referring to it please ensure that it is the most up to date version and has not been superseded.

The products are not intended for use in applications where a failure or malfunction may cause loss of life, injury or damage to property. The user must ensure that appropriate safety precautions are taken to prevent or mitigate the consequences of a product failure or malfunction.

The products must not be touched when operating because there is a danger of electrocution or severe burning. Always use protective safety equipment such as appropriate shields for the product and wear safety glasses. Even when disconnected any electric charge remaining in the product must be discharged and allowed to cool before safe handling using protective gloves.

Extended exposure to conditions outside the product ratings may affect reliability leading to premature product failure. Use outside the product ratings is likely to cause permanent damage to the product. In extreme conditions, as with all semiconductors, this may include potentially hazardous rupture, a large current to flow or high voltage arcing, resulting in fire or explosion. Appropriate application design and safety precautions should always be followed to protect persons and property.

Product Status & Product Ordering:

We annotate datasheets in the top right hand corner of the front page, to indicate product status if it is not yet fully approved for production. The annotations are as follows:-

Target Information:	This is the most tentative form of information and represents a very preliminary specification. No actual design work on the product has been started.
Preliminary Information:	The product design is complete and final characterisation for volume production is in progress. The datasheet represents the product as it is now understood but details may change.
No Annotation:	The product has been approved for production and unless otherwise notified by Dynex any product ordered will be supplied to the **current version of the data sheet prevailing at the time of our order acknowledgement.**

All products and materials are sold and services provided subject to Dynex’s conditions of sale, which are available on request.

Any brand names and product names used in this publication are trademarks, registered trademarks or trade names of their respective owners.

HEADQUARTERS OPERATIONS

DYNEX SEMICONDUCTOR LIMITED
Doddington Road, Lincoln, Lincolnshire, LN6 3LF
United Kingdom.
Phone: +44 (0) 1522 500500
Web: http://www.dynexsemi.com

CUSTOMER SERVICE

Phone: +44 (0) 1522 502753 / 502901
e-mail: powersolutions@dynexsemi.com