# Parallel Operation of Dynex IGBT Modules

Application Note

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## INTRODUCTION

IGBT modules can be connected in parallel to create a switch with a higher current rating. However, successful paralleling of IGBT modules requires some care. Depending on the application the system designer has to consider a number of issues to ensure that the system is reliable. These issues include the module characteristics, gate drive circuitry and circuit layout. The first step is to determine the optimum number of modules to be connected in parallel to obtain the required current rating for the system. Any solution must ensure that the safe operating area of the individual modules is not exceeded. Due to variations in module characteristics and circuit layout it cannot be assumed that the parallel connection of N modules each with a current rating of R amps will have a combined current rating of NR amps. For this reason it is necessary to derate the modules. This application note explains the theory behind derating with some examples and charts. The derating process can be applied to the entire range of Dynex IGBT modules. This note covers the static (conduction) and dynamic (switching) behaviour of parallel IGBT modules taking into consideration device characteristics only.

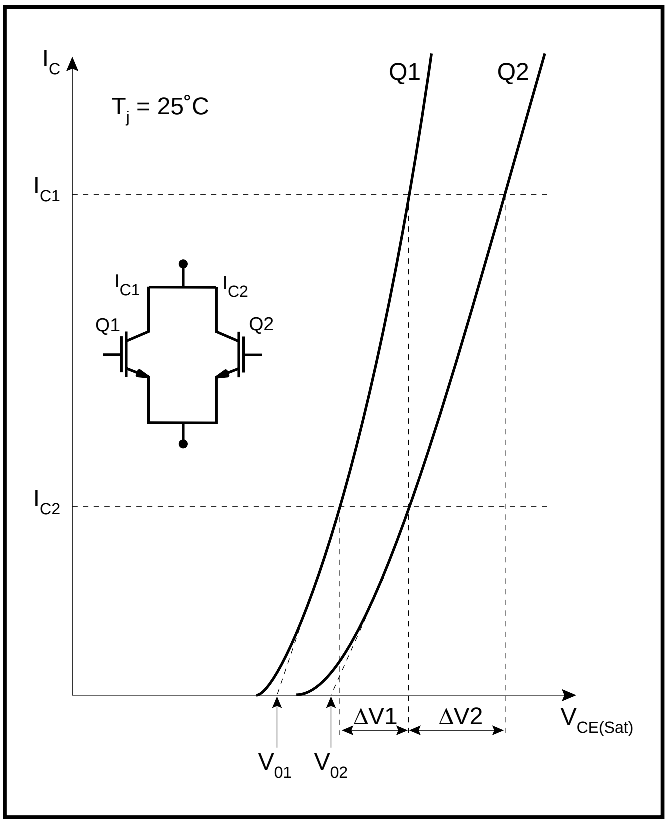


**Fig. 1 IGBT module output characteristics**

## STATIC SHARING OF IGBT MODULES CONNECTED IN PARALLEL

When two or more IGBT modules are connected in parallel a current imbalance occurs due to the difference in the dynamic and static characteristics of the individual IGBT modules. In a steady state condition it is principally the difference in output characteristics which causes the current to divide unequally between the modules. This is illustrated in figure 1, which shows that the device having the lower $V_{CE(sat)}$ (Q1) carries the largest portion of the total current.

Note that in the static situation the total circuit inductance including the load also influences the dc current sharing but the following analysis assumes that differences in each arm are negligible.

## WHAT IS THE STATIC (DC CURRENT) DERATING FACTOR FOR PARALLEL CONNECTED IGBT MODULES?

If two modules of the same type but with different $V_{CE(sat)}$ characteristics are connected in parallel the combined current rating is not twice the nominal current rating of the module (this assumes the current in neither module exceeds the nominal current rating). The reduction in effective current capability is known as the current derating factor. This is defined as:

$$\delta = 1 - \frac{I_T}{n_p \times I_M} \qquad [1]$$

Where,

$\delta$ = the derating factor,

$I_T$ = total current sustainable by the parallel combination of modules,

$I_M$ = maximum allowable current for a single module operating alone (dc current rating),

$n_p$ = number of modules in parallel.

**Example 1:**

Suppose we have two IGBT modules with a dc current rating of 800A, and that when operated in parallel one of the devices conducts 800A and the other 640A. We can calculate the derating factor from **[1]** thus:

$I_T$ = 800 + 640 = 1440A

$I_M$ = 800A

$n_p$ = 2

Hence,

δ = 1 – 1440 / (2 x 800)

= (1 – 0.9) x 100%

= 10%

Rearranging equation **[1]** we obtain:

$$I_T = (1 - \delta) n_p I_M \qquad \textbf{[2]}$$

Knowing the derating factor for a number of modules in parallel, one can determine the total current that can be sustained by the parallel system. For a system of $n_p$ parallel connected modules where none of them is to exceed the rated current, the worst case situation is when one of the devices is conducting the maximum rated current $I_M$ and the remaining ($n_p$ - 1) devices are each conducting some minimum current Imin. In this case the total current is given by:

$$I_T = I_M + (n_p - 1) I_{min} \qquad \textbf{[3]}$$

## WHAT IS THE MIS-SHARING FACTOR?

Following on from the derating factor, it is possible to define in a similar way the amount of mis-sharing between devices when connected in parallel. In this analysis the mis-sharing factor is a measure of the maximum current compared to the minimum current:

$$m = \frac{I_M - I_{min}}{I_M} \qquad \textbf{[4]}$$

Where

m = mis-sharing factor

$I_M$ = maximum allowable current for a single module operating alone.

$I_{min}$ = minimum current for a single module operating in a parallel connection.

We can express **[4]** as follows:

$$\frac{I_{min}}{I_M} = (1 - m) \qquad \textbf{[5]}$$

From **[1]**, **[3]** and **[5]** we have

$$\delta = 1 - \frac{(n_p - 1)(1 - m) + 1}{n_p} \qquad \textbf{[6]}$$

**Example 2:**

What is the derating factor for 4 devices in parallel with a mis-sharing factor of 20%?

Using equation **[6]**, we have

δ % = 1 – ((4 – 1)(1 – 0.2) +1)/4 = 0.15 x 100% = 15%.

The mis-sharing factor m is an important device characteristic for parallel connected IGBTs and it is related to the spread in IGBT output characteristics for a given device type. It is a function of

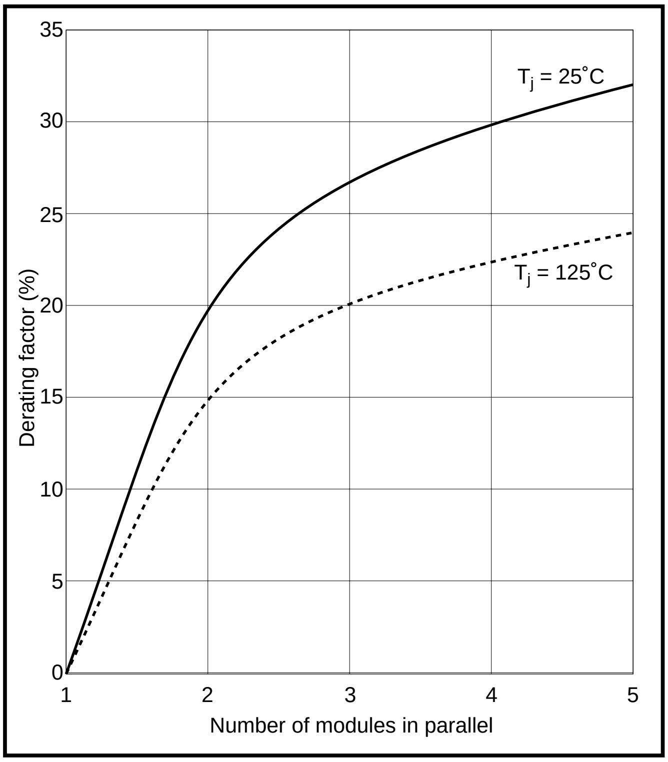


**Fig. 2 Static derating factor vs number of DIM800DDM17-A000 IGBT modules in parallel**

saturation voltage $V_{CE(sat)}$, junction temperature, device design and technology. Figure 2 (which is a plot of equation **[6]**) shows the derating factors for the Dynex DIM800DDM17 IGBT module for up to 5 modules in parallel.

Note that de-rating is more severe at lower temperatures. For a worst case design it is advisable to use derating factors applicable at 25°C junction temperature. The total system current can be estimated for up to 5 modules in parallel by reading off a derating factor from figure 2 and using equation **[2]**.

**Example 3:** Estimate total current for a system of four DIM800DDM17 connected in parallel.

From figure 2 the derating factor at 25°C for 4 devices in parallel is 30%. From equation **[2]**,

$I_T = (1 – 0.3) \times 4 \times 800 = 2240A$

## DYNAMIC BEHAVIOUR

The static rating a system of parallel connected IGBT modules assumes that none of the devices in parallel combination carries current more than its rated value. A similar approach can be applied to parallel connected-IGBT modules in dynamic conditions. The main reason for current imbalance during switching (turn-on and turn-off) assuming ideal gate drive conditions and circuit layout is the difference in the transfer characteristics (collector current vs. gate-emitter voltage ($V_{GE}$)) of the individual modules. Referring to figure 3, if the $V_{GE}$ applied to each of the parallel modules is identical during the switching transistions, the current divides dynamically according to the transfer characteristics. The IGBT module with the largest value of transconductance (i.e. the "steeper" transfer characteristic) carries the greater portion of the current and incurs the highest switching losses. The dynamic current rating ($I_{C(PK)}$) is related to the IGBT rated junction temperature and hence to the total device losses. <u>Thus the dynamic current rating depends on the specific application conditions.</u>

If we define $I_{C(PK)(max)}$ as the maximum allowable peak current for a single module operating alone in a specific appication and $I_{C(PK)(min)}$ as the minimum peak current for a single module operating in a parallel connection, then we can define the partial current $\Delta I_{C(PK)}$ as $I_{C(PK)(max)} – I_{C(PK)(min)}$ and the dynamic current mis-sharing factor by

$\varphi = \Delta I_{C(PK)} / I_{C(PK)(max)}$ **[7]**

Thus we can obtain the dynamic derating factor:

$\delta \text{ (dynamic)} = 1 – [(n_p – 1)(1 – \varphi) + 1]/n_p$ **[8]**

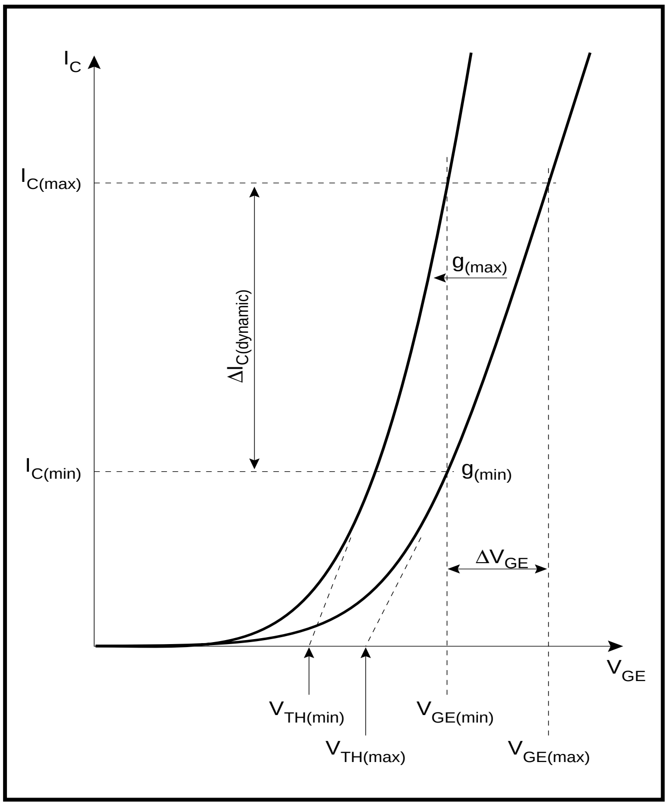


**Fig. 3 IGBT module transfer characteristics**

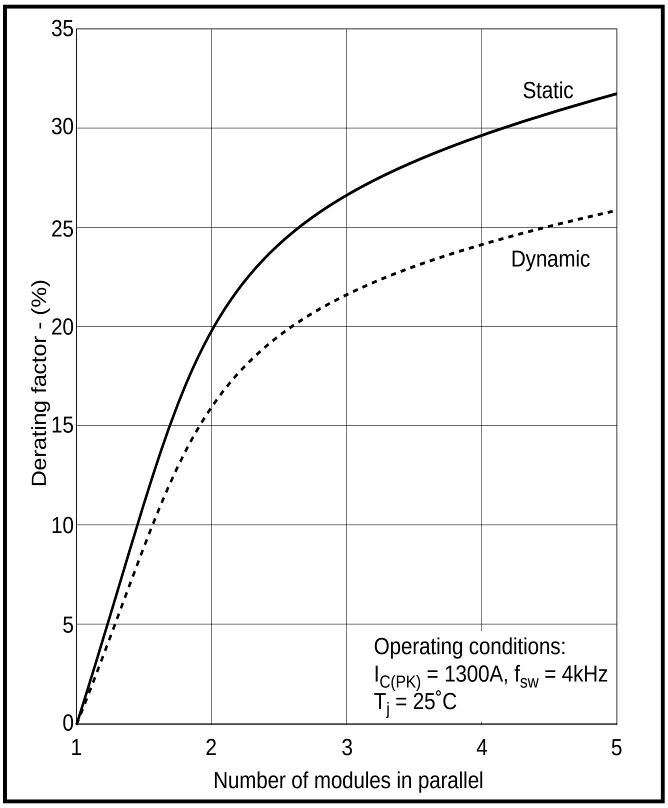


**Fig. 4 Comparison of static and dynamic derating factors for DIM800DDM17-A000**

Where

$\delta$ = dynamic derating factor

$n_p$ = number of modules in parallel

$\varphi$ = Mis-sharing factor

The dynamic mis-sharing factor $\varphi$ is related to the transfer characteristics ($V_{TH}$ and $g_{fe}$) of the IGBT.

Figure 4 compares static and dynamic derating for DIM800DDM17 IGBT modules at 25°C junction temperature under given operating conditions (in this case a PWM motor drive inverter). Note that the static derating factor is greater than the dynamic derating factor. This is true in general and so for most applications users need only consider the static derating factor when determing the number of modules required in parallel.

## EXTERNAL INFLUENCES ON SHARING

This note considers only the effects of device characteristics on static and dynamic sharing. However, it should be noted that dynamic sharing is more sensitive to external circuit factors (especially the stray inductance in the gate-emitter circuit loop) than the IGBT module dynamic characteristics (transconductance). Figure 5 illustrates how unequal stray inductances in the gate-emitter loops produce dynamic imbalance due to non equal gate emitter voltages (i.e. $V_{GE1} \neq V_{GE2}$) during switching and thus an unbalanced current in dynamic switching. The use of separate gate resistors $R_{g1}$ and $R_{g2}$ (figure 6) helps to restore the dynamic balance.

## SUMMARY

When a number of IGBT modules are connected in parallel, the total current capability must be derated due to mismatching of device characteristics and non-symmetrical external circuit layout. The derating factors for static and dynamic operation are presented for parallel combinations of up to five modules. Using the derating charts a system designer can estimate the total sustainable current for a system of parallel-connected IGBT modules.

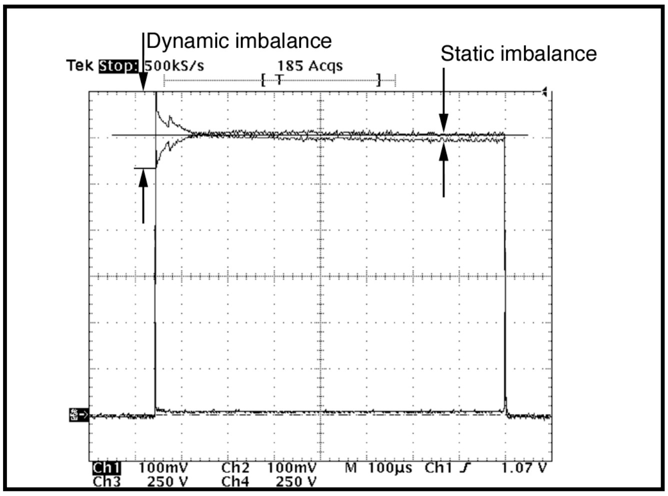


**Fig. 5 Static and dynamic collector current imbalance for two DIM800DDM17-A000 modules in parallel**

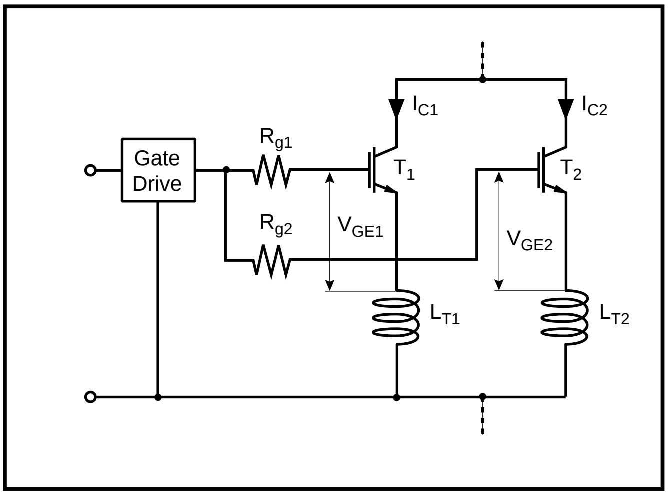


**Fig. 6 Use of $R_{g1}$ and $R_{g2}$ to restore dynamic balance**

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