Article: Practical application of the latest generation IGBT transistors in the ENI-PTC750/52 auxiliary power supply - part II

Introduction

The aim is to show the practical application of 7th generation IGBTs, based on the example of the latest ENI-PTC750/52 Auxiliary Power Supply (APS) from Enika. This was designed for the Light Rail Transit Authority (LRT1) in Manila, where the trains have been in operation since May 2019. A comparison is made between the latest 7th generation IGBT and the previous 5th generation IGBT.

Comparison of 5th and 7th generation IGBT modules

Development of semiconductors

In this age of electronics and power electronics, manufacturers are racing to improve their power semiconductors. The latest solutions, like SiC (Silicon Carbide) and GaN (Gallium Nitride) semiconductors, feature the best power density levels and efficiency, but they have one disadvantage: they are still very expensive. At the same time the manufacturers of IGBT transistors are also working to improve their products, with the 7th generation IGBT transistors recently being introduced.

This type of IGBT is characterized by faster switching and smaller losses. This allows operation at higher frequencies and better efficiencies, which leads to reductions in the required cooling system and size of the converters and inverters. A practical comparison between a 5th generation (Fuji 2MBI550VN-170-50) and a 7th generation (Mitsubishi CM600DX-34T) IGBT module installed in an ENI-PTC750/52 unit is shown below.

Both modules have very similar electrical parameters:

- Collector – emitter voltage: 1700 V_{DC}
- Continuous collector current: 550 A (2MBI550VN-170-50) and 600 A (CM600DX-34T)
- Package type: Semix

The 2MBI550VN-170-50 module is commonly used in many Enika applications and the CM600DX-34T is a successor, which is why these modules were chosen for the comparison. Despite the similar basic parameters, the 7th generation module has lower switching losses and shorter switching times. The figures below show the switching losses and switching times, based on the datasheets.

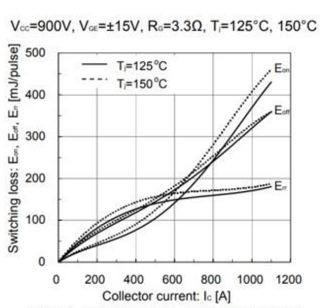

Figure 8. Switching energy vs. Collector current of 2MBI550VN-170-50

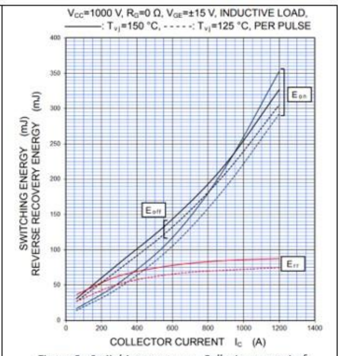

Figure 9. Switching energy vs. Collector current of CM600DX-34T

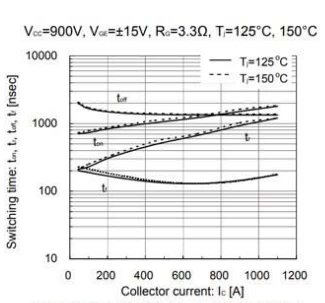

Figure 10. Switching time vs. Collector current of 2MBI550VN-170-50

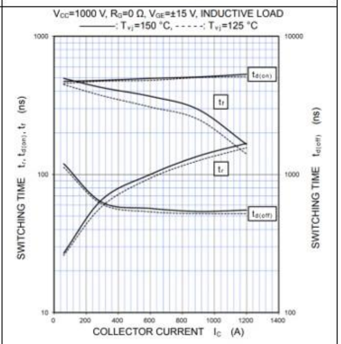

Figure 11. Switching time vs. Collector current of CM600DX-34T

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The figures cannot be directly compared due to the different initial conditions (which have to be calculated), which is why the differences in the figures above may not be visible at first sight.

Loss calculation for ENI-PTC750/52

Table 2 shows the loss calculations for each module for three different output powers of the ENI-PTC750/52: half power, nominal power and twice nominal power. All parameters are taken from the datasheets and have been recalculated to the same initial conditions. The loss calculations were made according to the equations below:

Conduction loss in the transistor

$$P_{p/T} = \frac{1}{2}\left(\frac{V_{CE0}}{\pi} \cdot i_M + \frac{r_{CE}}{4} \cdot i_M^2\right) + m \cdot \cos\varphi \cdot \left(\frac{V_{CE0}}{8} \cdot i_M + \frac{r_{CE}}{3 \cdot \pi} \cdot i_M^2\right)$$

Conduction loss in the diode

$$P_{p/D} = \frac{1}{2}\left(\frac{V_{F0}}{\pi} \cdot i_M + \frac{r_F}{4} \cdot i_M^2\right) - m \cdot \cos\varphi \cdot \left(\frac{V_{F0}}{8} \cdot i_M + \frac{r_F}{3 \cdot \pi} \cdot i_M^2\right)$$

Switching loss in the transistor

$$P_{onoff/T} = \frac{1}{\pi} \cdot f_s \cdot \left[E_{on/T}(i_M) + E_{off/T}(i_M)\right]$$

Switching loss in the diode

$$P_{onoff/D} = \frac{1}{\pi} \cdot f_s \cdot E_{off/D}(i_M)$$

Where:

V_{CE0} – collector – emitter saturation voltage (for I_C = 0 A),

r_{ce} – collector – emitter resistance,

V_{F0} – diode voltage drop (for I_C = 0 A),

r_F – diode resistance,

m – modulation index,

cos j – power factor,

I_M – peak current.

Table 2. Comparison of losses for each module at different output powers.

		2MBI550VN_170_50	CM600DX-34T	2MBI550VN_170_50	CM600DX-34T	2MBI550VN_170_50	CM600DX-34T
S_{OUT}	[kVA]	26	26	52	52	104	104
U_{Supply}	[V]	750	750	750	750	750	750
U_{OUT}	[V]	320	320	320	320	320	320
$f_{Switching}$	[kHz]	7	7	7	7	7	7
cos fi	[-]	0.9	0.9	0.9	0.9	0.9	0.9
P_{OUT}	[kW]	23.4	23.4	46.8	46.8	93.6	93.6
I_{OUT_RMS}	[A]	46.9	46.9	93.8	93.8	187.6	187.6
I_{OUT_peak}	[A]	66.1	66.1	132.3	132.3	264.6	264.6
P_{Cond_Q}	[W]	15.3	13.6	39.3	33.6	102.0	87.1
$P_{Switching\_Q}$	[W]	74.6	78.7	138.5	109.9	254.3	177.7
P_{Cond_D}	[W]	5.2	5.2	13.0	13.0	34.2	34.2
$P_{Switching\_D}$	[W]	61.4	47.7	113.1	60.2	192.8	80.5
P_{TOT_Q}	[W]	90	93	178	144	357	265
P_{TOT_D}	[W]	67	53	127	74	228	115
P_{TOT_Q+D}	[W]	157	146	304	217	584	380
P_{Module}	[W]	314	292	608	434	1168	760
$P_{Inverter}$	**[W]**	**942**	**876**	**1824**	**1302**	**3504**	**2280**
η	**[%]**	**96.0**	**96.3**	**96.1**	**97.2**	**96.3**	**97.6**
T_{on}	[ns]	765	458	800	462	872	468
T_{off}	[ns]	1874	1217	1790	1051	1658	790
T_{rise}	[ns]	225	13	254	19	317	32
T_{falls}	[ns]	221	467	211	443	193	402

The efficiencies indicated in Table 2 are based only on the losses from the IGBT modules, ignoring the losses from the inductive elements. In all cases, the efficiency of an inverter with a 7^{th} generation module is higher: for nominal power it is about 28% higher. The faster switching time allows deadtime to be decreased by 30%.

Results of the simulation

The calculations presented in section Loss calculation for ENI-PTC750/52 have been compared to simulations of the ENI-PTC750/52 converter, using the PSIM software. This allows not only a check of the converter waveforms but also the thermal losses from the modules. The figures below show the converter losses at nominal power and twice nominal power for each module.

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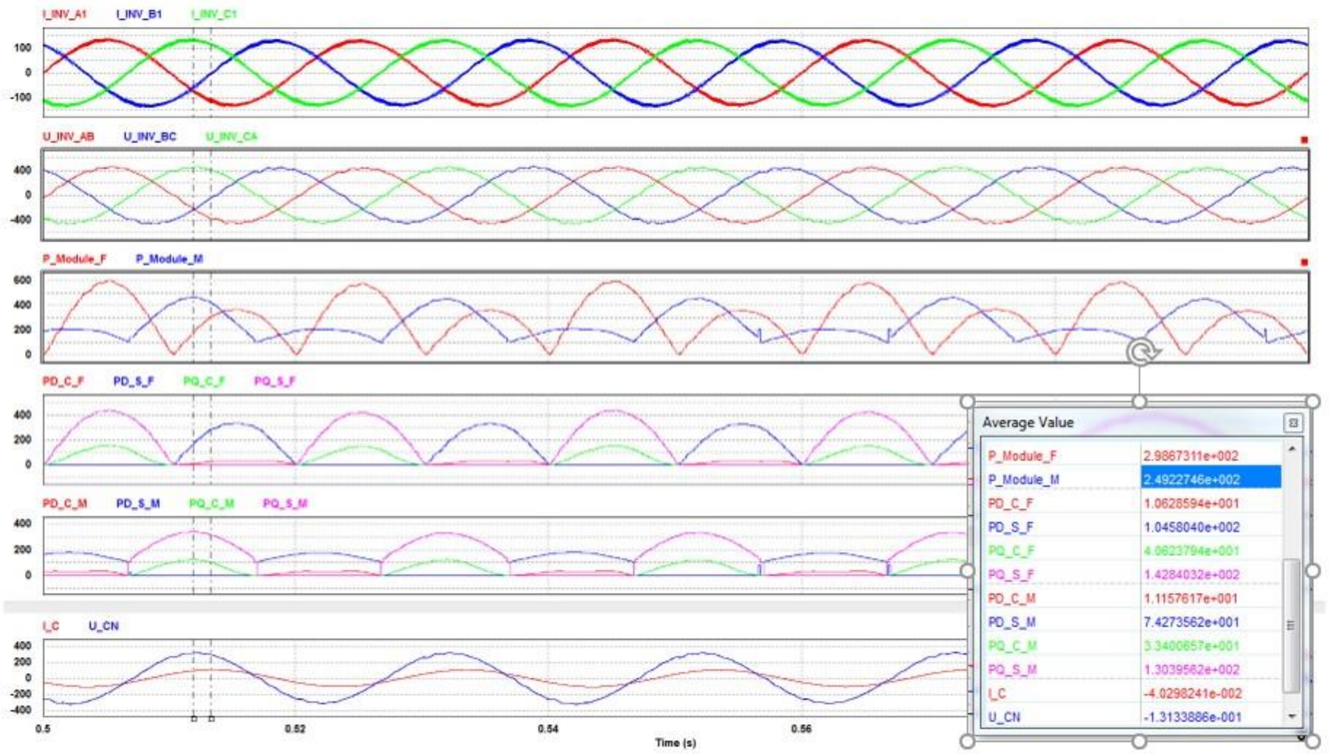

Figure 12. Losses in the IGBT module for nominal converter power

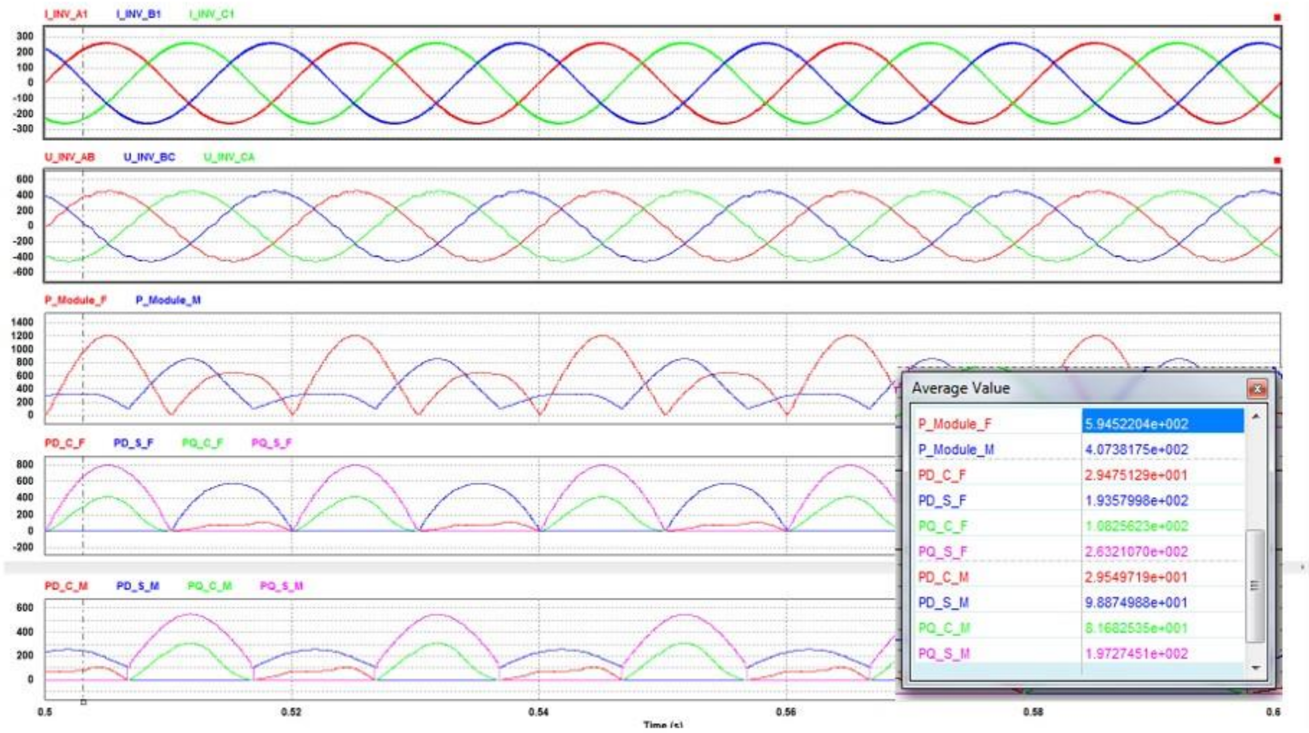

Figure 13. Losses in the IGBT module for twice the nominal converter power

Table 3 shows the calculated and simulated losses for each module. For all scenarios the results are similar, with the differences between calculation and simulation resulting from the different approximation methods used for the module characteristics, and which clearly shows that the losses for the 7th generation module is much lower. At nominal power, the inverter for the 7th generation module achieved a reduction in losses of 523 W.

Table 3. Comparison of losses between the two modules, for the simulation and calculation

Nominal power					
		2MBI550VN-170-50		CM600DX-34T	
		Calculation	Simulation	Calculation	Simulation
IGBT conduction loss	[W]	39.3	40.6	33.6	33.4
IGBT switching loss	[W]	138.5	142.8	109.9	130.3
Diode conduction loss	[W]	13.0	10.6	13.0	11.2
Diode switching loss	[W]	113.1	104.5	60.2	74.2
IGBT loss	**[W]**	**177.8**	**183.4**	**143.5**	**163.7**
Diode loss	**[W]**	**126.1**	**115.1**	**73.2**	**85.4**
Overall loss	**[W]**	**303.9**	**298.5**	**216.7**	**249.1**
Twice nominal power					
		2MBI550VN-170-50		CM600DX-34T	
		Calculation	Simulation	Calculation	Simulation
IGBT conduction loss	[W]	102.0	108.3	87.1	81.7
IGBT switching loss	[W]	254.3	263.2	177.7	197.3
Diode conduction loss	[W]	34.2	29.5	34.2	29.6
Diode switching loss	[W]	192.8	193.6	80.5	98.9
IGBT loss	**[W]**	**356.3**	**371.5**	**264.8**	**279.0**
Diode loss	**[W]**	**227.0**	**223.1**	**114.7**	**128.5**
Overall loss	**[W]**	**583.3**	**594.6**	**379.5**	**407.5**

The PSIM simulation also allows the waveforms to be checked at each point of the converter. Figure 14 and Figure 15 show the IGBT current achieved by simulation and by oscilloscope measurement.

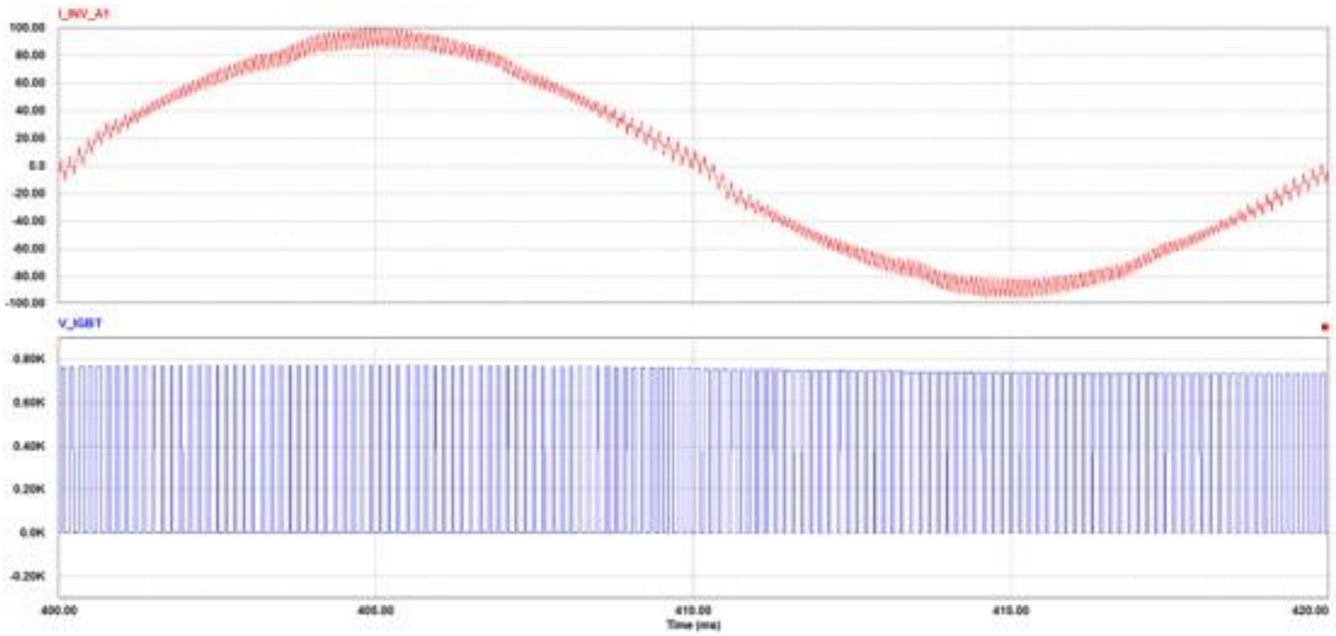

Figure 14. Inverter current and voltage on the IGBT transistor in the simulation

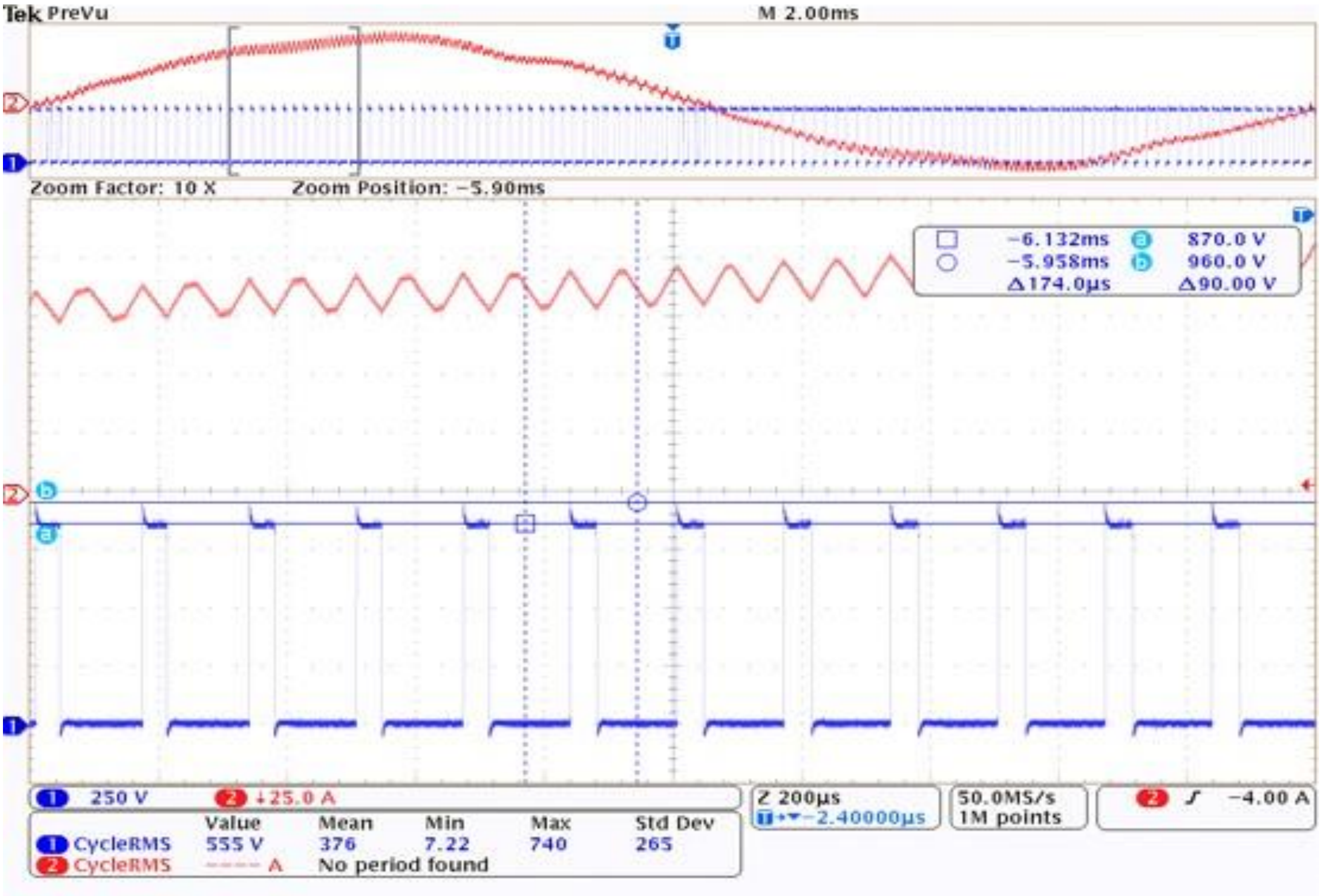

Figure 15. Inverter current and voltage on the IGBT transistor by measurement

Conclusions

The calculations and simulations presented here show that the 7th generation IGBT features much smaller losses than the 5th generation. Efficiency measurements of actual converters have values between 90.1% and 91.7%, depending on supply voltage and converter load. This shows that even with IGBT transistors, high converter efficiency can be achieved. A 30% reduction in losses on the IGBT allow reductions in the heatsink and cooling systems, reducing the price and weight of the converter.

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