Advantages of SiC Devices in PV String Inverters

SiC SBD and SiC MOSFET

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This Application Note focuses on Boost Converters which are typically used as the Frontend to provide a stable DC link voltage for the Solar PV string inverters. Boost converters are widely used in a variety of applications like solar photovoltaic power generation, power factor correction (PFC), uninterruptible power supplies (UPS), etc. There is a continuous demand for increased power density and higher Efficiency targets in Solar PV generation systems, where traditional Silicon Devices show limitations, paving the way for the use of SiC Devices to replace the traditional Silicon devices (IGBTs, Schottky/ Ultrafast Recovery Diodes)with more robust and better-performing SiC SBD and SiC MOSFETs. In this application note, San'an's 1200V/40mΩ SiC MOSFET, the AMS1200040M2, with a maximum on-current of 48A, has been showcased for its use in boost conversion applications in solar photovoltaic generation applications. The AMS1200040M2 boasts of low on-resistance with higher switching speed, low capacitance and low junction-case resistance. It has low switching losses and an excellent avalanche reliability.

Based on actual product test data, this Application Note compares and analyzes the performance of the AMS1200040M2 against Si devices and competing SiC devices in the market in detail. The test data is based on a 1000V level, 10kW photovoltaic system. Table 1 shows the different devices used for benchmarking, and Figure 1 shows the schematic of the boost converter used for benchmarking.

Table 1: Devices and Operating Frequency for Different Test Groups.

Test Group	Active switching device (TO247-4L)	Boost diode (TO247-2L)	Switching Frequency
1	San'an SiC MOSFET AMS120040M2	San'an SiC SBD SDS120J020H5	20 kHz 40 kHz 60 kHz
2	Comp.A SiC MOSFET 1200V/40mΩ	San'an SiC SBD SDS120J020H5	40 kHz
3	Comp.B Si IGBT 1200V/75A	San'an SiC SBD SDS120J020H5	20 kHz
4	Comp.B Si IGBT 1200V/75A	Comp.B Si FRD 1200V/30A	20 kHz

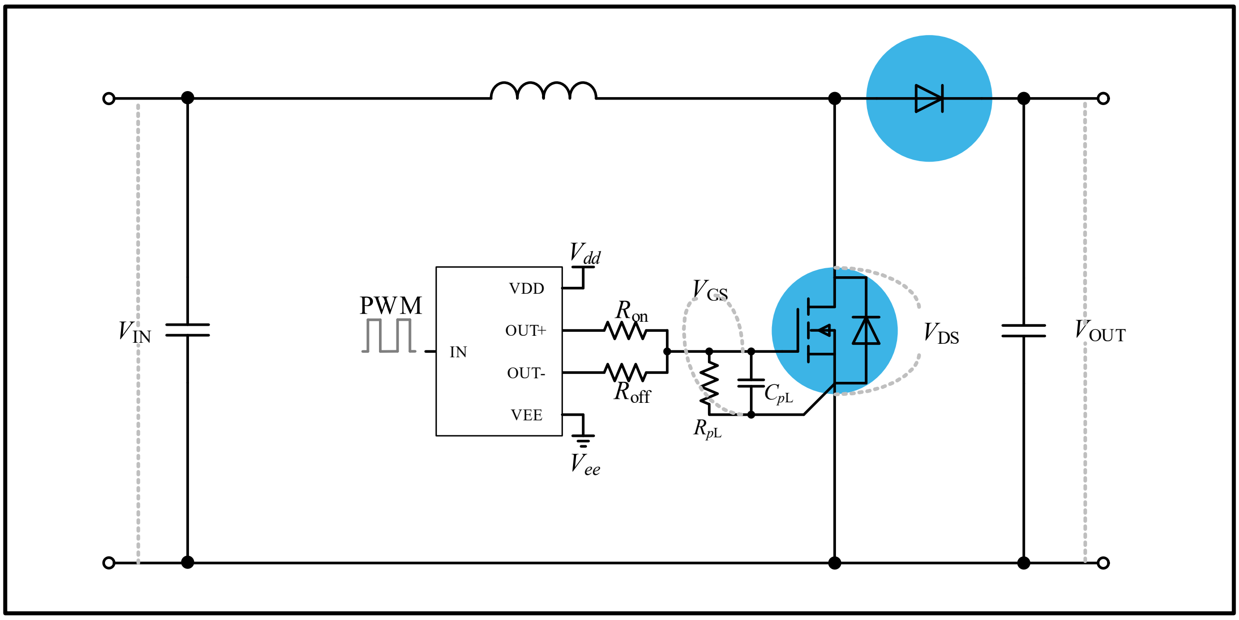

Figure 1: Circuit Topology of Boost Converter

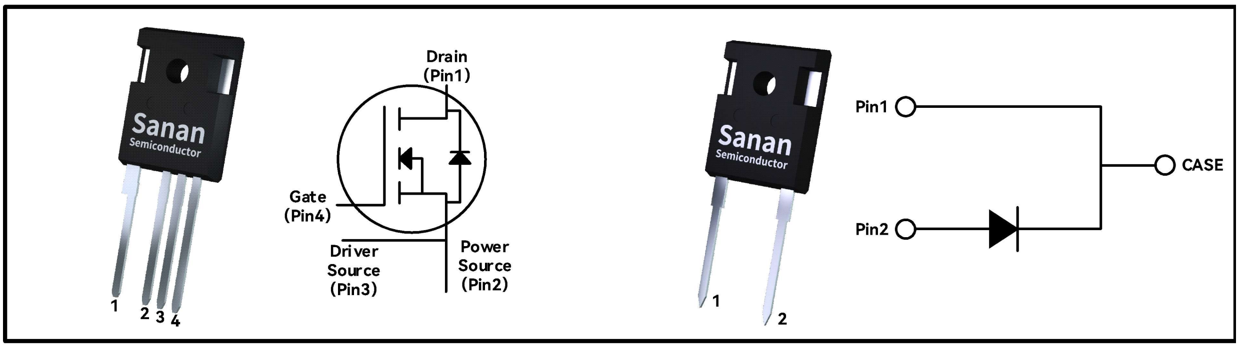

Figure 2: AMS1200040M (1200V/40mΩ SiC MOSFET), SDS120J020H5 (1200V/20A SiC SBD)

1 Performance of San'an Power Devices in Boost Circuits

The results and data presented in this section refer to the devices described in Test Group 1 of Table 1. The main switch is the AMS1200040M2, and the Diode is the SDS120J020H5 (5^{th} Generation SiC Schottky Barrier Diodes from San'an). The switching frequency and output power are changed during the test to evaluate the performance of San'an's devices under different operating conditions. Table 2 shows the operating points of the converter.

Table 2: Operating Points and Specifications of the Boost Converter

Parameter	Symbol	Value
Input Voltage	V_{IN}	350V
Output Voltage	V_{OUT}	650V
Inductor	L	390µH (Sendust core for Boost Converters)
Gate Voltage	V_{GS}	+18V/-5V
External Gate Resistance	R_g ($R_{g\_on} = R_{g\_off}$)	2.4Ω

Parameter	Symbol	Value
Ambient Temperature	T_{amb}	22°C
Output Power	P_{out}	4kW/6kW/8kW/10kW
Switching Frequency	F_{sw}	20kHz/ 40kHz/ 60kHz

Figure 3 shows the waveforms captured at 40kHz switching frequency for full load of 10kW. In the figure:

- CH1 (Black) is the gate voltage (V_{GS})
- CH2 (Cyan) is the drain to source voltage, V_{DS} of the MOSFET
- CH3 (Red) is the switch current (I_{DS})
- CH4 (Green) is the input voltage (V_{IN})
- CH5 (Orange) is the output voltage (V_{OUT})
- CH6 (Blue) is the inductor current (I_L)

The waveform shows that device has a good switching performance with a turn-on time of 32ns and a turn of time of 35ns.

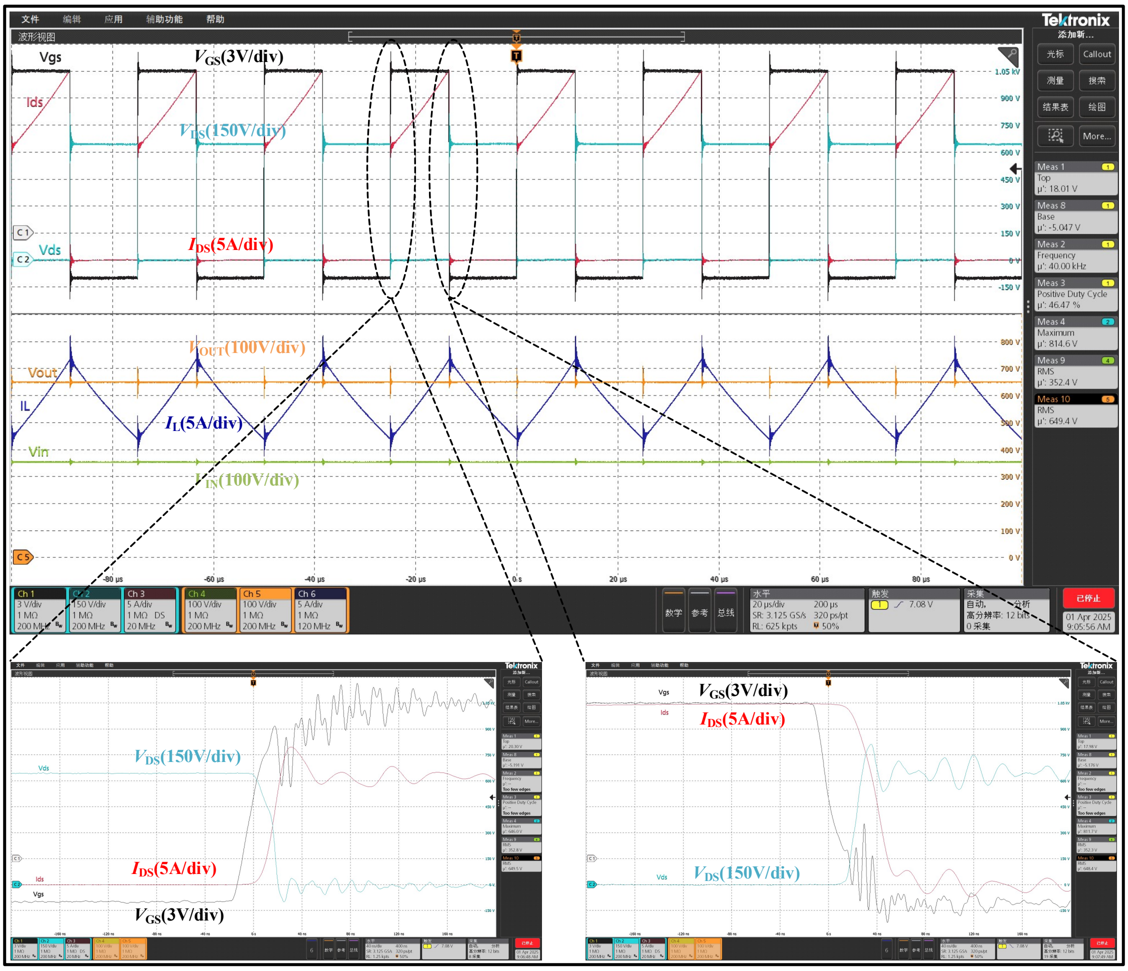

Figure 3: Switching Waveforms at 10kW Load and 40kHz Switching Frequency

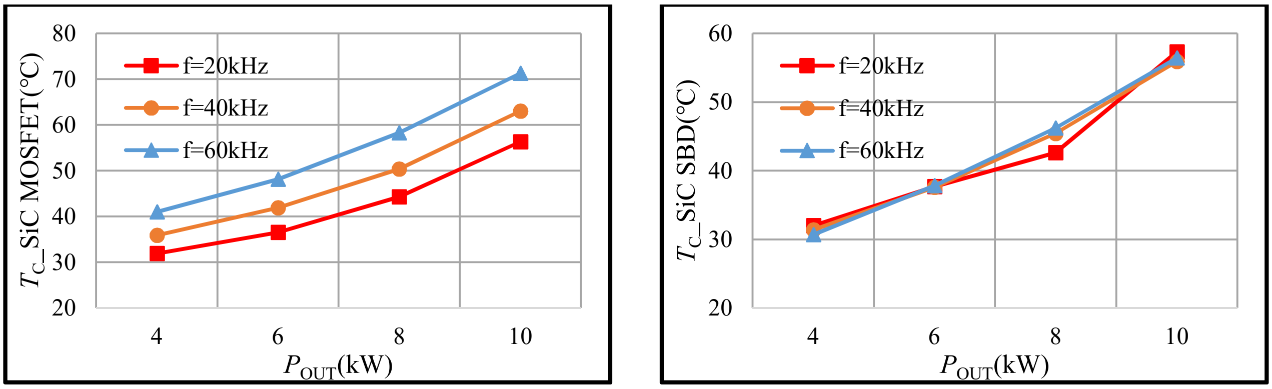

Figure 4: Temperature Rise of SiC MOSFET (left) and SiC SBD (right) at Different Operating Points

Figure 4 shows the temperature rise of AMS1200040M2 and SDS120J020H5 at different loads for switching frequencies of 20kHz, 40kHz and 60kHz. T_C in the figures is the maximum Case Temperature on the molding compound of the device. As the load increases, the Case Temperature also increases. At higher switching frequencies, the switching losses (which is a function of switching frequency) also increase leading to higher case temperatures. Figure 5 shows the IR thermal image of the devices operating at 60kHz switching frequency and a full load of 10kW. The maximum Case Temperature of the MOSFET is 71.3°C and that of the SBD is 56.5°C. The thermal performance of both the devices are relatively good.

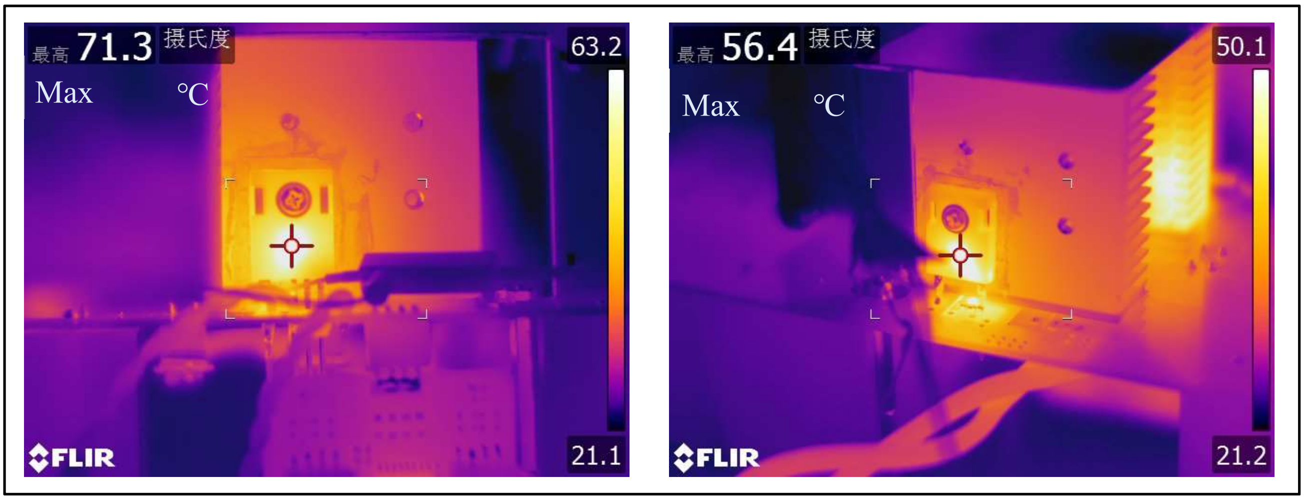

Figure 5: Thermal Images of the SiC MOSFET (left) and SiC SBD (right) Operating at 60kHz Switching Frequency at Full Load

Figure 6 below shows the efficiency curves corresponding to different output powers at different frequencies. The overall Efficiency is above 98.6%. As the switching frequency increases and the overall efficiency increases accordingly. The efficiency and output power curves show a trend of first increasing and then decreasing, and the efficiency reaches a maximum value at 6kW.

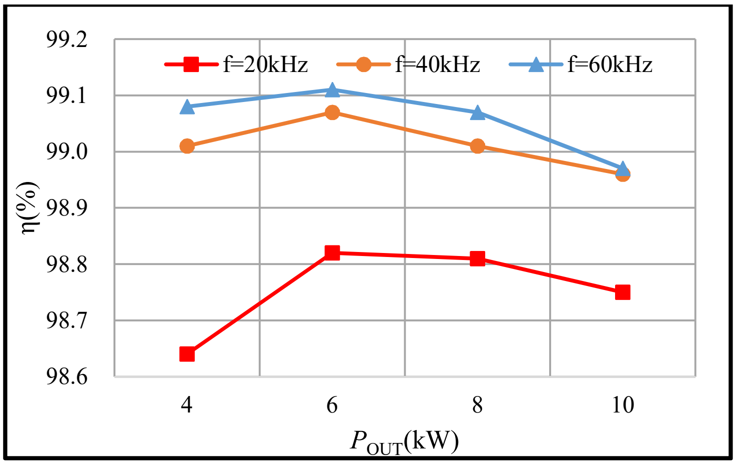

Figure 6: System Efficiency vs Load at Different Switching Frequencies

2 Competitor-A Performance (1200V/40mΩ SiC MOSFET)

This section documents the results of the devices mentioned in Table 1, under Test Group 2. The active switch is a 1200V/40mΩ SiC MOSFET from Competitor-A, and the diode is a 5th Generation 1200V/20A SiC SBD from San'an. The San'an SBD used is SDS120J020H5. The operating conditions are consistent with Test Group 1. The benchmarking is done at a switching frequency of 40kHz under all loads: 4kW, 6kW, 8kW, and 10kW. The Temperature rise of the device and the overall system efficiency are measured and used for benchmarking and comparison.

Figure 7 below shows the temperature curves and the efficiency curves of the performance of the SiC MOSFETs (Competitor A and AMS1200040M2 from San'an) operating at 40kHz switching frequency under various load conditions. It can be seen that the overall efficiency for both the devices is similar with the efficiency trend showing an increasing and then decreasing behavior, with a peak efficiency at 6kW. The difference in Efficiency between the two devices is within a 0.05% difference. Although, the overall efficiencies are basically the same, it can be observed that the AMS1200040M2 operates at a lower temperature in comparison to the SiC MOSFET from Competitor-A. Under full load conditions, AMS1200040M2 operates 8.6°C lower than the Competitor-A counterpart. The lower temperature rise can be attributed to the fact that the Thermal resistance, $R_{th(j-c)}$, of AMS1200040M2 is 0.52 °C/W whereas the device from Competitor-A has a higher thermal resistance, $R_{th(j-c)}$ at 0.65°C/W. This means that the AMS1200040M2 can operate at higher ambient temperature conditions further optimizing the system.

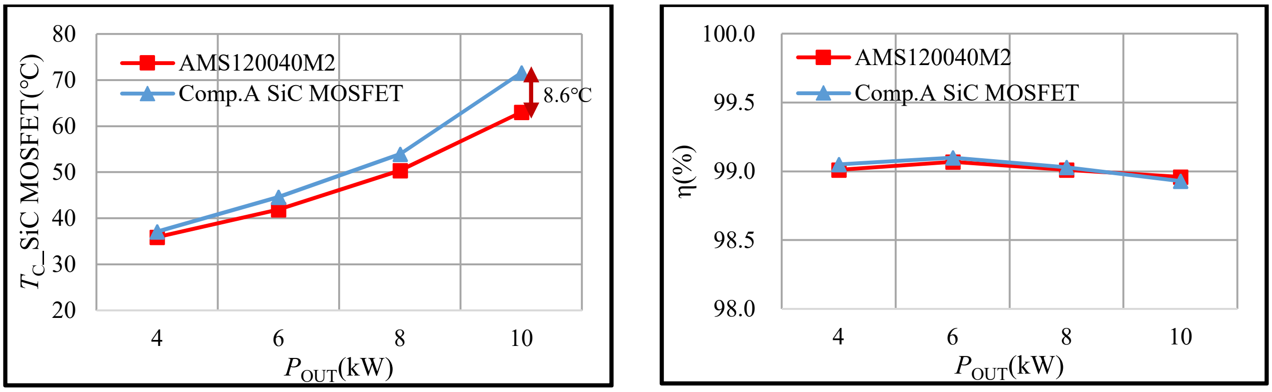

Figure 7: Operating Case Temperature (left) and System Efficiency (right) Curves Comparing the Performance of SiC MOSFETs from San'an and Competitor-A

3 Performance comparison of SiC over Si Devices in Boost Circuits

This section outlines the performance of the devices highlighted in Table 1 under the Test Groups 3 and 4. The purpose of performing the measurements on Boost Circuits with Si devices is to compare the performance of Si devices with SiC devices and to highlight the advantages of SiC over Si. The Test Group 3 uses a combination of Si and SiC devices, with the main switch being a 1200V/75A Si-IGBT from Competitor B used with a 5th Generation 1200V/20A SiC SBD from San'an (SDS120J020H5). Test Group 4 uses Si devices for both main switch and diode. The devices uses are a 1200V/75A Si-IGBT from Competitor-B for the main switch and a 1200V/30A Si-FRD from Competitor-B for the diode. The test conditions are consistent with the test conditions used for Test Group 1; however, the switching frequency for Si IGBT is limited to 20kHz. This is because of the current tailing effect of Si-IGBT where the measured on-time and off-times were 76ns and 240 ns respectively. Due to the slow switching, the switching losses of the Si-IGBT is higher than in SiC MOSFETs, leading to a higher temperature rise. Hence, the comparison of the devices used in Test Groups 3 and 4 is carried out with the devices of Test Group 1 at 20kHz switching Frequency.

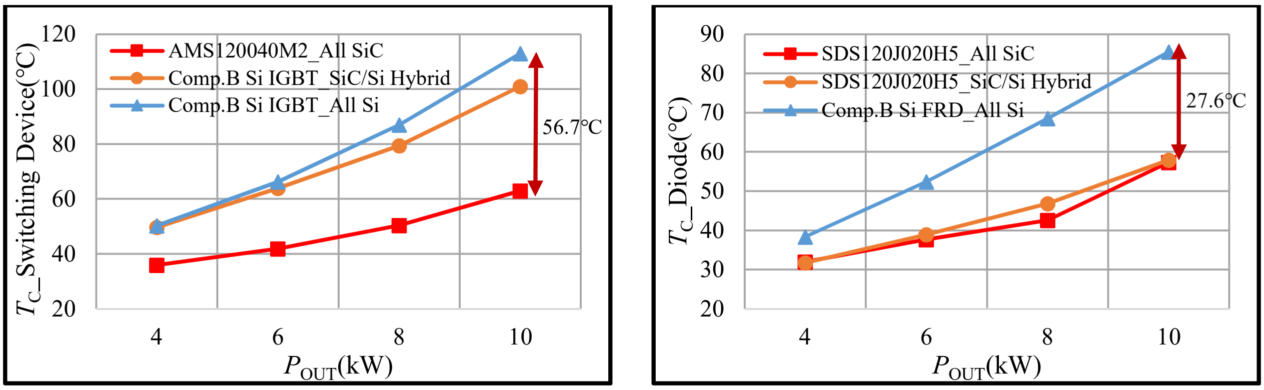

Figure 8: Temperature Curves of the Main Switch (left) and Diode (right)

Figure 8 shows the temperature curve of the main switch and the diode comparing the different devices used in Test Groups 1, 3 and 4 operating at 20kHz switching frequency under various load conditions. It can be seen that the all-SiC performs the best with the lowest temperature rise for both the main switch and the diode. At full load, all-SiC converter outperforms the other converters with hybrid Si/SiC devices and all-Si devices. For the hybrid-Si/SiC case, at full load, the case Temperature of the Si-IGBT is at 101°C since the SiC Diode, having lower losses, and hence lower temperature rise, keeps the overall temperature of the main switch lower. For the all-Si case, Si FRD has higher reverse recover losses compared to SiC SBD, and hence, operates at a higher temperature, which in turn affects the temperature of the main switch (Si-IGBT). In this case the Si-IGBT operates at 113°C which is 56.7°C higher than the SiC MOSFET. Similarly, the Si-FRD operates at 85.5°C at Full load, which is 27.6°C higher than the SiC SBD.

Figure 9 below shows the efficiency vs load curves for all the device combinations of Test Groups 1, 3 and 4, switching at 20kHz. At Full Load of 10kW, the all-SiC is 0.32% more efficient than the Hybrid-Si/SiC case, and since the diode is a SiC SBD, the temperature rise in both these cases is almost the same, indicating that the losses in the Si-IGBT is about 32W higher than the SiC MOSFET. Similarly, at full load, the efficiency of Hybrid-Si/SiC is 0.25% more all-Si condition. Since Si-IGBT is common between these conditions and is operating a 10°C higher temperature, and Si FRD operating at 27.6°C higher than SiC SBD, it can be shown that Si-FRD has about 20W more loss than SiC-SBD.

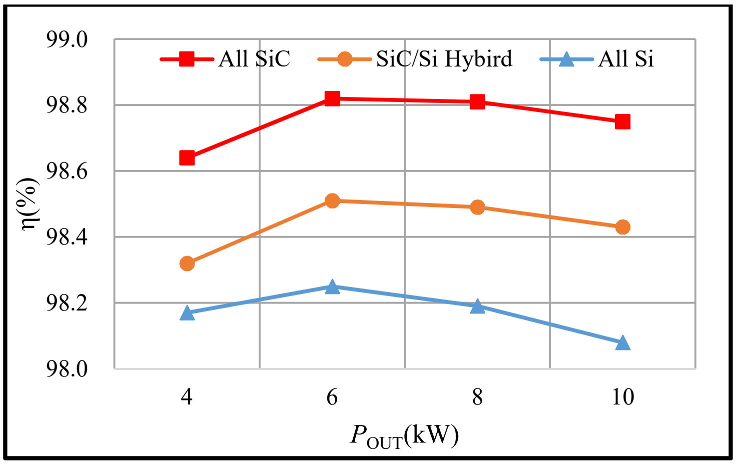

Figure 9: Efficiency vs Load curve comparing All-SiC, Hybrid-Si/SiC and All-Si configurations.

4 Conclusion

This application note has compared the performance of SiC device against the competition as well as with traditional Si-IGBT and Si-FRD and it can be seen that:

- ✓ SiC Devices operate at higher switching frequencies in comparison to Si devices.
- ✓ SiC devices demonstrate higher performance resulting in higher system efficiency and lower operating temperature in comparison to Si-devices.
- ✓ Among the competition, AMS1200040M2 from San'an performs better than the competition; for similar system efficiency, the operating temperature is lower leading to smaller heatsink and reducing overall Thermal Management size reducing the cost for larger systems.

San'an Semiconductor is continuously engaged in the Research and Development of Technological Innovation in SiC power devices, continuously iterating and optimizing device performance, and is committed to providing high-quality products than meet various demands. San'an continues to strive for excellence and releasing high-quality products meeting the standards and stringent demands of Industrial and Automotive Applications.