AN-PJ1001

PANJIT Power Diode Electrical Characteristics

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1 Revision History

Rev.	Revision Description	Edit by	Date
Rev.00	Document release	DM Kim	2020/09/14
Rev.01	FRED Line-up update	DM Kim	2021/04/23
Rev.02	FRED Line-up update	DM Kim	2021/08/16
Rev.03	FRED Line-up update	DM Kim	2023/02/18

2 Introduction of PANJIT Power Diode Product Family

Power diodes can be used as rectification and freewheeling in power electronic systems. In order to achieve high system efficiency, it is important to choose the proper power diode whose electrical characteristics are meeting the requirement of each application. PANJIT International Inc. has released two distinct power diode product families which are appropriate for various power applications. This application note is designed to help power electronic system engineers to understand the electrical characteristics of PANJIT power diodes and to improve the system efficiency with the right choice of power diode: for example, “Optima FRED” for rectifying circuit such as high power bridge diode and by-pass diode, and “Speedy FRED” for high-frequency freewheeling circuit in CCM boost PFC and Vienna PFC to achieve the maximum system efficiency.

- **Optima FRED:** Low V_F / Optimized T_{RR}
- **Speedy FRED:** Low T_{RR} / Optimized V_F / Better EMI Characteristics

PANJIT Gen. 1 FRED has 600V, 1000V, 1200V line-up as listed in Table 1 to support various application needs.

Table 1. PANJIT Gen. 1 FRED Line-up

Optima FRED (Low V_f) : Minimize Conduction Loss
Speedy FRED (Low T_{rr}) : Minimize Switching Loss

* NC 1 pin

Series	BV (V)	I_f (A)	$V_{f\ Typ.}$ (V)	$T_{rr\ Typ.}$ (ns)	 TO-252AA	 TO-263	 TO-220AC	 ITO-220AC	 TO-247-2LD	 TO-247-3LD
600V FRED Optima (Low Vf)	600	8	1.3	60	PSDD0860L1 PSDC0860L1*	PSDB0860L1	PSDP0860L1	PSDF0860L1		
		15	1.3	70		PSDB1560L1	PSDP1560L1	PSDF1560L1		
		30	1.3	75		PSDB3060L1	PSDP3060L1	PSDF3060L1	PSDH3060S1	
			1.3	70						PSDH3060CCL1
		60	1.25	135					PSDH6060L1	
			1.3	75						PSDH6060CCL1
600V FRED Speedy (Low Trr)		8	1.8	35	PSDD0860S1 PSDC0860S1*	PSDB0860S1	PSDP0860S1	PSDF0860S1		
		15	1.8	42		PSDB1560S1	PSDP1560S1	PSDF1560S1		
		30	1.8	45		PSDB3060S1	PSDP3060S1	PSDF3060S1	PSDH3060S1	
			1.8	42						PSDH3060CCS1
		60	1.65	55					PSDH6060S1	
			1.8	45						PSDH6060CCS1
1000V FRED Speedy (Low Trr)	1000	30	2.65	95					PSDH30100S1	
1200V FRED Optima (Low Vf)	1200	8	2.1	70			PSDP08120L1			
		15	2.1	105			PSDP15120L1			
		30	2.1	160			PSDP30120L1		PSDH30120L1	
		60	2.0	220					PSDH60120L1	
1200V FRED Speedy (Low Trr)		8	3.0	45			PSDP08120S1			
		15	3.0	70			PSDP15120S1			
		30	3.0	135			PSDP30120S1		PSDH30120S1	
		60	2.7	170					PSDH60120S1	

2.1 PANJIT FRED trade-off characteristic between V_F and Q_{RR}

Figure 1 shows a simple P-i-N structure of power diode. Generally, P-i-N diode has a trade-off relation between V_F and Q_{RR}, which is determined by the injection efficiency of the hole. The life time which is to remove the trapped minority carrier during conductivity modulation in epi layer is controlled by Pt diffusion life time killing method. Short life time period can improve reverse recovery while it can affect to higher forward voltage, VF. So, this trade-off characteristic should be optimized according to the target application.

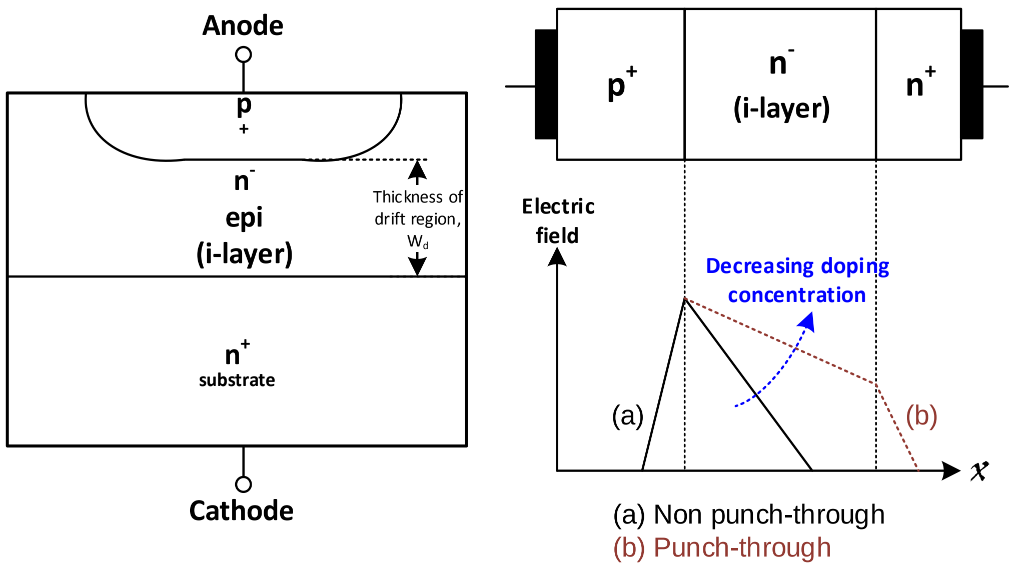
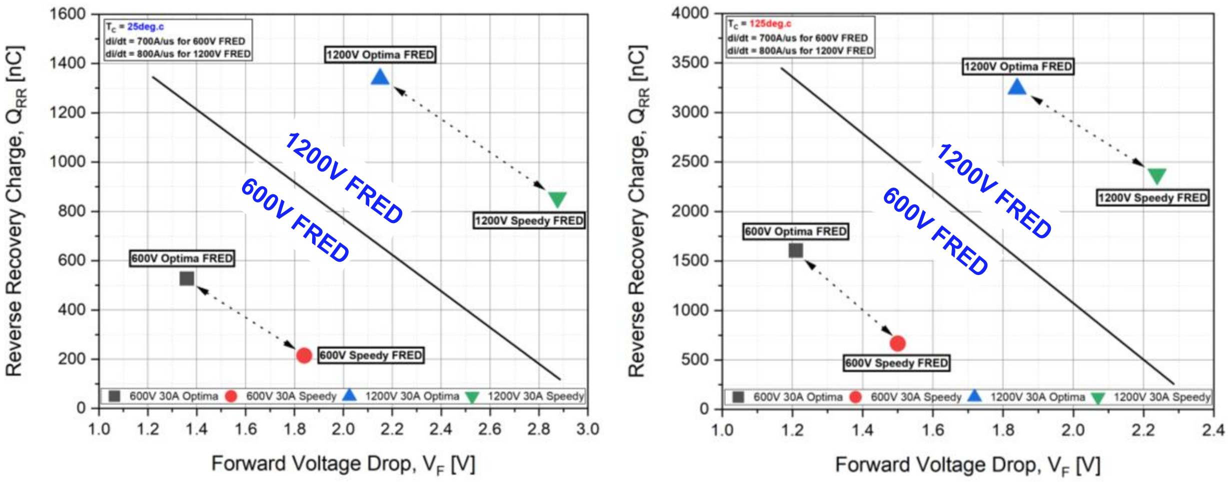


Figure 1. Simple P-i-N Structure of Power Diode

As shown in figure 2, PANJIT Optima FRED is optimized for lower conduction loss with lower V_F while Speedy FRED is optimized for lower switching loss with lower Q_{RR}. Due to these different characteristics, Optima FRED is appropriate for low switching frequency applications and Speedy FRED is suitable for the applications with high switching frequency.



(a) Room temperature (b) High temperature

Figure 2. PANJIT FRED Trade-off Characteristic Between V_F and Q_{RR}

3 PANJIT FRED Electrical Characteristics

The electrical characteristics of power diode is relevant to the power system efficiency and reliability. And especially power losses are the major factor for deciding the system efficiency. The power losses can be affected by DC and AC characteristic as depicted in figure 3.

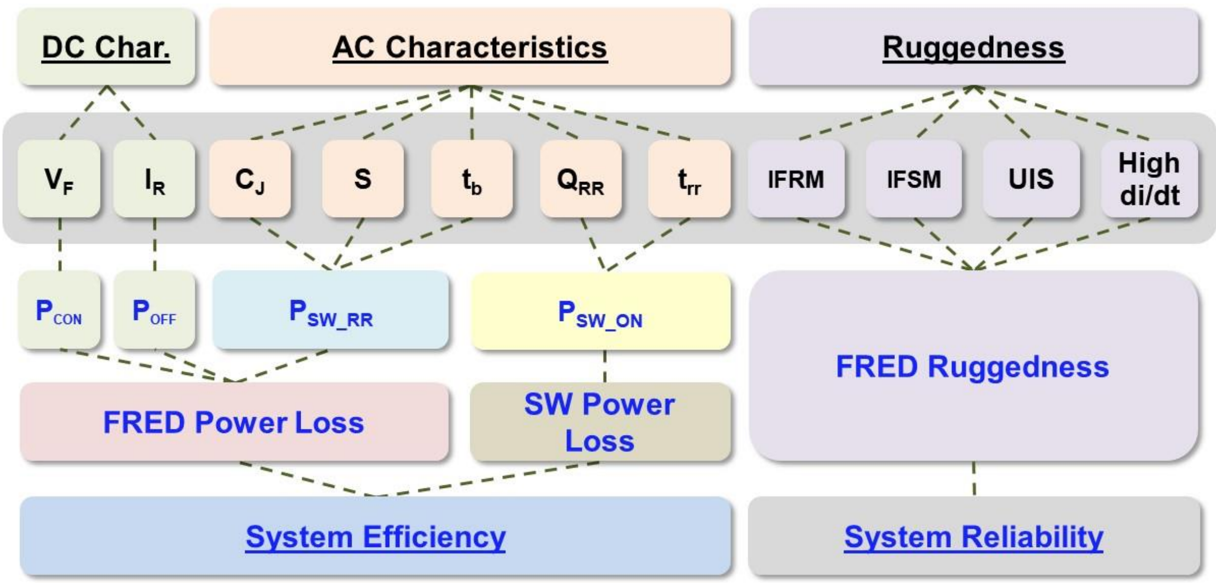


Figure 3. Electrical Characteristics Related to System Performance

Refer to below equations to understand the relation between each power loss and power diode electrical characteristics:

- P_{CON} (Conduction loss) $= I_F \times V_F$
- P_{OFF} (Reverse Conduction Loss) $= I_R \times V_R$

- P_{SW_RR} (Reverse Recovery Switching Loss) = $E_{RR} \times F_{SW}$
- P_{SW_ON} (Turn-on Switching Loss of Switch) = $E_{ON} \times F_{SW}$

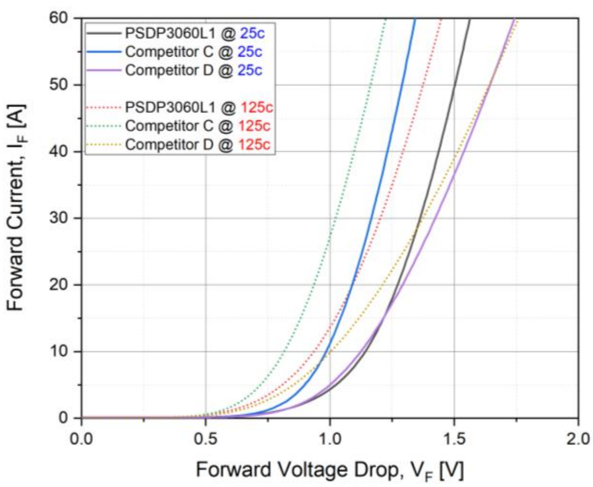
Annotations) I_F: forward current / V_F: forward voltage drop / I_R: reverse leakage current / V_R: reverse bias voltage / E_{RR}: energy loss of reverse recovery / E_{ON}: turn-on loss of main switch

P_{CON}, P_{OFF} and P_{SW_RR} are the power losses dedicated to power diode while P_{SW_ON} is the power loss of the main switch affected by power diode. All these power losses should be minimized to get a better system efficiency.

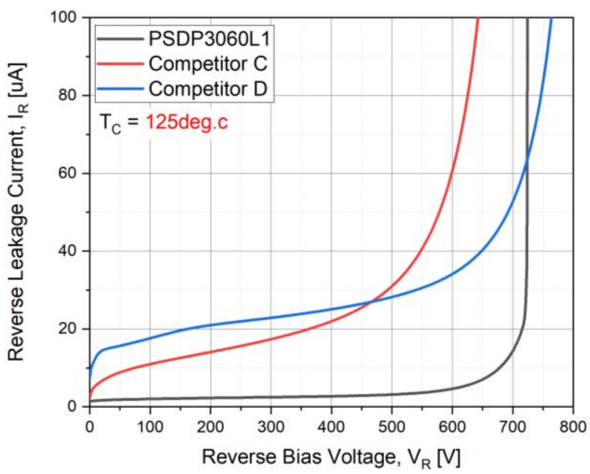
3.1 PANJIT FRED DC and AC Characteristic

- DC characteristics of 600V and 1200V Optima FRED

V_F and I_R are the key parameters to show DC characteristic of power diode. The characteristics of PANJIT 600V and 1200V Optima FRED are summarized in figure 4 and 5 respectively. PANJIT Gen. 1 Optima FREDs have stable leakage current performance with a moderate forward voltage drop.

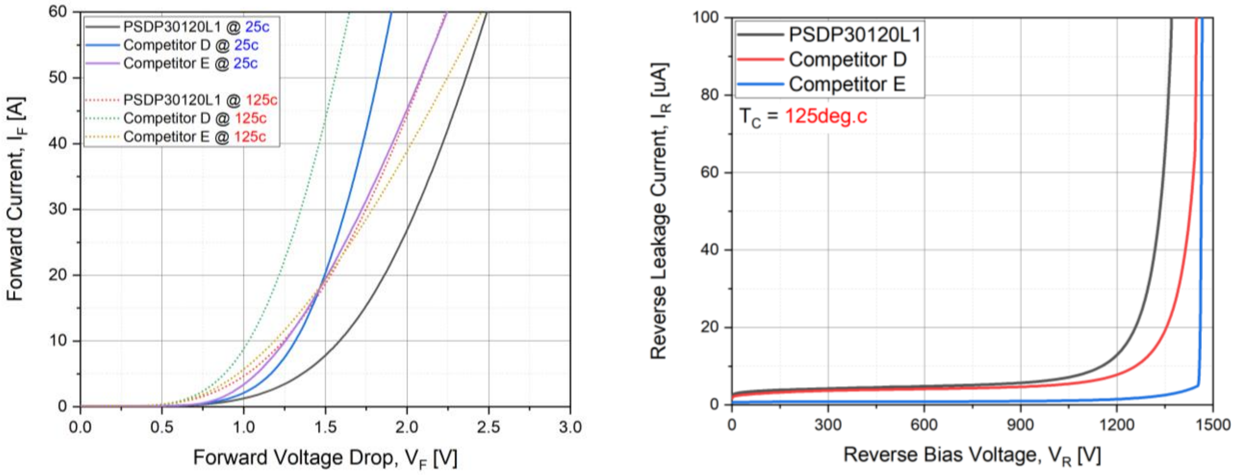


(a) Optima 600V/30A I_F-V_F Char.



(b) Optima 600V/30A I_R-V_R Char. @ 125°C

Figure 4. 600V Optima FRED Forward Voltage Drop and Reverse Leakage Current



(a) Optima 1200V/30A I_F-V_F Char. (b) Optima 1200V/30A I_R-V_R Char. @ 125°C

Figure 5. 1200V Optima FRED Forward Voltage Drop and Reverse Leakage Current

- AC characteristics of 600V and 1200V Speedy FRED

There are several AC parameters such as C_J, T_{RR}, I_{RR} and Q_{RR} for the system engineers to consider to get an appropriate system performance with power diode. The softness factor ($S=t_b/t_a$) depicted in figure 6, is the key parameter to get better EMI performance, t_a is the time from zero current to I_{RR} and t_b is the time from I_{RR} to the next zero current. The severe current and voltage oscillation can be caused by a poor softness factor and these may cause improper EMI to a system.

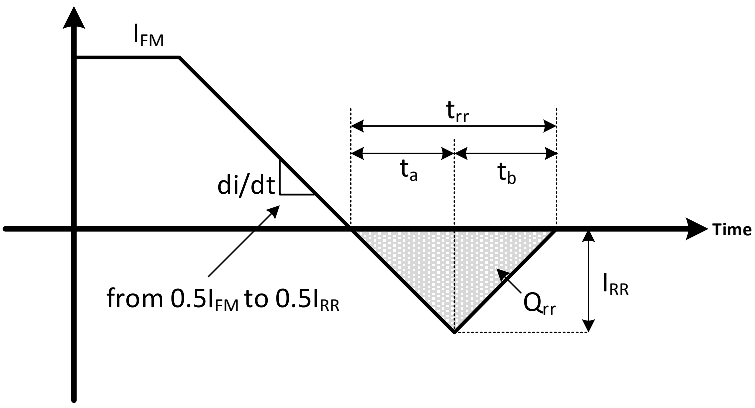
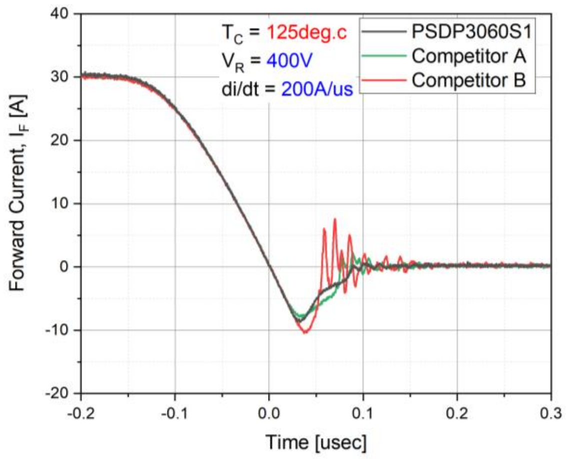


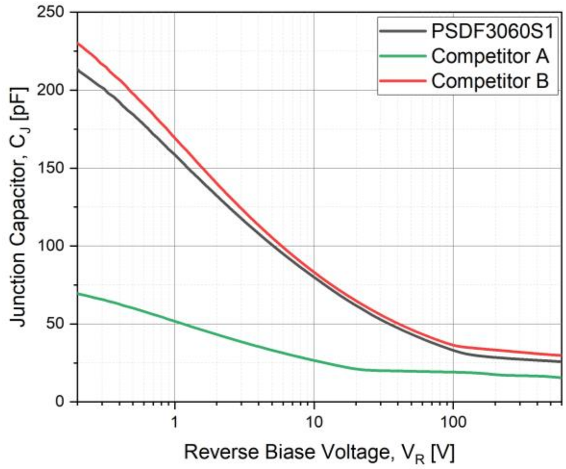
Figure 6. The Parameter Definition of the Reverse Recovery Waveform

3.2 PANJIT 600V Speedy FRED

The switching loss E_{ON}, and reverse recovery waveform of power diode are measured in inductive load switching circuit. The comparison table of 600V Speedy FRED is summarized in Table 2. PANJIT 600V Speedy FRED shows less oscillation than competitors as shown in Figure 7. As a result, system engineers can use higher di/dt with PANJIT 600V Speedy FRED to minimize switching loss or keep the same di/dt with competitors to get a better EMI result.



(a) 600V/30A reverse recovery current @ 125°C



(b) 600V/30A C-V char. @ 1Mhz

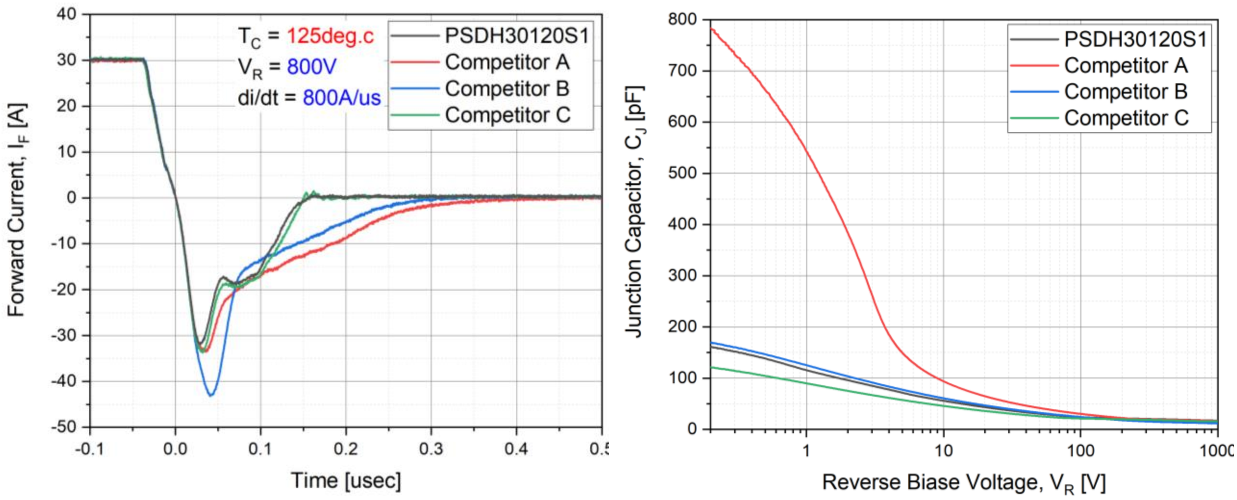
Figure 7. 600V Speedy FRED Reverse Recovery Waveform and Junction Capacitor

Table 2. 600V Speed FRED Electrical Characteristics @ I_F=30A, di/dt=700A/us, E_{ON} for IGBT, T_C=125°C

Device	V_F [V]	I_{RR} [A]	Q_{RR} [nC]	E_{RR} [uJ]	E_{ON} [uJ]
PSDP3060S1	**1.55**	**8.7**	**460**	**179**	**1331**
Competitor A	**1.83**	**8.0**	**378**	**292**	**1241**
Competitor B	**1.60**	**10.5**	**355**	**194**	**1268**

3.3 PANJIT 1200V Speedy FRED

Figure 8 shows reverse recovery waveform and junction capacitance graph of 1200V Speedy FRED. In this waveform, PANJIT 1200V Speedy FRED shows an outstanding Trr and Junction Capacitance characteristics compared to other competitors. Accordingly, PANJIT FRED will make the lowest switching loss so that lower E_{ON} can be achieved. Furthermore, with the advantage of the moderate junction capacitance value, PANJIT 1200V Speedy FRED would show the lowest E_{RR} among other competitors.



(c) 1200V/30A reverse recovery current @ 125°C

(b) 1200V/30A C-V char. @ 1Mhz

Figure 8. 1200V Speedy FRED Reverse Recovery Waveform and Junction Capacitor

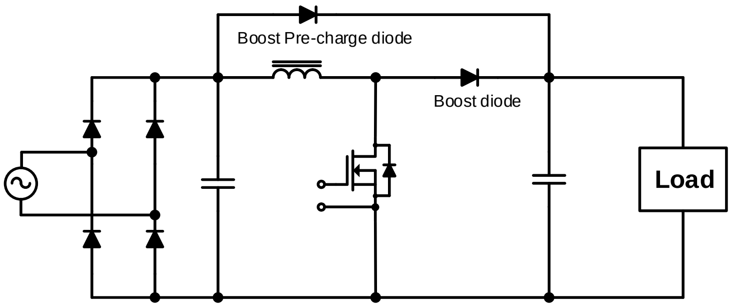
Table 3. 1200V Speedy FRED Electrical Characteristics @ I_F=30A, di/dt=800A/us, E_{ON} for IGBT, T_C=125°C

Device	V_F [V]	I_{RR} [A]	Q_{RR} [nC]	E_{RR} [uJ]	E_{ON} [uJ]
PSDP30120S1	**2.2**	**31.7**	**2268**	**395**	**1984**
Competitor A	**2.0**	**33.5**	**3939**	**832**	**2065**
Competitor B	**2.1**	**43.2**	**3590**	**575**	**2297**
Competitor C	**2.1**	**33.7**	**2487**	**441**	**2024**

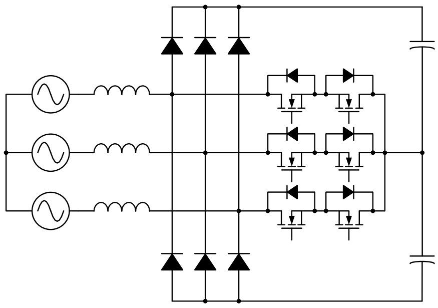
According to the test result shown in Table 3, PANJIT FRED is able to perform superior if engineers apply proper FREDs depending on the application needs. These electrical characteristics also can be used in power loss simulation to estimate system level efficiency as well as to have comprehensive understanding of PANJIT FREDs' performance.

4 Power Loss Calculation of Speedy FRED

The circuit diagrams used for power loss calculation in this document are depicted in Figure 9 - CCM Boost PFC and Single phase Vienna PFC. The electrical characteristics of PANJIT Speedy FREDs were applied to these topologies thus calculations were also done with Speedy FRED.



(a) Circuit diagram for CCM Boost PFC



(b) Circuit diagram for Vienna PFC

Figure 9. Circuit Diagram for the Power Loss Simulation

4.1 PANJIT 600V Speedy FRED in CCM Boost PFC Circuit

PFC circuit is used for home appliance, welding machine for European market, and on-line UPS. CCM Boost PFC depicted in Figure 9 (a) is one of the PFC circuit widely used in these applications thanks to the simple structure and control scheme.

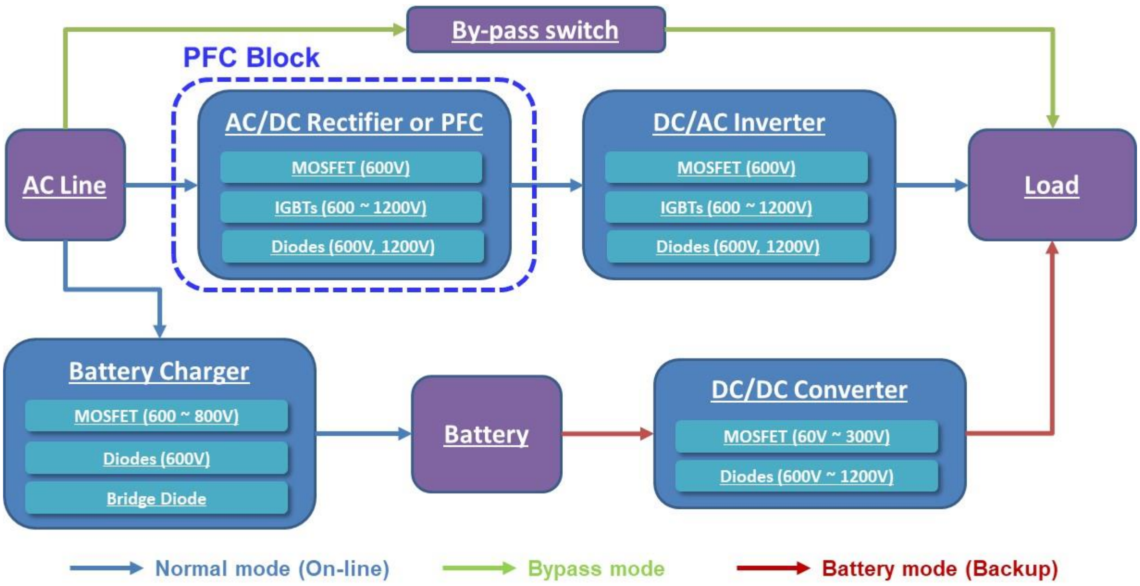
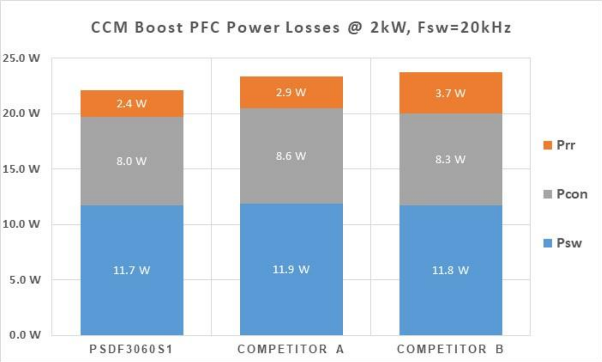


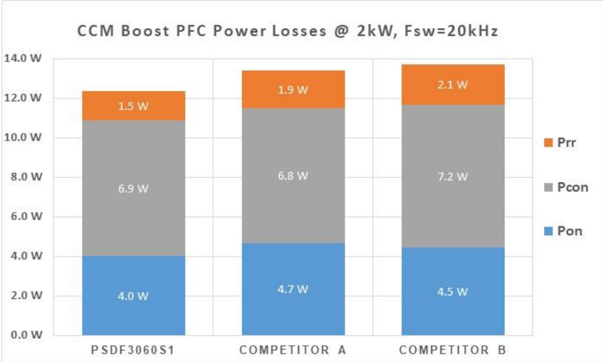
Figure 10. Block Diagram for On-line UPS Application

Figure 10 shows UPS system block diagram. PFC block is applied at the first stage for power factor correction or DC-link voltage control when on-line UPS is operating. As depicted in Figure 9 (a), 600V FRED can be used as freewheeling diode in CCM Boost PFC. Figure 11 shows power loss simulation result of PNAJIT 600V Gen. 1 Speedy FRED and competitors' devices. As a result, PANJIT FRED surpasses competitor's devices at various conditions due to its' better trade-off performance between V_F and Q_{RR}.



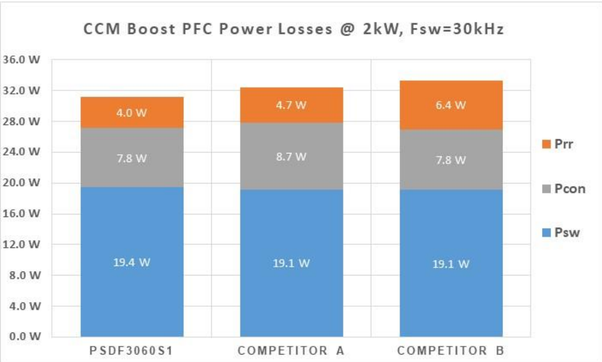
(a) Power loss @ 2kW, 110Vac, 400VDC,

F_{SW}=20kHz



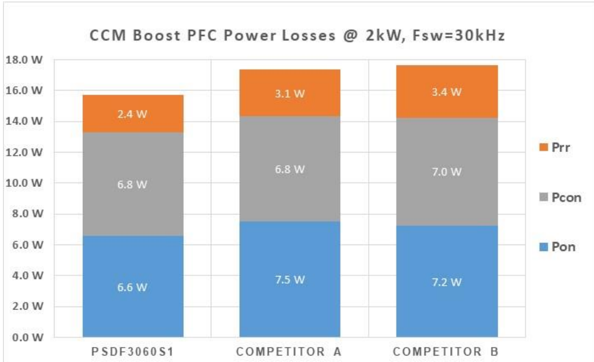
(b) Power loss @ 2kW, 220Vac, 400VDC,

F_{SW}=20kHz



(c) Power loss @ 2kW, 110Vac, 400VDC,

F_{SW}=30kHz

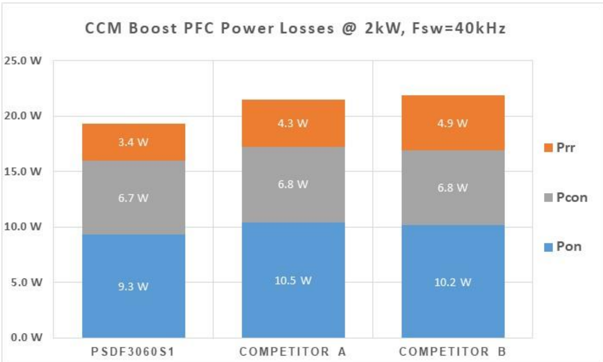


(d) Power loss @ 2kW, 220Vac, 400VDC,

F_{SW}=30kHz

(e) Power loss @ 2kW, 110Vac, 400VDC,

F_{SW}=40kHz



(f) Power loss @ 2kW, 220Vac, 400VDC,

F_{SW}=40kHz

Figure 11. Power Loss Calculation for CCM Boost PFC in Various Conditions

4.2 PANJIT 1200V Speedy FRED in Vienna PFC Circuit

Figure 12 is the system block diagram of EV charging system with 3 Phase Vienna PFC. 3 Phase Vienna PFC is widely adopted in PFC block as it provides improved efficiency of system. In this circuit, only 50% of DC link voltage is applied to the MOSFET device of PFC block, thus the voltage stress on the MOSET devices can be reduced.

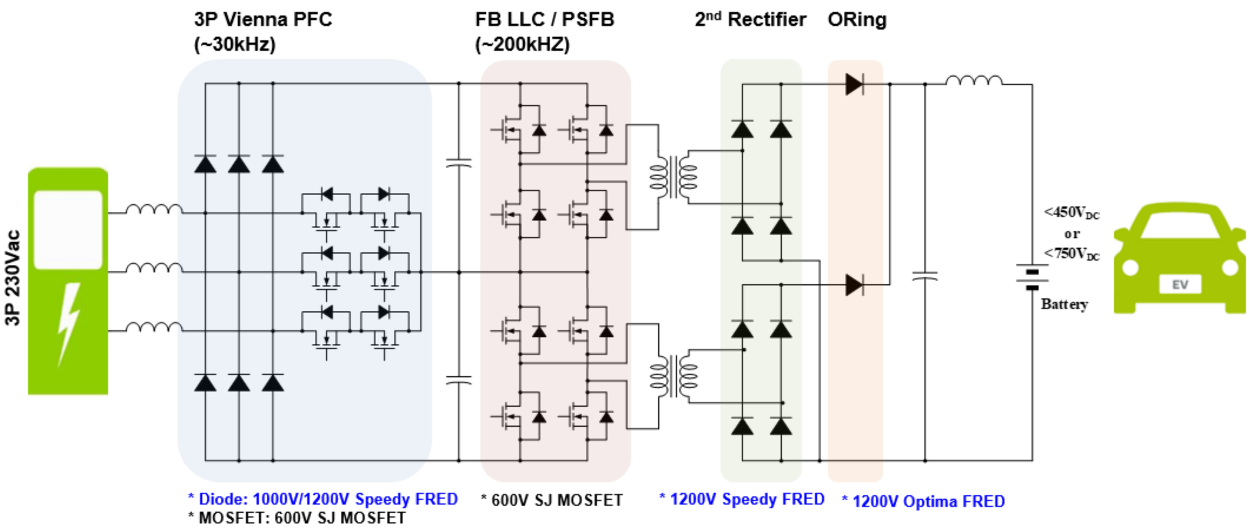
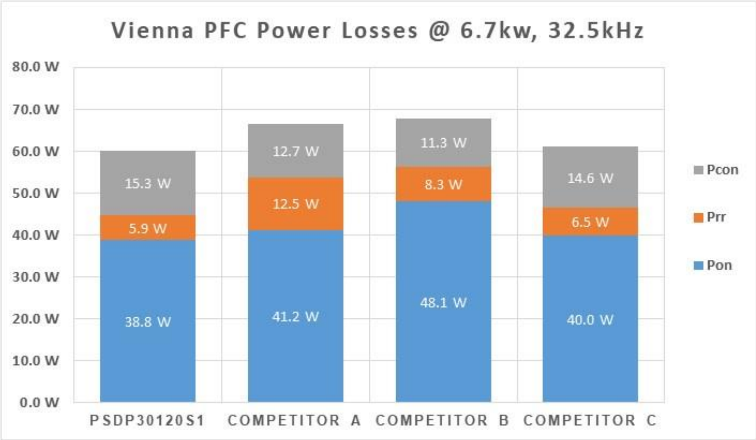


Figure 12. System Block Diagram of EV Charging Pole

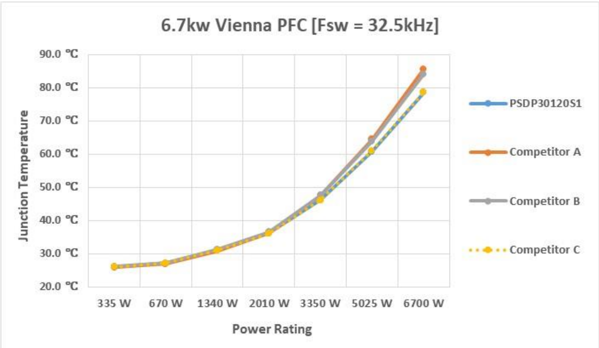
Below system condition is used to calculate the power loss of Vienna PFC.

- Input AC Voltage: 230V_{ac} / 50Hz
- Switching Frequency for MOSFET and Diode: 32.5 kHz
- Output DC Link Voltage: 600Vdc
- Maximum Power: 6670W per phase
- Inductor: 470uH
- Ambient Temperature: 25°C
- R_{thsa}, Heatsink to Ambient: 0.1°C per Watt
- R_{thcs}, Case to Heatsink: 0.5°C per Watt

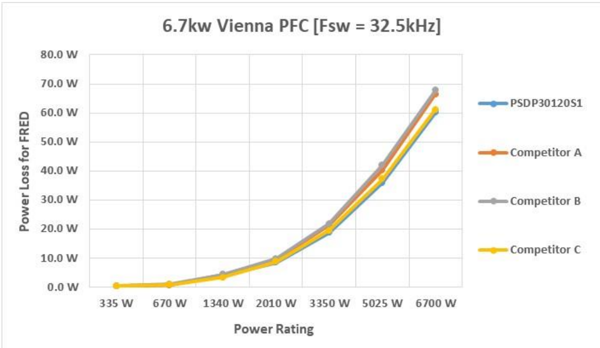
Referring to the power loss result calculated with above system condition shown in Figure 13, PANJIT 1200V Gen. 1 Speedy FRED is the best solution to achieve the lowest power loss among competitors.



(a) Power loss calculation result at 6700W Vienna PFC



(b) Junction temperature comparison



(c) Power loss comparison at various power ratings

Figure 13. The Power Loss Calculation for 6.7kW Vienna PFC

5 Summary

PANJIT has released 600V & 1200V Gen. 1 Optima and Speedy FRED, which can be used for low frequency (Optima) and high frequency (Speedy) applications respectively. In order to achieve higher system efficiency, power system design engineers should clearly understand the different electrical performance of each FRED product series. Also, as shown in reverse recovery characteristic of PANJIT Speedy FRED, the current oscillation is superior to other competitors and the power system design engineer can choose better efficiency with same EMI or same efficiency with better EMI as using PANJIT FRED in their system. In conclusion, PANJIT 600V & 1200V Gen. 1 FREDs are lined up in various current ratings to provide the most sufficient solution to various applications.

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