



# **AN-PJ1001**

## **PANJIT Power Diode Electrical Characteristics**

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## 1 Revision History

<b>Rev.</b>	<b>Revision Description</b>	<b>Edit by</b>	<b>Date</b>
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

## 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**

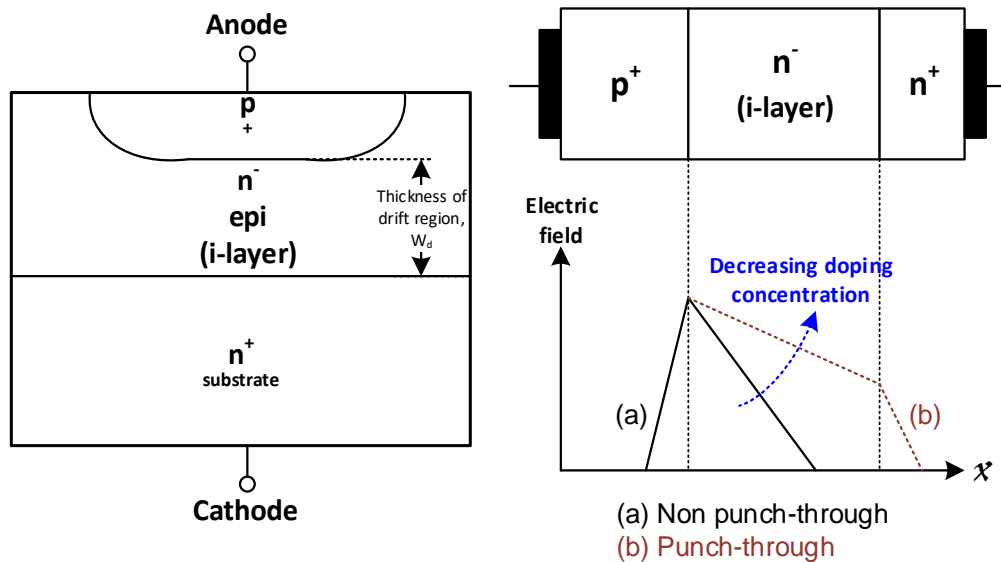
Optima FRED (Low  $V_f$ ) : Minimize Conduction Loss  
Speedy FRED (Low  $T_{rr}$ ) : Minimize Switching Loss

Series	BV (V)	$I_f$ (A)	$V_f$ Typ. (V)	$T_{rr}$ Typ. (ns)	 TO-220AC	 ITO-220AC	 TO-263	 TO-247-2LD	 TO-247-3LD	
600V FRED Optima (Low $V_f$ )	600	8	1.3	60	PSDP0860L1	PSDF0860L1	PSDB0860L1			
		15	1.3	70	PSDP1560L1	PSDF1560L1	PSDB1560L1			
		30	1.3	75	PSDP3060L1	PSDF3060L1	PSDB3060L1	PSDH3060L1		
			1.3	70					PSDH3060CCL1	
		60	1.25	135					PSDH6060L1	
			1.3	75						PSDH6060CCL1
600V FRED Speedy (Low $T_{rr}$ )	600	8	1.8	35	PSDP0860S1	PSDF0860S1	PSDB0860S1			
		15	1.8	42	PSDP1560S1	PSDF1560S1	PSDB1560S1			
		30	1.8	45	PSDP3060S1	PSDF3060S1	PSDB3060S1	PSDH3060S1		
			1.8	42					PSDH3060CCS1	
		60	1.65	55					PSDH6060S1	
			1.8	45						PSDH6060CCS1
1000V FRED Speedy (Low $T_{rr}$ )	1000	30	2.65	95				PSDH30100S1		
1200V FRED Optima (Low $V_f$ )	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 $T_{rr}$ )	1200	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 $Q_{RR}$

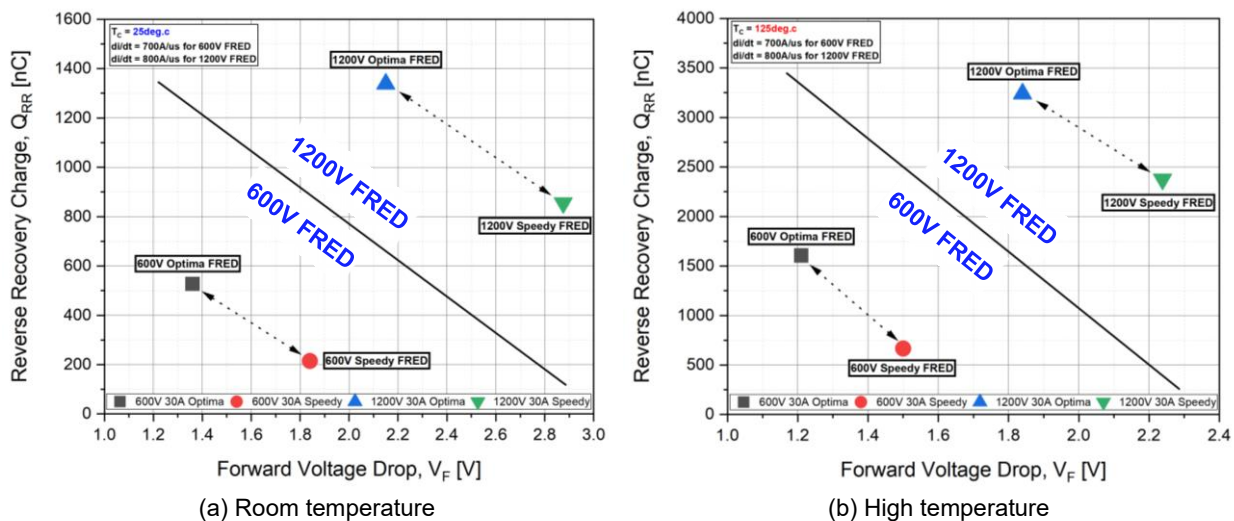
Figure 1 shows a simple P-i-N structure of power diode. Generally, P-i-N diode has a trade-

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,  $V_F$ . So, this trade-off characteristic should be optimized according to the target application.



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

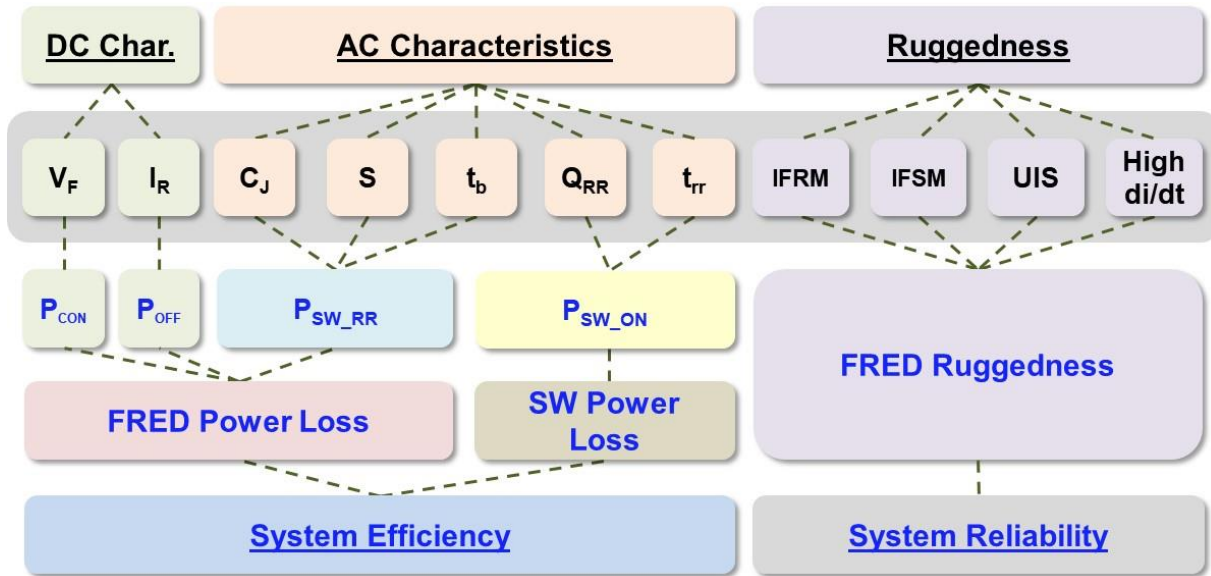
As shown in figure 2, PANJIT Optima FRED is optimized for lower conduction loss with lower  $V_F$  while Speedy FRED is optimized for lower switching loss with lower  $Q_{RR}$ . Due to these different characteristics, Optima FRED is appropriate for low switching frequency applications and Speedy FRED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



**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

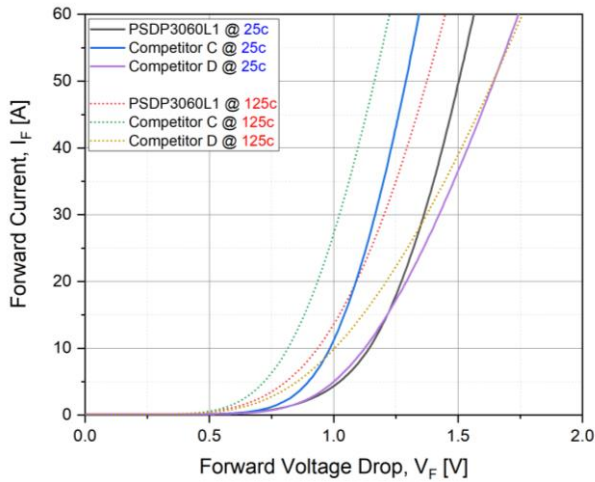
$P_{CON}$ ,  $P_{OFF}$  and  $P_{SW\_RR}$  are the power losses dedicated to power diode while  $P_{SW\_ON}$  is the power loss of the main switch affected by power diode. All these power losses should be minimized to get a better system efficiency.

#### 3.1 PANJIT FRED DC and AC Characteristic

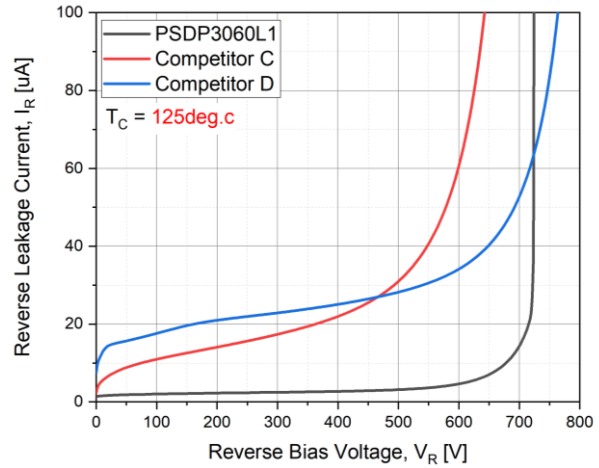
- DC characteristics of 600V and 1200V Optima FRED

$V_F$  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.

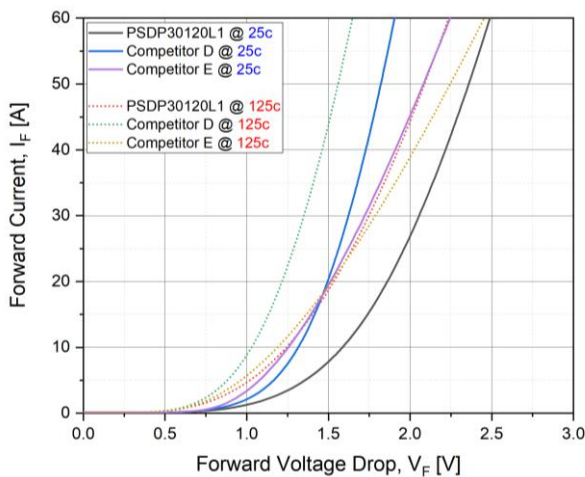


(a) Optima 600V/30A  $I_F$ - $V_F$  Char.

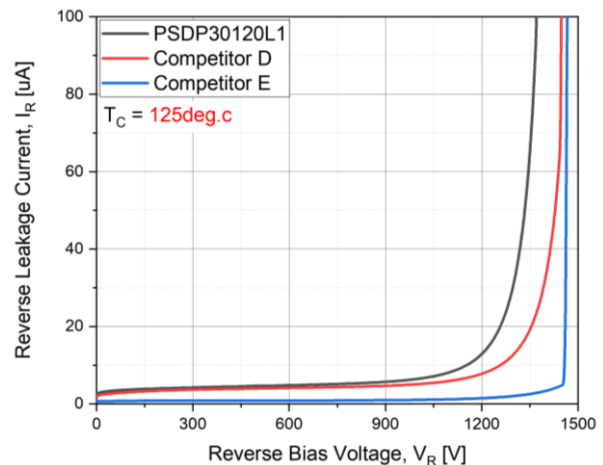


(b) Optima 600V/30A  $I_R$ - $V_R$  Char. @ 125°C

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



(a) Optima 1200V/30A  $I_F$ - $V_F$  Char.

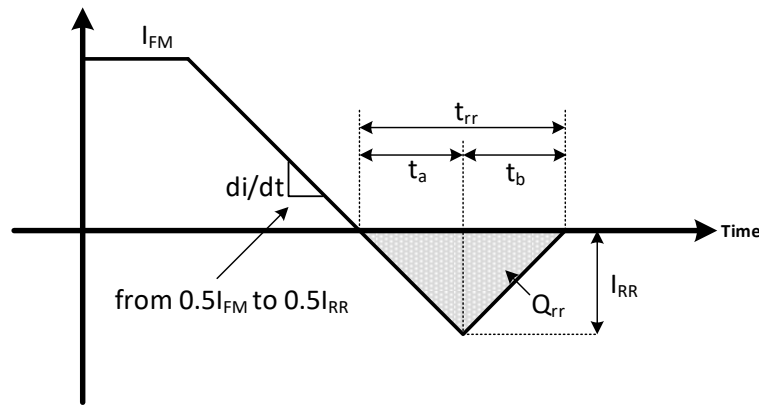


(b) Optima 1200V/30A  $I_R$ - $V_R$  Char. @ 125°C

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

- AC characteristics of 600V and 1200V Speedy FRED

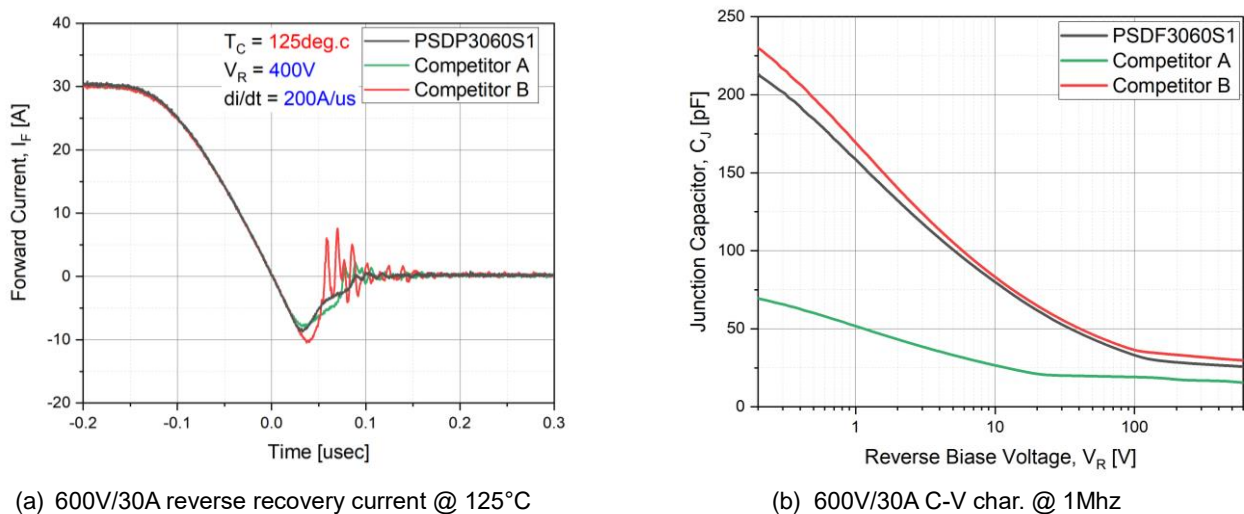
There are several AC parameters such as  $C_J$ ,  $T_{RR}$ ,  $I_{RR}$  and  $Q_{RR}$  for the system engineers to consider to get an appropriate system performance with power diode. The softness factor ( $S=t_b/t_a$ ) depicted in figure 6, is the key parameter to get better EMI performance,  $t_a$  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

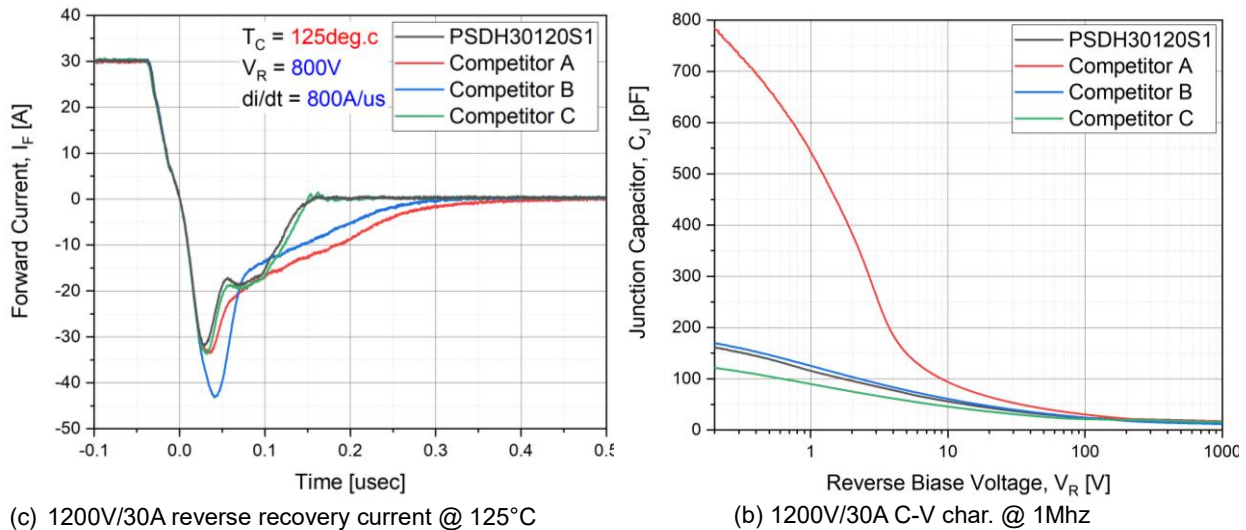
**Figure 7. 600V Speedy FRED Reverse Recovery Waveform and Junction Capacitor**

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

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  $T_{rr}$  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.



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

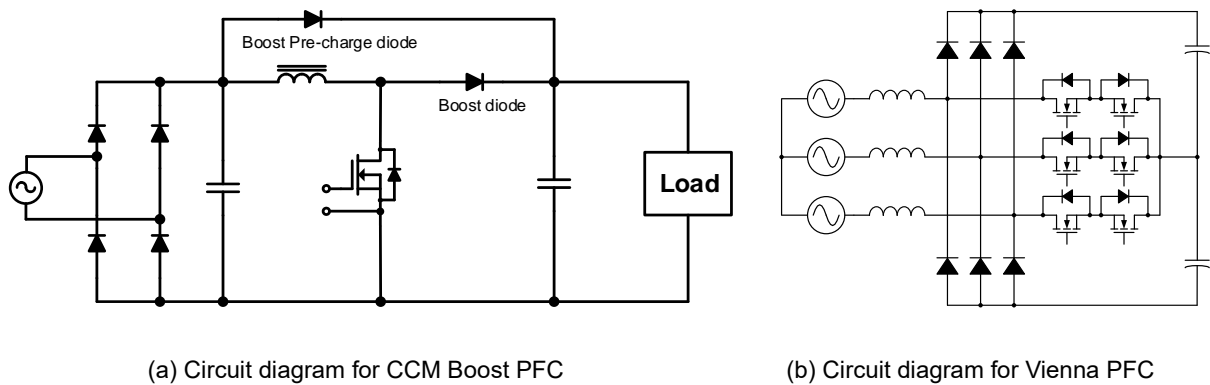
**Table 3. 1200V Speedy FRED Electrical Characteristics @  $I_F=30A$ ,  $di/dt=800A/us$ ,  $E_{ON}$  for IGBT,  $T_C=125^\circ C$**

Device	$V_F$ [V]	$I_{RR}$ [A]	$Q_{RR}$ [nC]	$E_{RR}$ [ $\mu$ J]	$E_{ON}$ [ $\mu$ J]
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

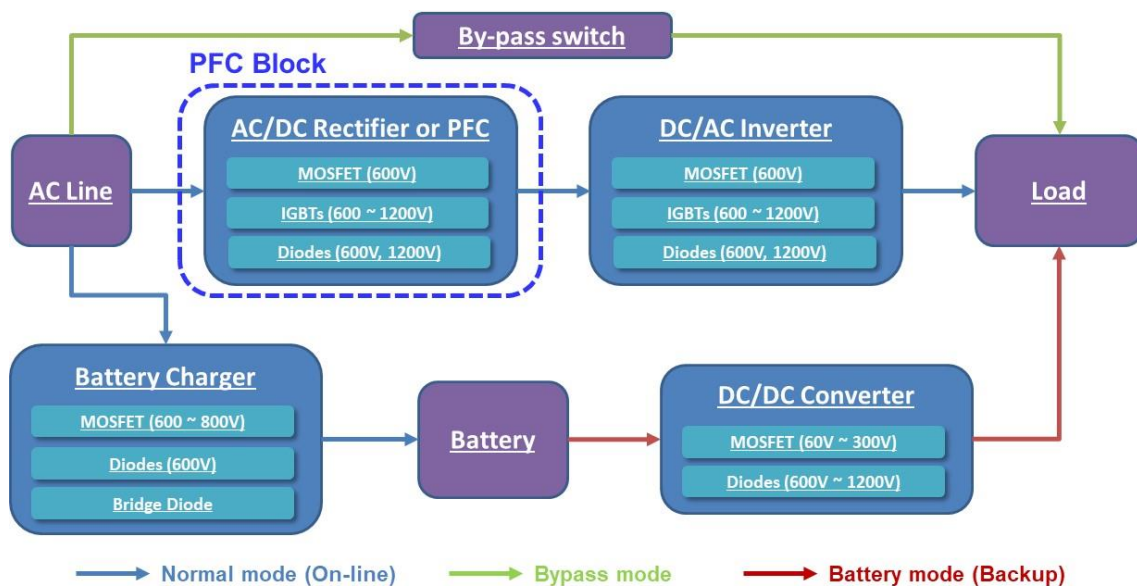
The circuit diagrams used for power loss calculation in this document are depicted in Figure 9 - CCM Boost PFC and Single phase Vienna PFC. The electrical characteristics of PANJIT Speedy FREDs were applied to these topologies thus calculations were also done with Speedy FRED.



**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.



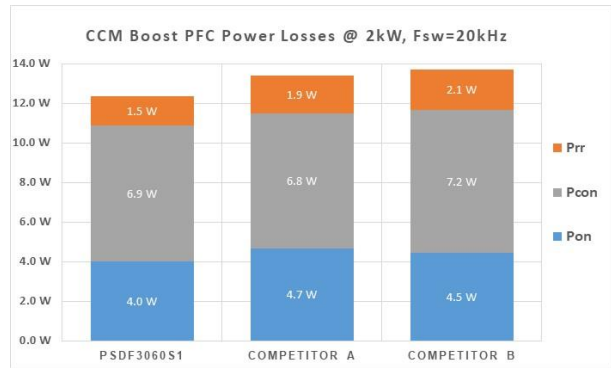
**Figure 10. Block Diagram for On-line UPS Application**

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 PANJIT 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<sub>sw</sub>=20kHz**



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

**F<sub>sw</sub>=20kHz**



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

**F<sub>sw</sub>=30kHz**



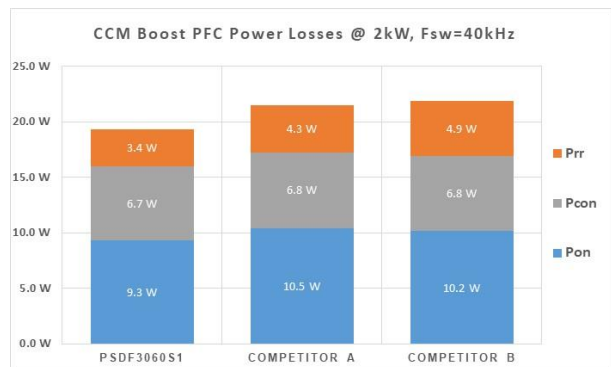
(d) Power loss @ 2kW, 220Vac, 400VDC,

**F<sub>sw</sub>=30kHz**



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

**F<sub>sw</sub>=40kHz**



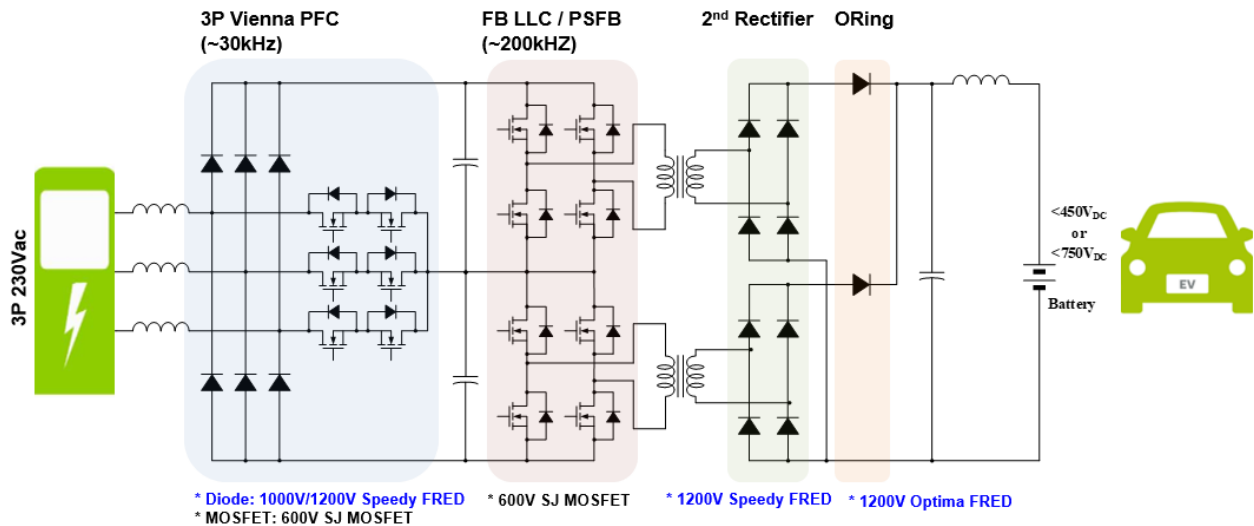
(f) Power loss @ 2kW, 220Vac, 400VDC,

**F<sub>sw</sub>=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 MOSFET devices can be reduced.

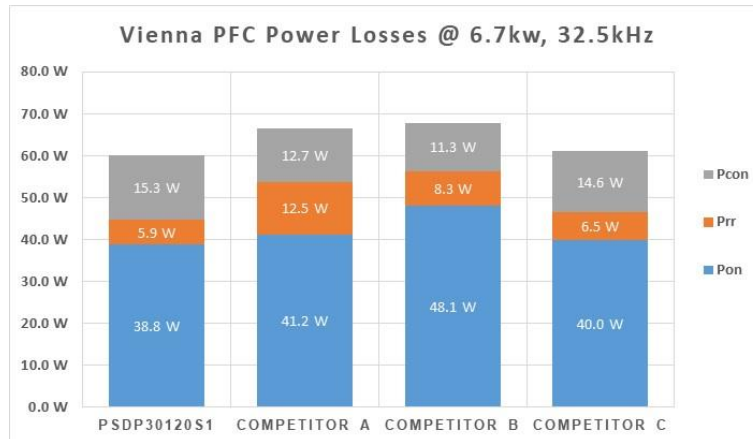


**Figure 12. System Block Diagram of EV Charging Pole**

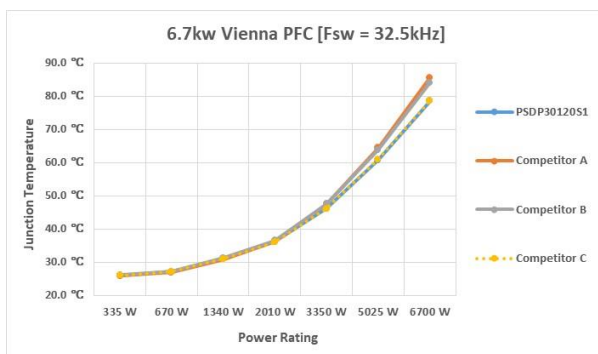
Below system condition is used to calculate the power loss of Vienna PFC.

- Input AC Voltage: 230V<sub>ac</sub> / 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<sub>thsa</sub>, Heatsink to Ambient: 0.1°C per Watt
- R<sub>thcs</sub>, Case to Heatsink: 0.5°C per Watt

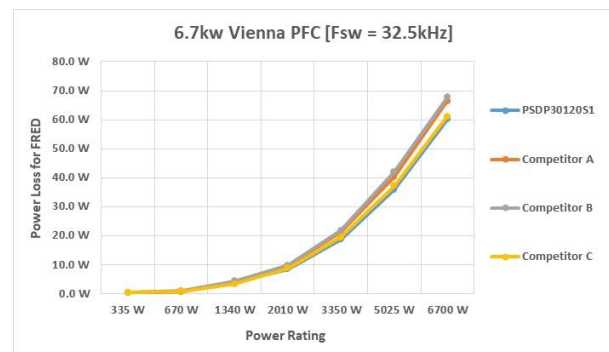
Referring to the power loss result calculated with above system condition shown in Figure 13, PANJIT 1200V Gen. 1 Speedy FRED is the best solution to achieve the lowest power loss among competitors.



(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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