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Gan and SiC Based 500kHz Resonant Bidirectional DC/DC Design for 800V OBCM Application

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Navitas

Introduction

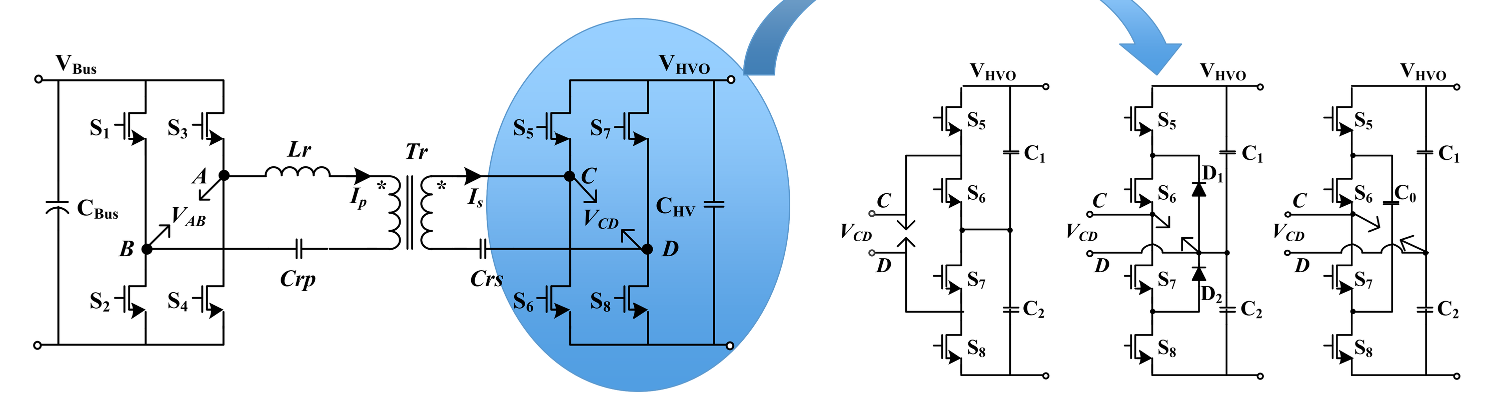


Fig.1. (a) is the topology for 400V system and (b) is the topology for 800V system

- GaN devices are mainly 650V voltage resistant, which is suitable for electric vehicle (EV) on-board charger (OBC) systems with 400V battery voltage and high switching and high-power density design.
- In the application of 800V battery voltage, it is necessary to use series half-bridge (SHF), three-level neutral point clamped (NCP) or three-level flying-capacitor (FC) topology, but the corresponding control, component number and drive design are relatively complex.
- SiC devices can withstand voltage up to 1200V and are suitable for 800V battery voltage applications, and evaluating SiC applications at 500khz will simplify the problems caused by three-level topology and increase product reliability.

Topology and control

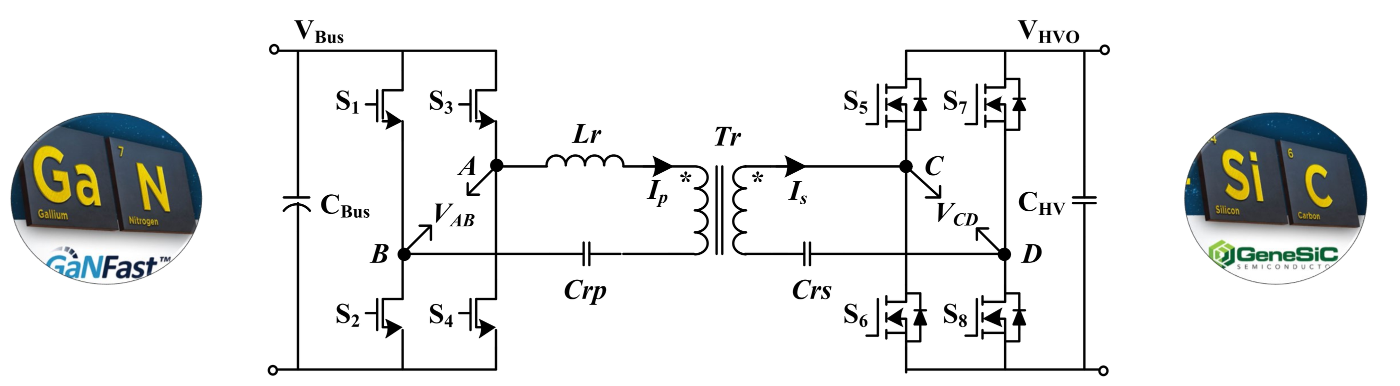


Fig.2. Topology of resonant DAB

- Bus voltage side is 400V, using 650V GaN device, high voltage output side is 800V, using 1200V SiC device.
- In order to reduce the switching loss and improve the efficiency of the bidirectional converter, resonant DAB topology is selected for design.

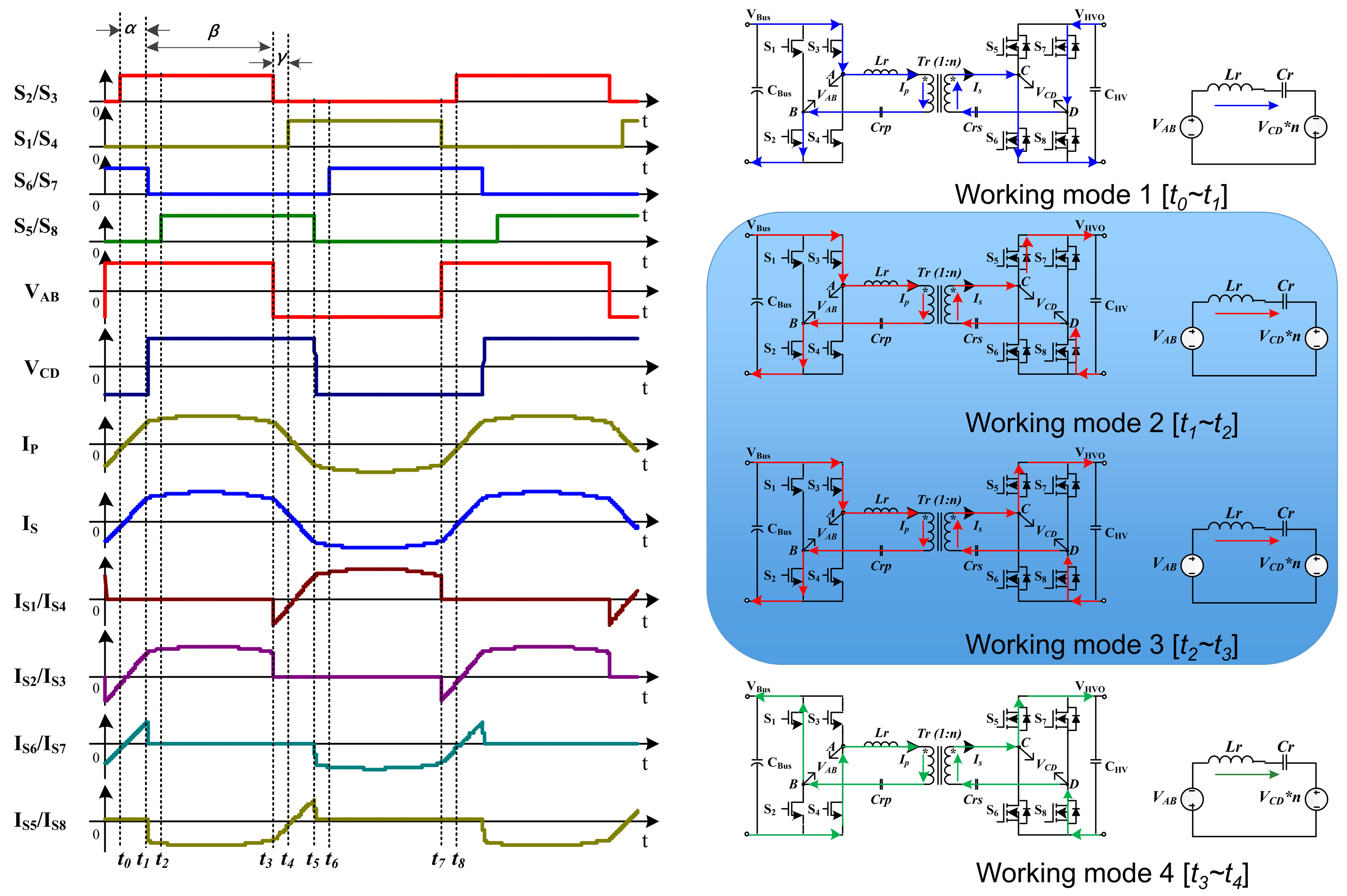


Fig.3. Key waveforms of a switching cycle and working mode analysis

- Mode 2 and mode 3 have the same equivalent circuit, so that there are three working modes corresponding within half a switching cycle.

- All parameters are normalized based on V_{Bus}.
- Input voltage: $M_g = V_{Bus}/V_{Bus} = 1$
- Output voltage: $M = n * V_{HVO}/V_{Bus}$
- Voltage of Cr: $m_c = V_{CR}/V_{Bus}$
- Peak voltage of Cr: $M_{RP} = V_{CR_{PEK}}/V_{Bus}$
- Resonant current: $j_L = i_{Lr} R_0/V_{Bus}$, $R_0 = \sqrt{Lr/Cr}$
- According to geometric relations in Fig. 4.:

$$a_1 = \frac{R_3^2 - R_2^2 + d_1^2}{2d_1} \qquad h_1 = \sqrt{R_3^2 - a_1^2}$$

$$a_2 = \frac{R_1^2 - R_2^2 + d_2^2}{2d_2} \qquad h_2 = \sqrt{R_1^2 - a_2^2}$$

- Angle α and γ are:

$$\alpha = sin^{-1}\frac{h_2}{R_1} \qquad \gamma = \sin^{-1}\frac{h_1}{R_3}$$

- Angle β is:

$$\beta = \pi - sin^{-1}\frac{h_2}{R_1} - sin^{-1}\frac{h_1}{R_3}$$

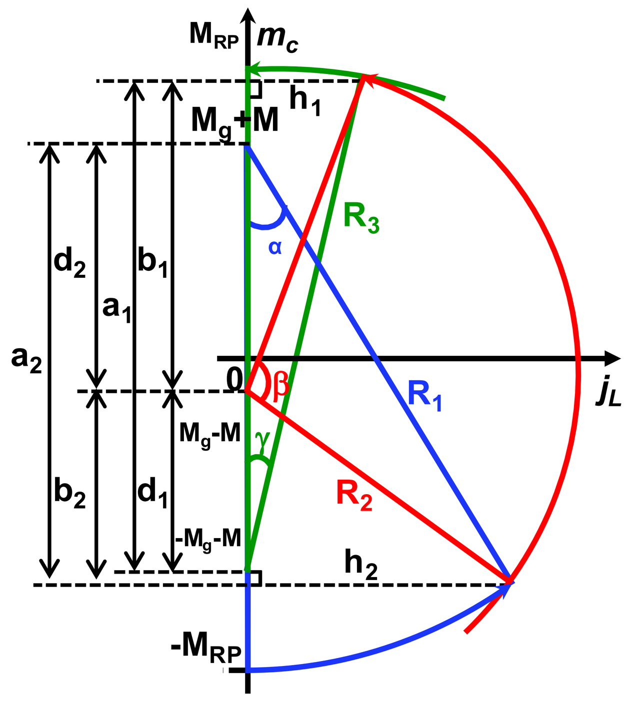


Fig.4. Phase plan analysis

- Finally, the expression of resonant current is:

$$I_{Lr}(t) = \begin{cases} \frac{V_g}{R_0}[R_1\sin(\omega t)] & 0 \le t < T_\alpha \\ \frac{V_g}{R_0}\{R_2\sin[\omega(t-T_\alpha)+\beta_{start\_angle}]\} & T_\alpha \le t < T_\alpha + T_\beta \\ \frac{V_g}{R_0}\{R_3\sin[\omega(t-T_\alpha-T_\beta)+\pi-\gamma]\} & T_\alpha+T_\beta \le t \le \frac{T_s}{2} \\ -\frac{V_g}{R_0}\left[R_1\sin\omega\left(t-\frac{T_s}{2}\right)\right] & \frac{T_s}{2} \le t < \frac{T_s}{2}+T_\alpha \\ -\frac{V_g}{R_0}\left\{R_2\sin\left[\omega\left(t-\frac{T_s}{2}-T_\alpha\right)+\beta_{start\_angle}\right]\right\} & \frac{T_s}{2}+T_\alpha \le t < \frac{T_s}{2}+T_\alpha+T_\beta \\ -\frac{V_g}{R_0}\left\{R_3\sin\left[\omega\left(t-\frac{T_s}{2}-T_\alpha-T_\beta\right)+\pi-\gamma\right]\right\} & \frac{T_s}{2}+T_\alpha+T_\beta \le t \le T_s \end{cases}$$

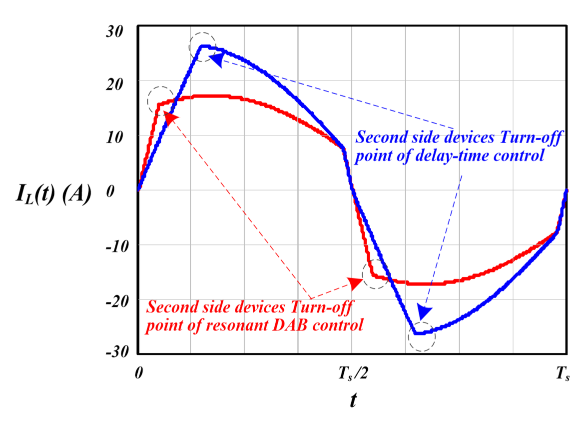


Fig.5. Comparison of resonant current between resonant and traditional DAB

- The turn-off current controlled by resonant DAB is nearly two times smaller than that controlled by traditional DAB, as shown in Fig.5..

High frequency transformer design

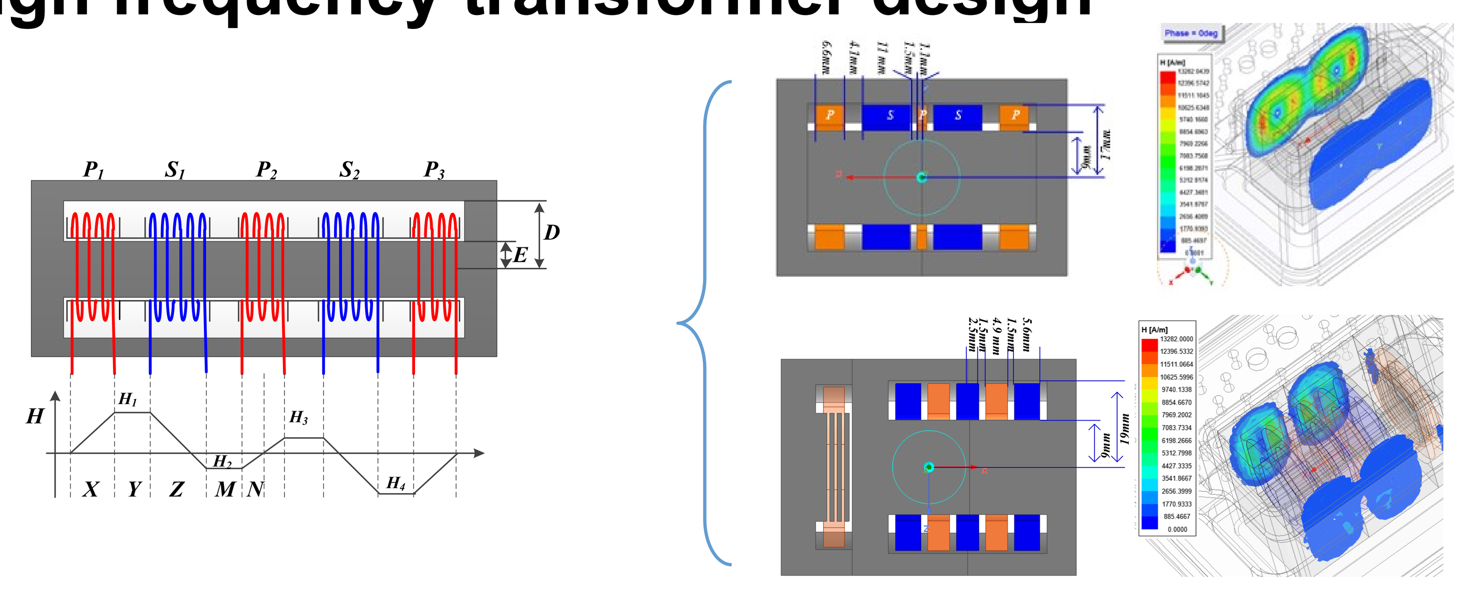


Fig.6. Integrated transformer design

- The integrated transformer adjusts the leakage induction by adjusting the coupling coefficient of the primary side and the secondary side.
- With the same leakage inductance design, the loss of fully integrated magnetic flux leakage in the metal cavity is greater, so partial integration is a compromise choice.

Loss calculation and experiment results

- The curves of Eon and Eoff VS ID currents of **NV6514** and **G3R75MT12J** are shown in Fig. 7. It can be seen that Eon of SiC higher by at least 2 times than GaN, while Eoff by at least 10 times.
- According to loss breakdown, by controlling the turn-off current of SiC within 20A, its application in high-frequency 500khz can be realized.

Main parameters	Value
V_{Bus} range	360~420V
V_{HVO} range	550~900V
Charging power	6.6kW
Discharging power	6.0kW
Frequency range	400~600kHz
Primary side GaN	NV6514
Secondary side SiC	G3R75MT12J
Transformer turns ratio	12:20
Lr	6uH
Lm	80uH
Crp/Crs	100nF/300nF
fr	290kHz

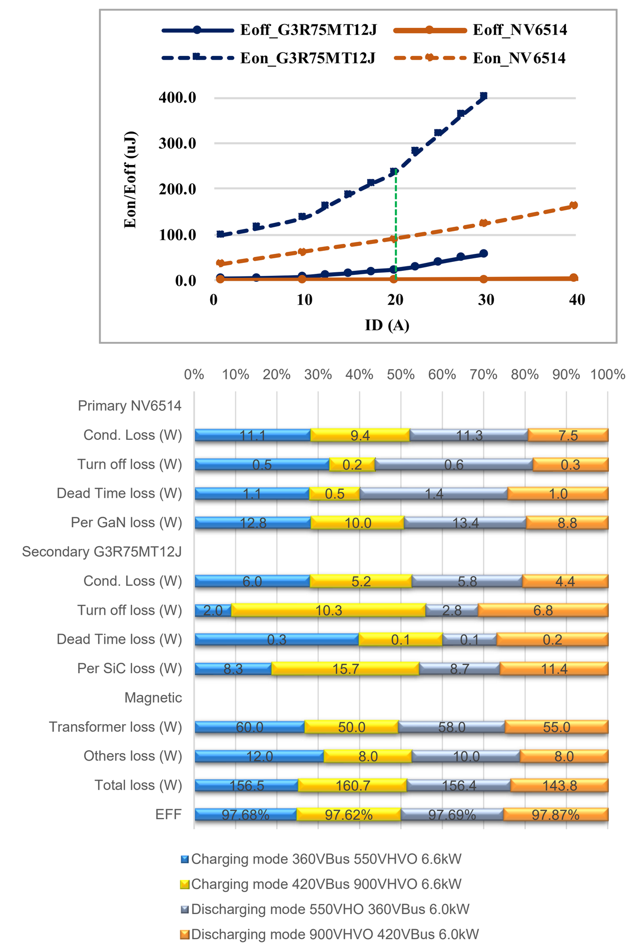


Fig.7. System main parameters, Eon & Eoff and Loss breakdown

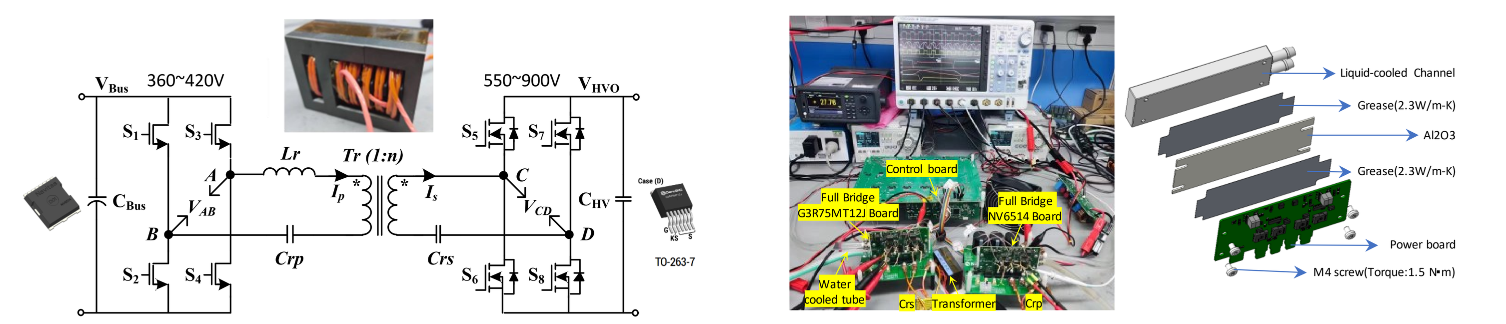
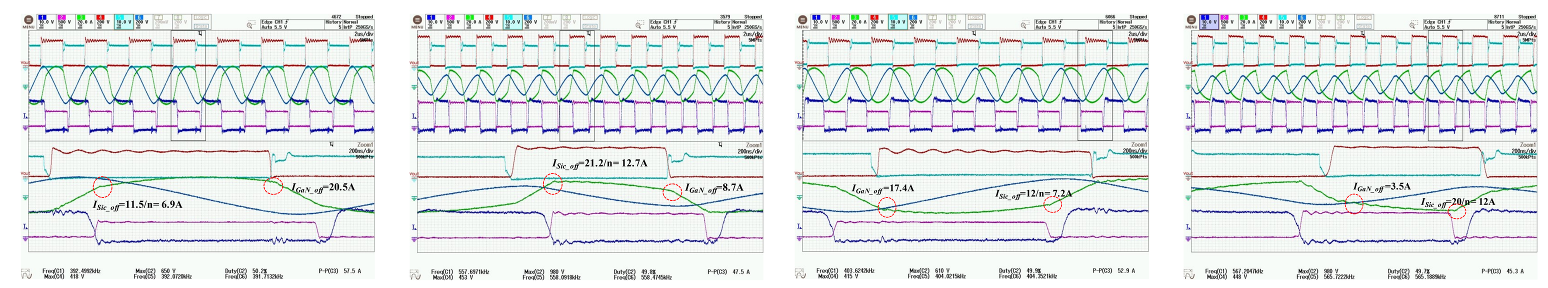


Fig.8. Transformer, experimental platform setup and water-coolant solution



(a) (b) (c) (d)

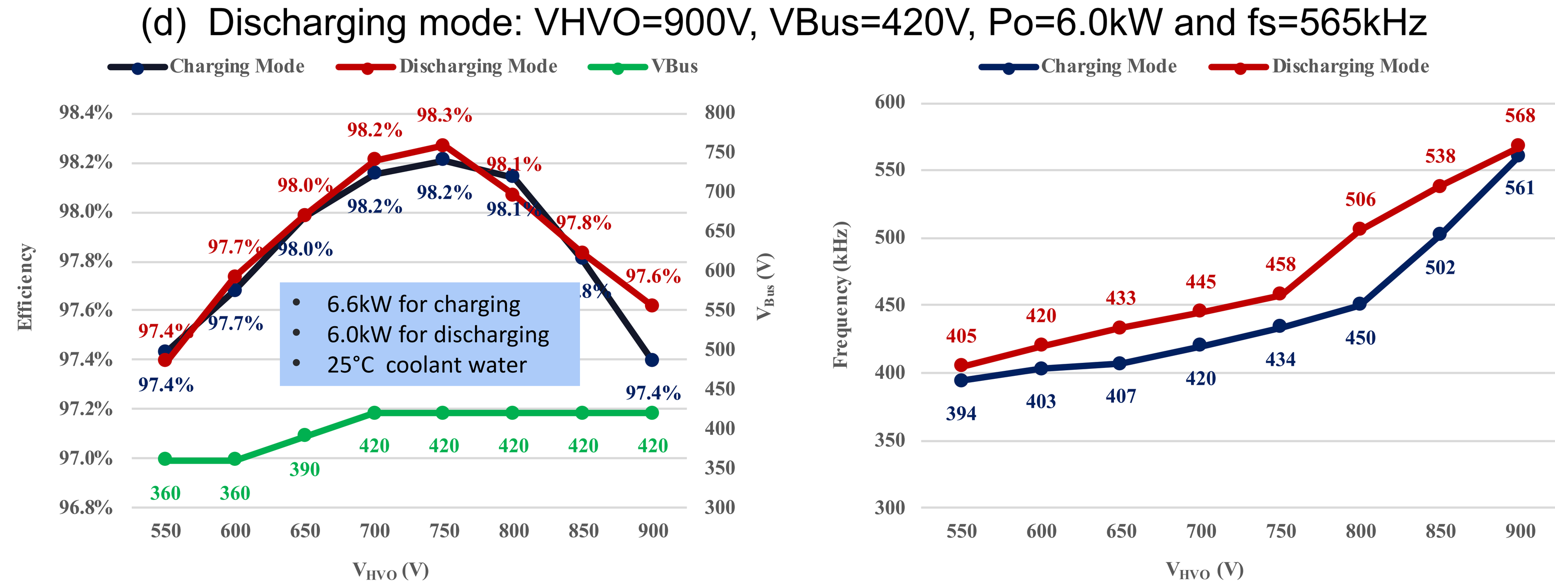
Fig.9. Experimental results (Ch_1:Vgs_S8, Ch_2:VDS_S8, Ch_3:Ip, Ch_4: VDS_S2, Ch_5: Vgs_S2, Ch_6:VCrp).

(a) Charging: VBus=360V,VHVO=550V, Po=6.6kW and fs=392kHz.

(b) Charging mode: VBus=420V,VHVO=900V, Po=6.6kW and fs=558kHz.

(c) Discharging mode: VHVO=550V, VBus=360V, Po=6.0kW and Fs=405kHz.

(d) Discharging mode: VHVO=900V, VBus=420V, Po=6.0kW and fs=565kHz



- Peak Efficiency is 98.3% @charging mode.
- Output voltage 550V to 900V supports full load operation.
- Switching frequency range is from 400kHz to 570kHz
- Designed with a turn-off current below 20A, SiC can also operate at 500khz.

References

- Gang, Liu , et al. "Implementation of a 3.3-kW DC–DC Converter for EV On-Board Charger Employing the Series-Resonant Converter." IEEE Transactions on Power Electronics 32.6(2017):1-1.