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Failure Diagnosis and Reconfiguration Scheme for Distributed Photovoltaic Converter Array in Solar Unmanned Aerial Vehicles

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Background

- **Photovoltaic(PV) Applications**

Factory

Station

Mobile device

Satellite

Traditional UAV

Improve Energy System

Capacity
Reliability
Diversity

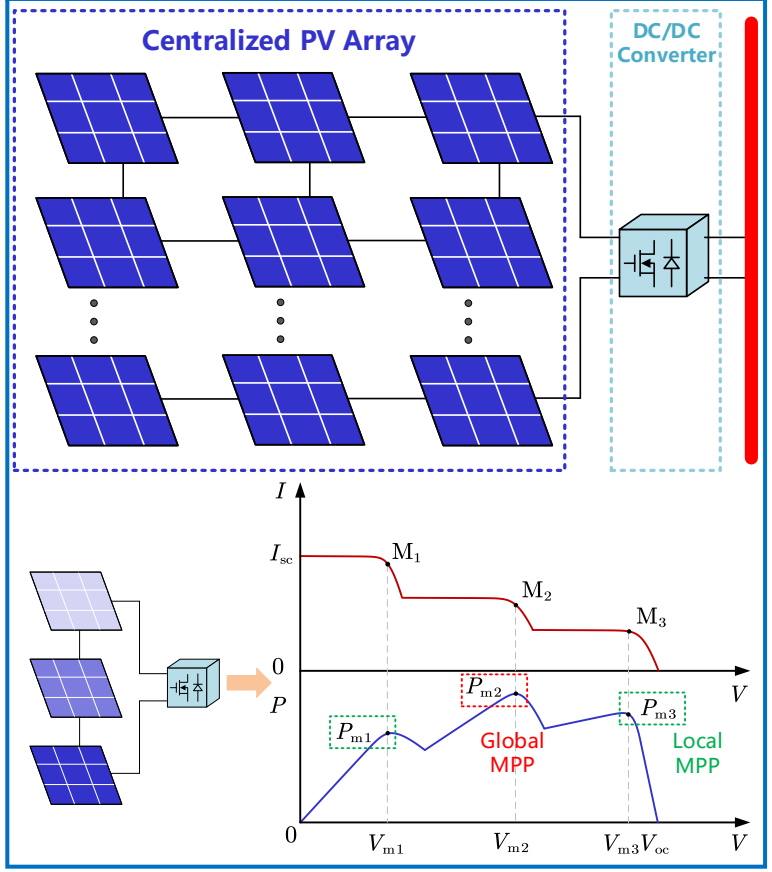
Solar UAV

Electric Power → Batteries
Fuel Power→ Internal Combustion Engines

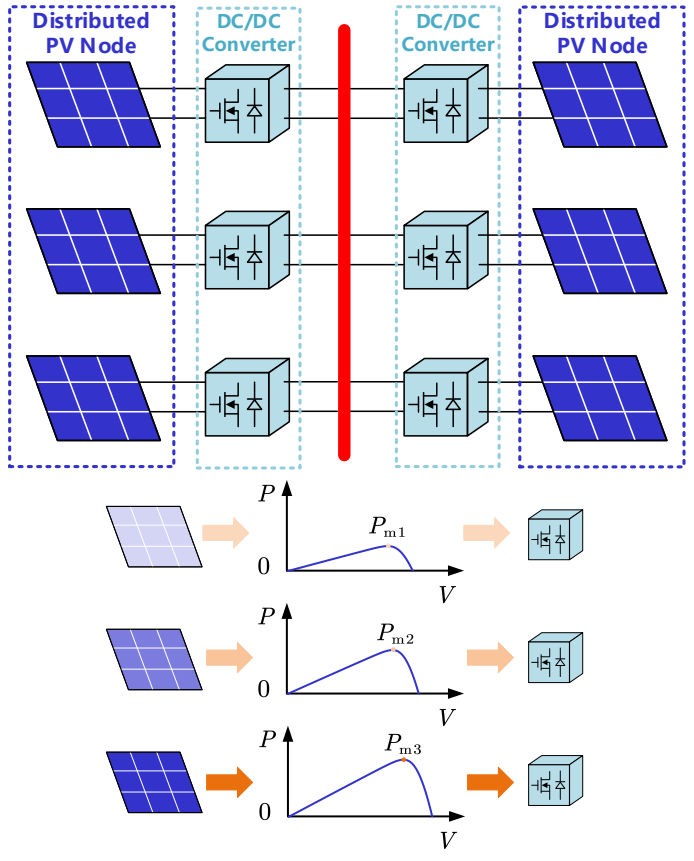
✓ **Automation** ✓ **Clean Energy**
✓ **Long-duration** ✓ **Long-distance**

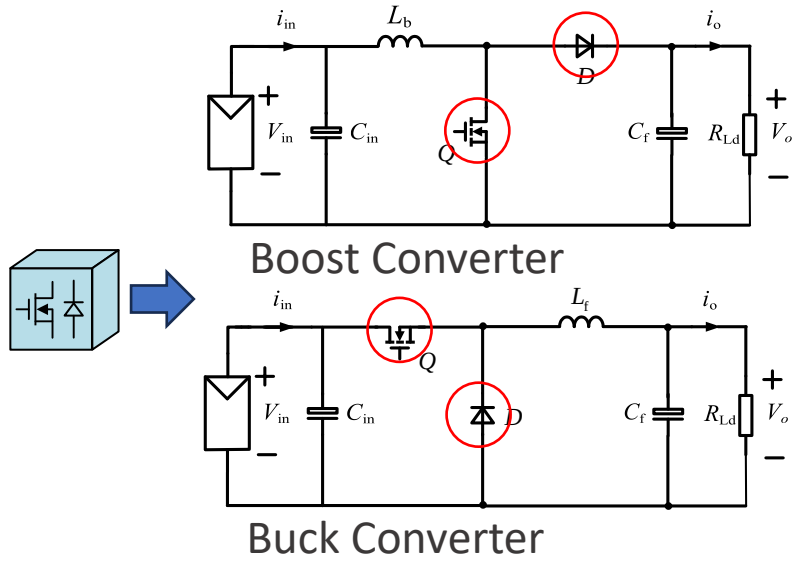
Background

Centralized Structure

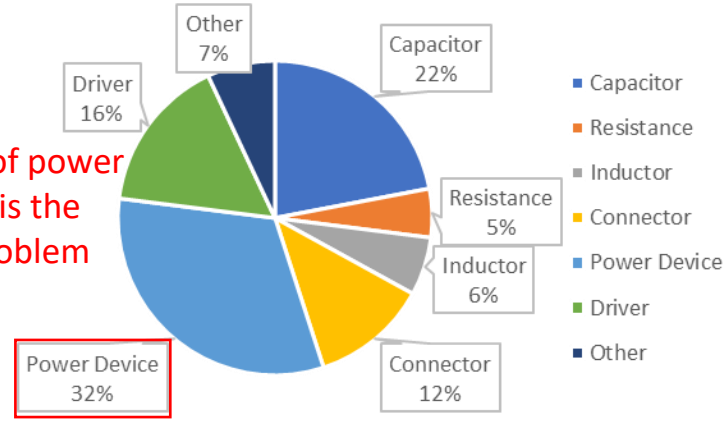


Distributed Structure





Failure of power devices is the main problem



Distributed PV array can improve energy utilization efficiency in UAV

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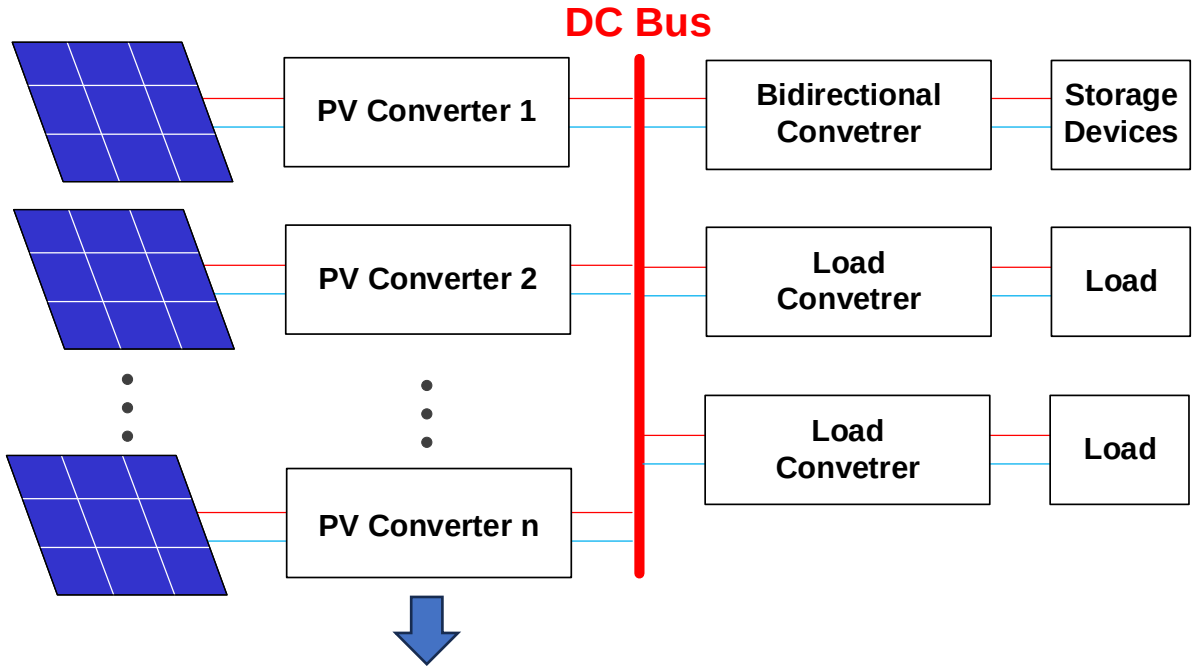
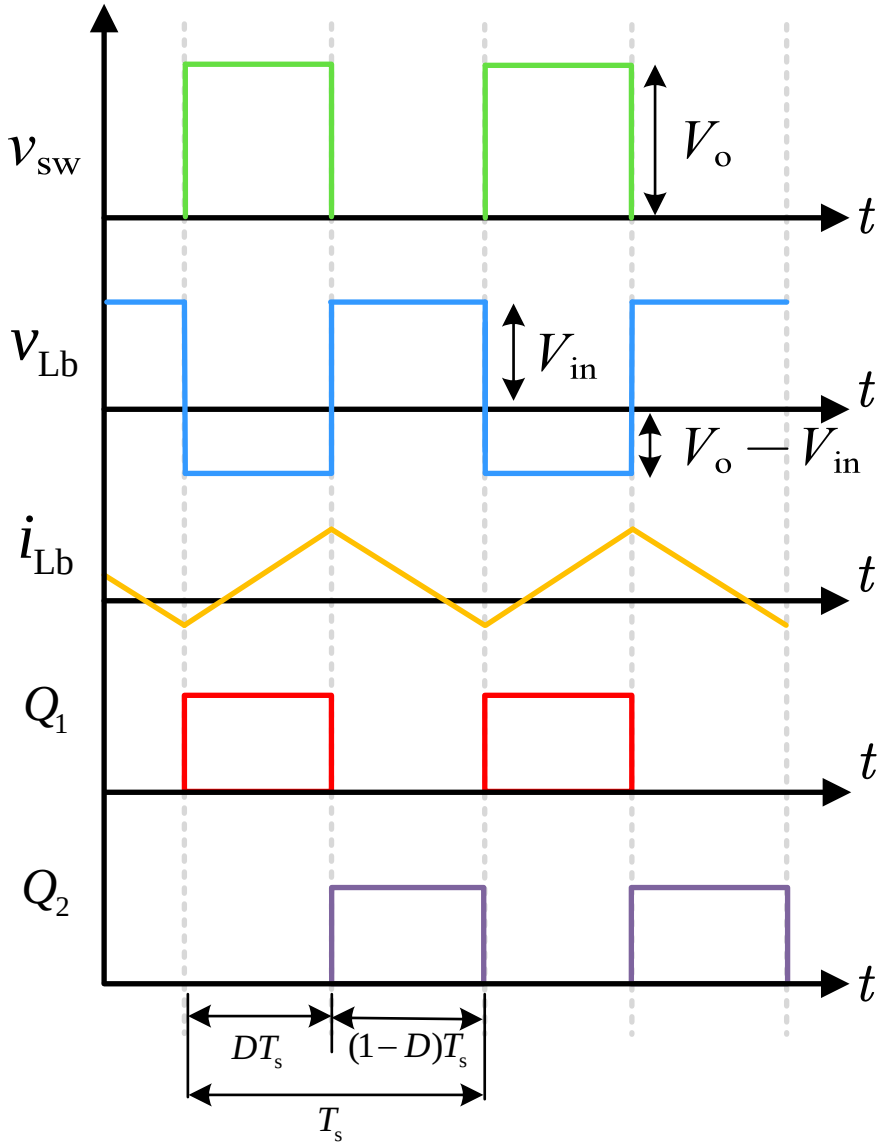
System Structure and Operation



Synchronous Rectification (SR) Boost Converter



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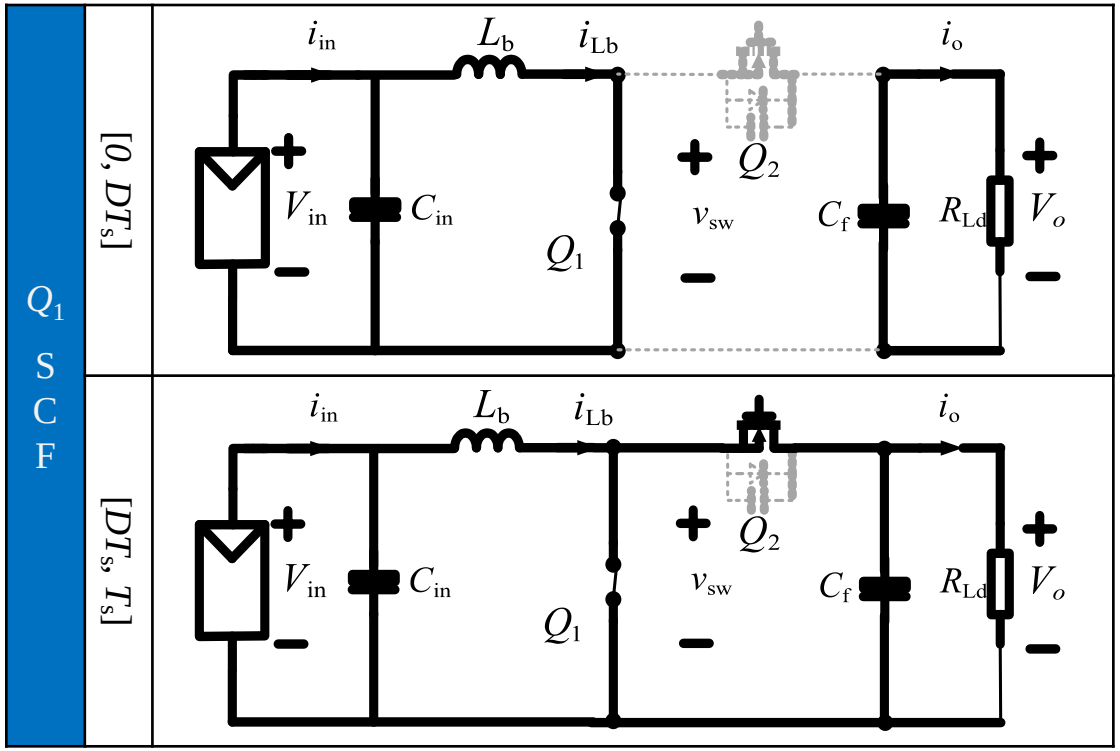
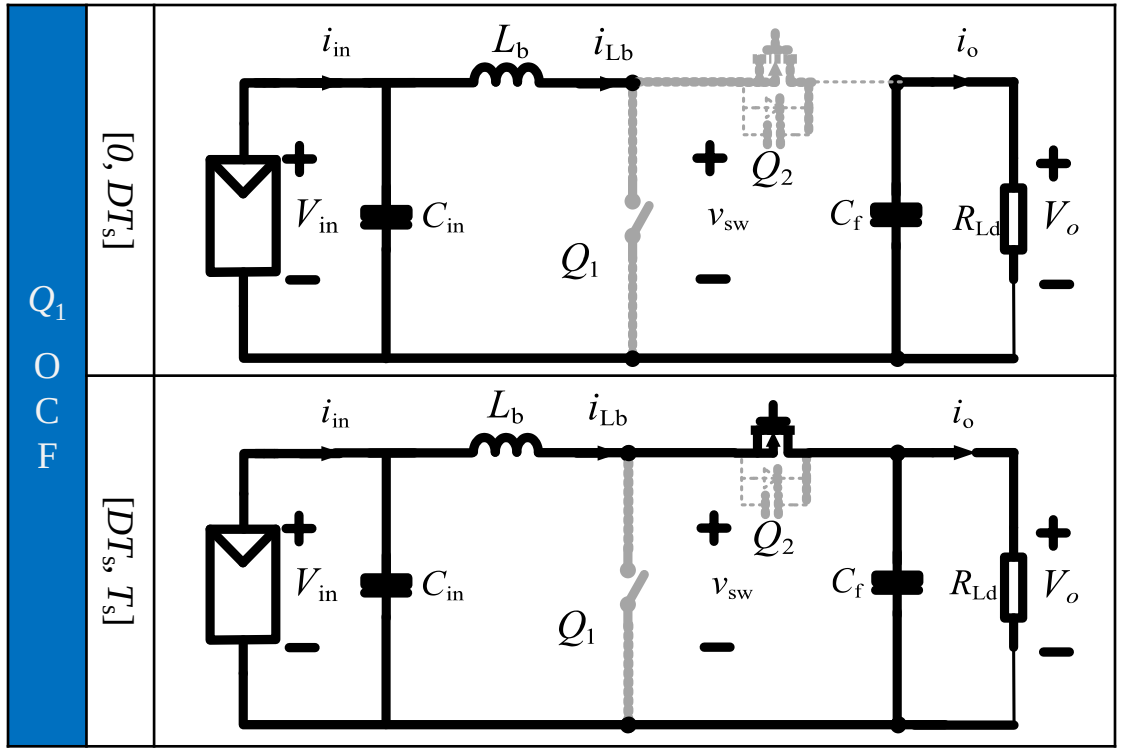
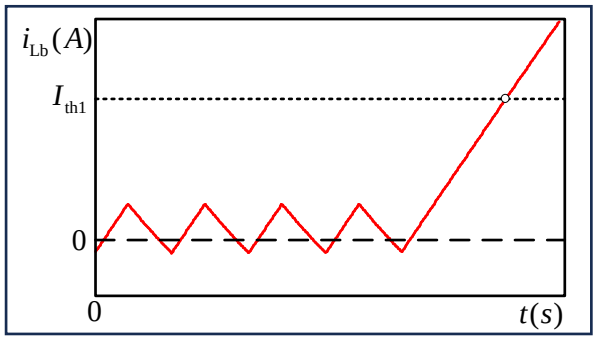
Fault Diagnosis Method

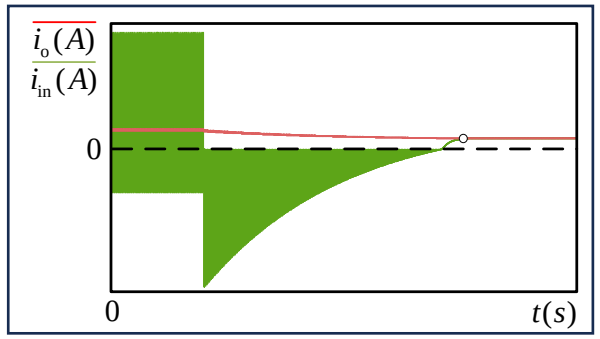






$$i_{Lb}(t) = \frac{V_{in}}{r_{s1}} + [\frac{V_{in}}{(1-D)^2 R_{Ld}} - \frac{V_{in}}{r_{s1}}]e^{-\frac{r_{s1}}{L_b}t}$$

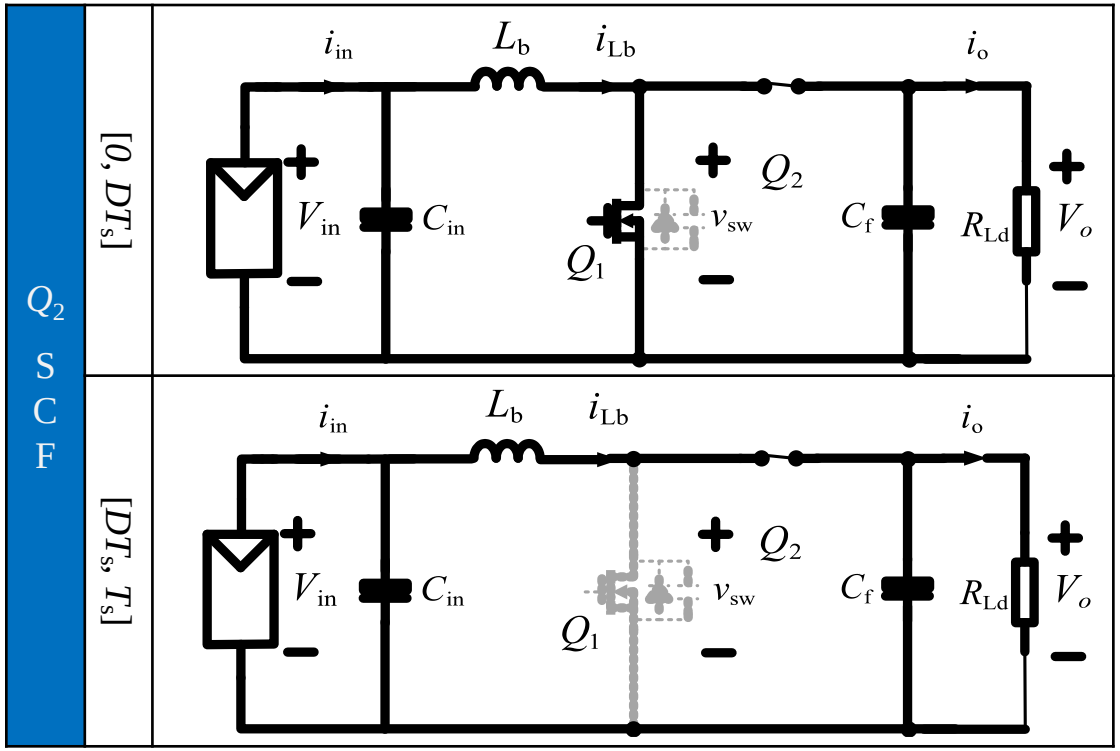
i_{Lb} is sampled and the threshold I_{th1} is set, Q_1 SCF is diagnosed if $i_{Lb} > I_{th1}$.

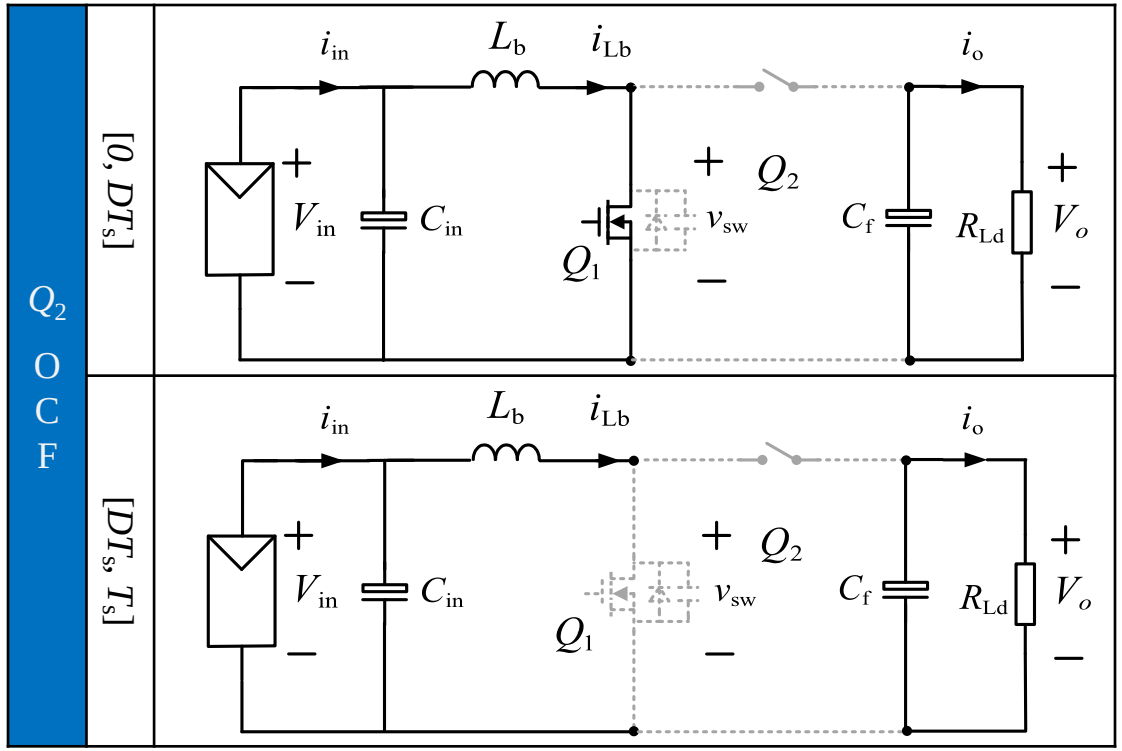


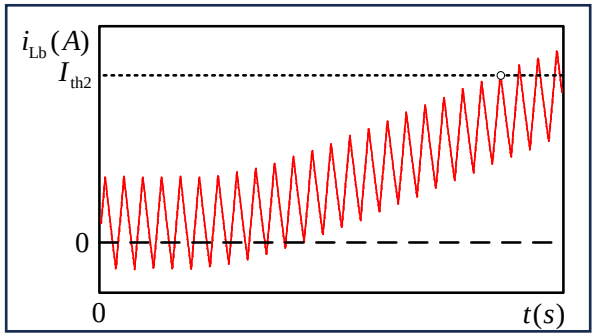
$$\begin{cases} P = V_{in} I_{in} = V_o I_o \\ I_{in} = \frac{1}{1-D} I_o \end{cases}$$

i_{in} and i_o are sampled and the threshold I_{th2} is set, Q_1 OCF is diagnosed if i_{in}-i_o<I_{th2}.

Fault Diagnosis Method

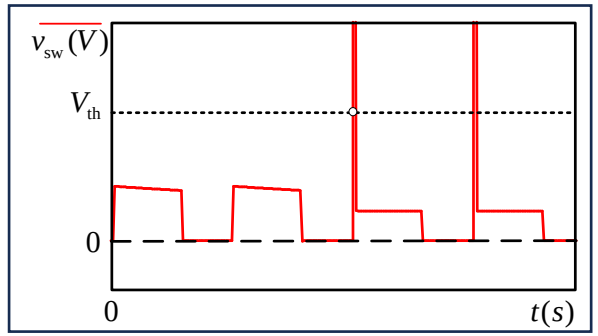






$$I_{Lb} = \frac{V_{in}}{(1-D)^2 \dfrac{R_{Ld}}{1+D\dfrac{R_{Ld}-ESR}{ESR}}} \quad I_{Lb0} = \frac{V_{in}}{(1-D)^2 R_{Ld}}$$

i_{Lb} is sampled and the threshold I_{th3} is set, Q_2 SCF is diagnosed if $i_{Lb} > I_{th3}$.



$$v_{sw}(t) = V_{in} - (V_{in} - \frac{r_{o2} V_{in}}{L_b} DT_S) e^{-\frac{r_{o2}}{L_b} t}$$

v_{sw} is sampled and the threshold V_{th} is set, Q_2 OCF is diagnosed if $v_{sw} > V_{th}$.

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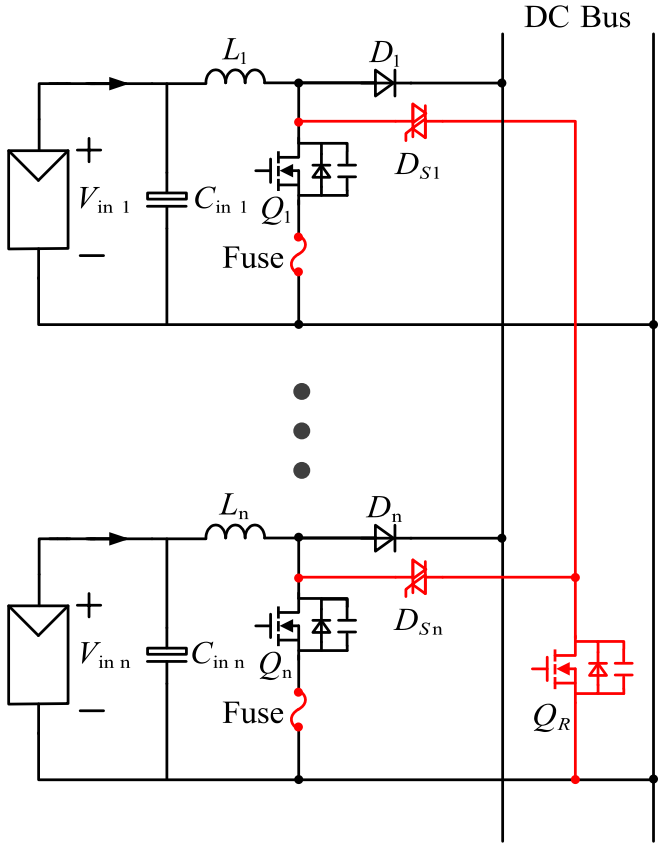
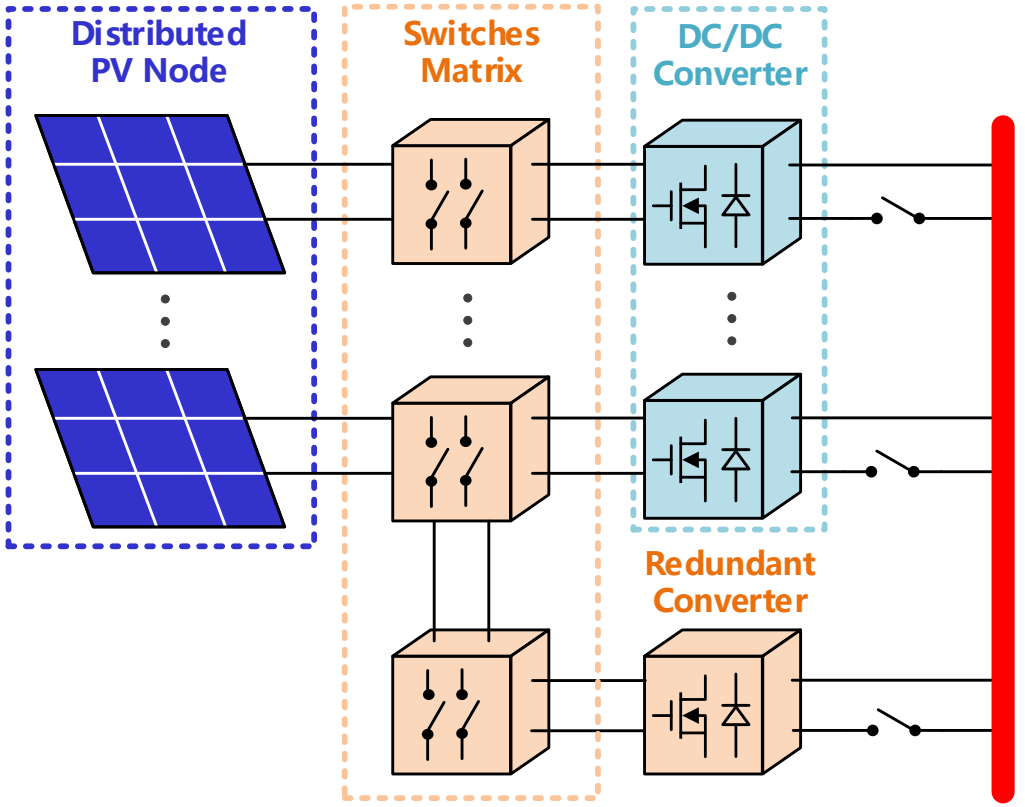
Fault Reconfiguration Scheme





■ Device-level Reconfiguration

Simple in structure but has weak redundancy capabilities

■ Module-level Reconfiguration

Replace the entire converter to achieve greater device redundancy

Fault Reconfiguration Scheme

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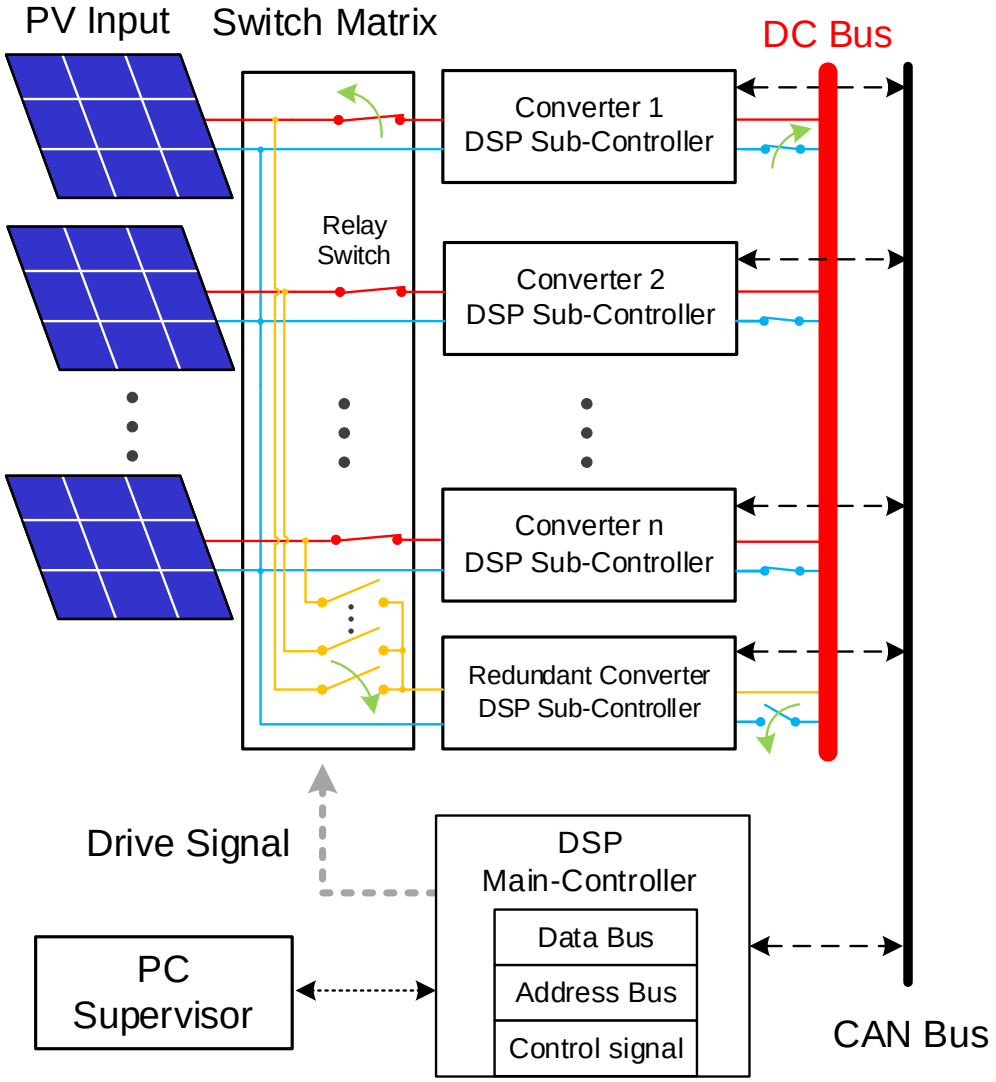
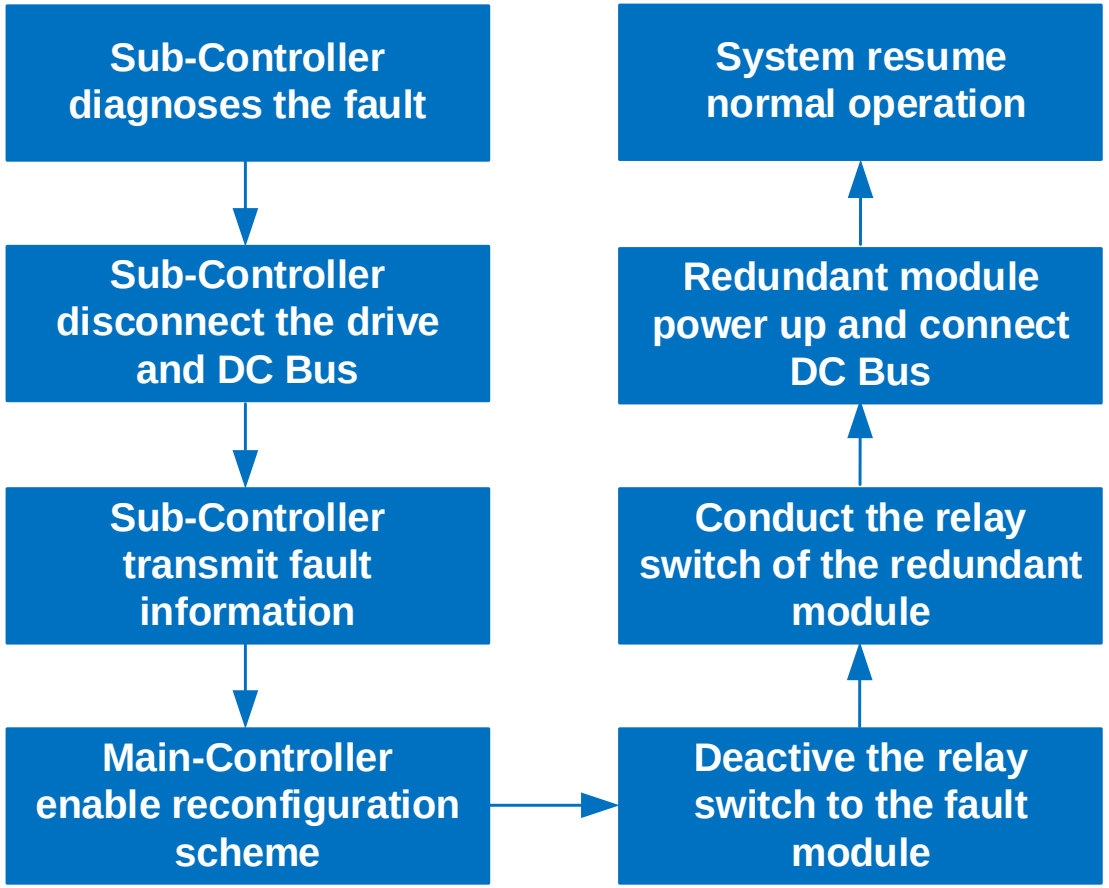
- **FR framework**



- **Step diagram**



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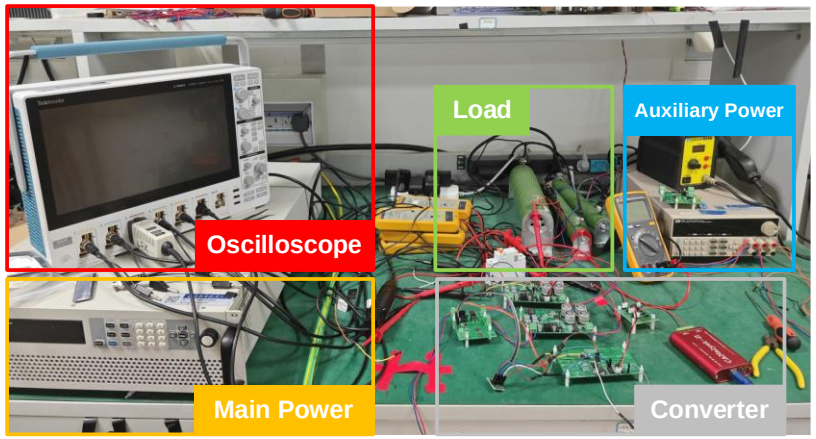
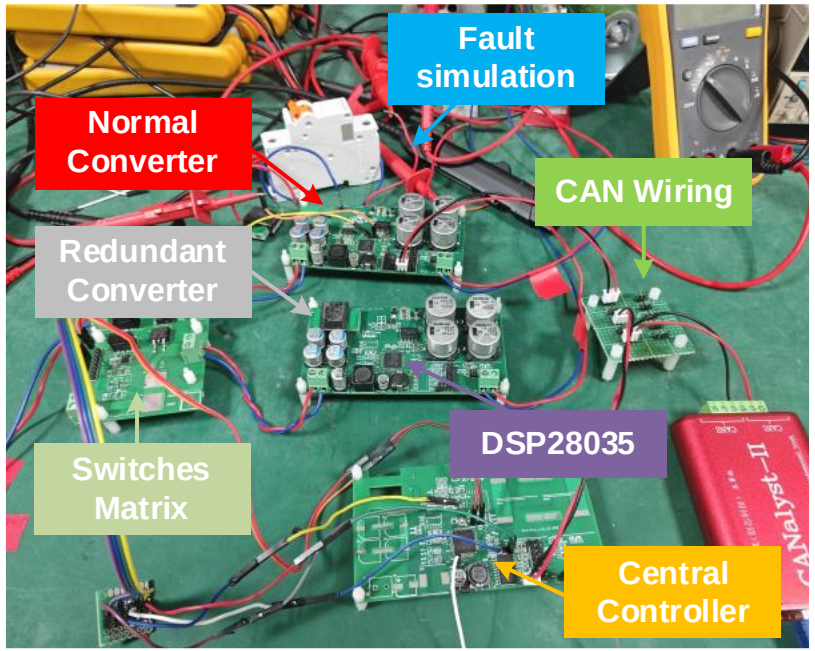
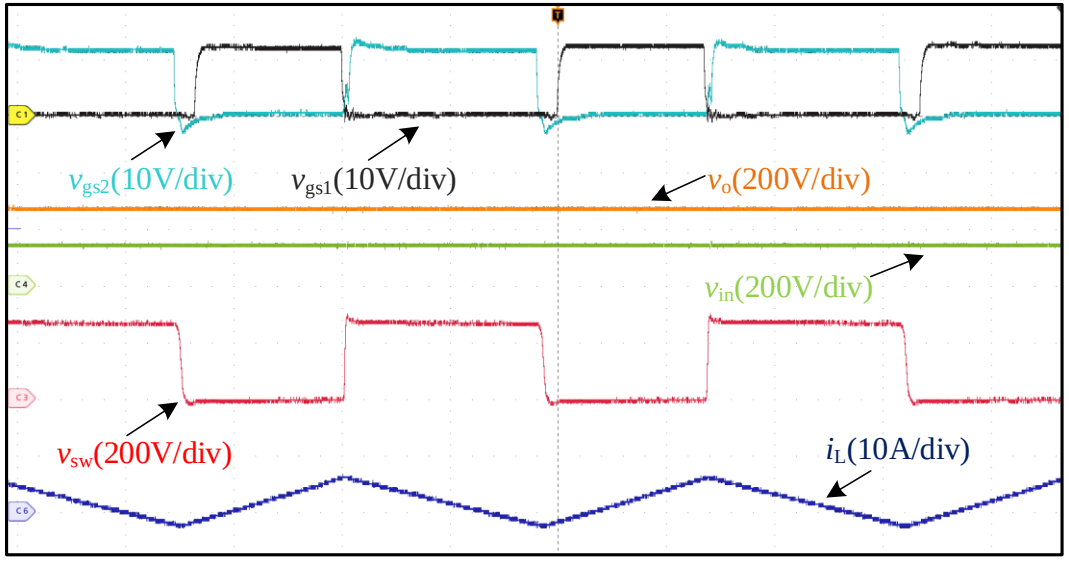
Experimental Result

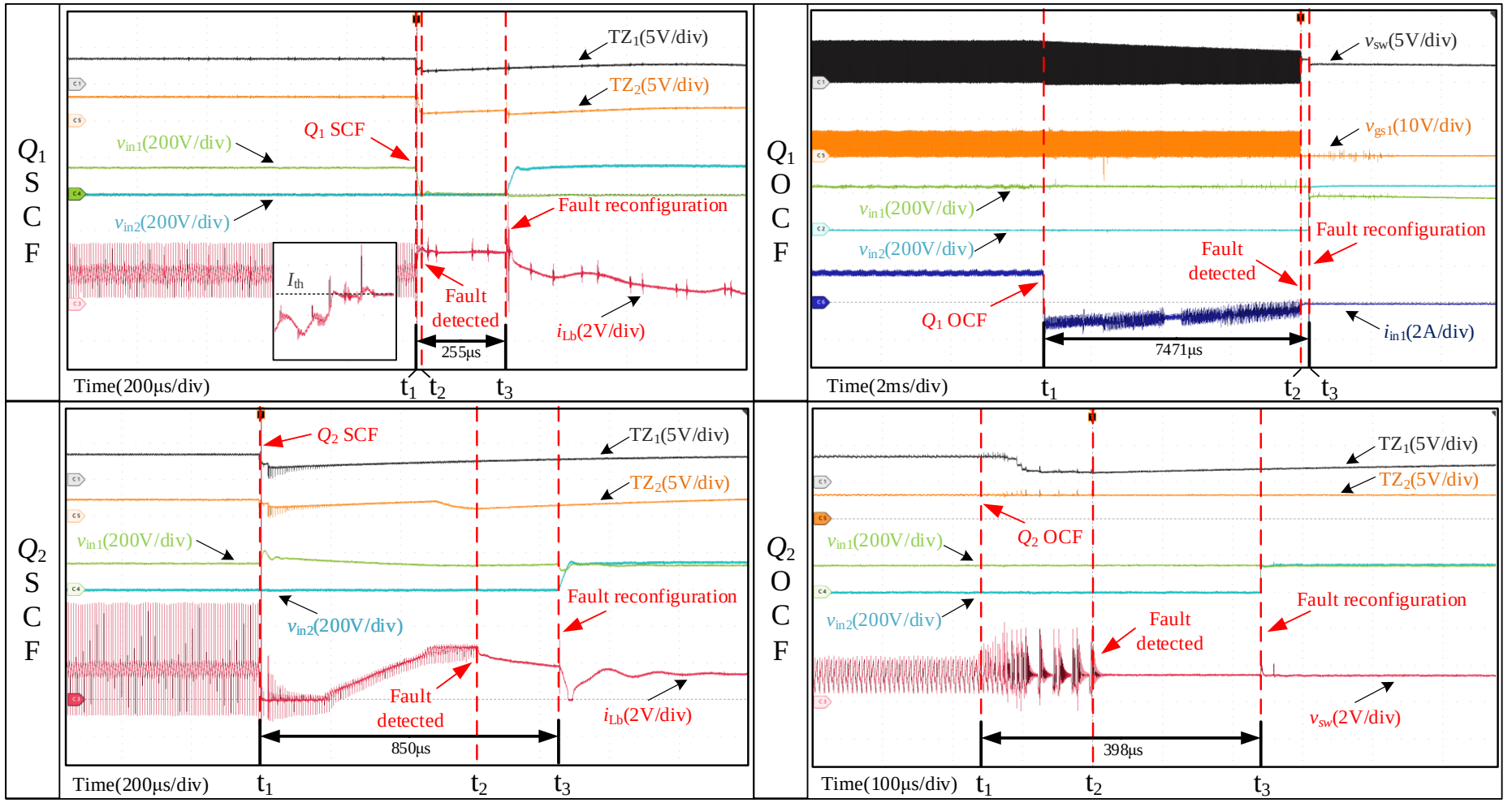




Parameters	Value
V_{in}	150V
V_o	270V
Power switch	IPB60R165
L	56μH
C_{in}	20μF
C_f	100μF
R_{Ld}	243Ω
Switching frequency(f)	150kHz



Experimental Result



t_1: Fault occurrence

t_2: Fault detected

t_3: Fault reconfiguration

Fault Type	Diagnosis Time
Q_1 SCF	255μs
Q_2 SCF	398μs
Q_2 SCF	850μs
Q_1 SCF	7471μs

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Conclusion

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- A fault diagnosis method with good performance and integration for switches in the SR Boost converter that serves as the PV converter in solar UAV by detecting the inductor current and the voltage across switches is proposed.
- A fault reconfiguration scheme for distributed PV converter array which uses the switches matrix to remove the fault module and adds fault redundancy to the system is proposed.
- The validity of the scheme is verified through experiments on the prototype of the PV converter array and the system can resume normal operation up to 7471 μs.

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Thanks for your listening!

Q&A