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An Algorithm for Failure Detection of A Power Mosfets In Non-Isolated Boost DC-DC Converters for Photovoltaic (PV) Power Systems

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Abstract

Considering the intermittent nature of photovoltaic (PV) power generation and the potential faults within PV systems, this paper proposes an algorithm for detecting power switch failures in DC-DC converters. The algorithm does not require an additional MOSFET or extra sensors. Instead, it utilizes over-current at the slope of the input inductor as an indicator of system failure. This method proves to be cost-effective and simpler compared to traditional approaches that involve adding redundant MOSFETs or sensors, or designing specialized monitoring software. The algorithm was tested in a simulation environment and validated through a simple laboratory experiment. The results indicate promising potential for improving the reliability of power MOSFETs in non-isolated converters integrated into PV power systems.

Keywords: MOSFET Failure, DC-DC Converters, PV Power System.

Introduction

Recently, there has been rapid growth in the power capacity of conversion systems to meet escalating industrial power demands (Isah and Ali, 2024; Isah *et al*., 2020). Although PWM converters are widely used in industrial applications due to their flexibility, low current ripple, high power gain compared to conventional converters, they are not suitable for standalone use in high-power systems due to the current limitations of power devices (Isah *et al*., 2019 ;Singh and Beniwal, 2025). Therefore, research into multi-stage operation of DC-DC PWM converters, such as classical boost converters in parallel, offers advantages, including improved current quality from interleaved PWM, easier maintenance, and better thermal management (Isah *et al*., 2021 ; Boudjellal and Benslimane, 2022).

In power conversion systems, the failure rate of semiconductor components like MOSFETs is estimated to be around 30-40% (Xu *et al*., 2021). When gate driver malfunctions are considered, the total failure rate for control devices approaches 50%. MOSFET failures can be categorized as over-current (short-circuit failures, SCF) or over-voltage (open-circuit failures, OCF) (Singh and Beniwal, 2025). In the event of an SCF, circuit breakers or fuses typically disconnect the device quickly to prevent severe damage. For an OCF, the converter may continue to operate without critical failure, but its performance may degrade. usually, the system is halted to prevent further damage (Abdelghani *et al*., 2021). However, applications in security, airspace, renewable energy, and distributed power generation require continuous operation even under fault conditions, as unplanned shutdowns can lead to significant financial losses. Therefore, it is essential for faulty converters to remain operational despite a decline in semiconductor device performance (Jagtap and More, 2020).

Various fault detection and tolerant control techniques have been proposed to maintain power conversion system performance under OCF conditions (Boudjellal and Benslimane, 2022 ; Xu and Chen, 2021 ; Jagtap and More, 2020). During fault identification, faults can be detected through

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measured current or voltage signals. Once detected, a fault-tolerant control (FTC) strategy is applied to mitigate performance decline and prevent additional failures. In three-phase two-level converter systems, FTC methods often involve altering PWM switching patterns to improve efficiency and power factor by minimizing current imbalance and distortion. For example, (Kumar *et al.,* 2021) presents an FTC method that switches a three-level T-type converter to a two-level operation. While effective, such methods are often topology-specific. Conversely, (Xu *et al.,* 2021) highlight that in systems with two-parallel-connected two-level PWM converters, OCF issues persist even after applying traditional FTC methods to the compromised converter with redundant switches. To avoid increased losses, phase current distortion, and DC-link voltage instability, the use of redundant switches should be minimized.

In recent years, significant research has focused on single-switch DC-DC converters. Reference Dusmez *et al.*, (2016) proposes a software-based frequency response analysis method to monitor power MOSFET degradation in single-switch converters, this technique does not effectively address OCF in the power switch.

Consequently, this paper proposes an algorithm for detecting power switch failures in DC-DC converters within PV power systems. The method uses over-current at the slope of the input inductor as a failure indicator. This approach is simple, reliable, and cost-effective compared to the traditional methods that require additional hardware, sensors, or redundant switches. MATLAB/Simulink was used for converter design, and a practical experiment was conducted to validate the algorithm.

Materials and Method

Materials

The materials used in this work includes one input inductor L_1, one power switch, two capacitors, one diode, load resistor, Oscilloscope and analog & digital trainer.

Method

After designing the proposed classical boost converter, a practical set-up was prepared, and the prototype circuit is shown in figure 1. In this circuit, when the current slope of the input inductor (L_1) exceeds the normal value, the power switch does not conduct, and the diode is forward biased. When the current slope equals the normal value, the power switch conducts, and the diode does not.

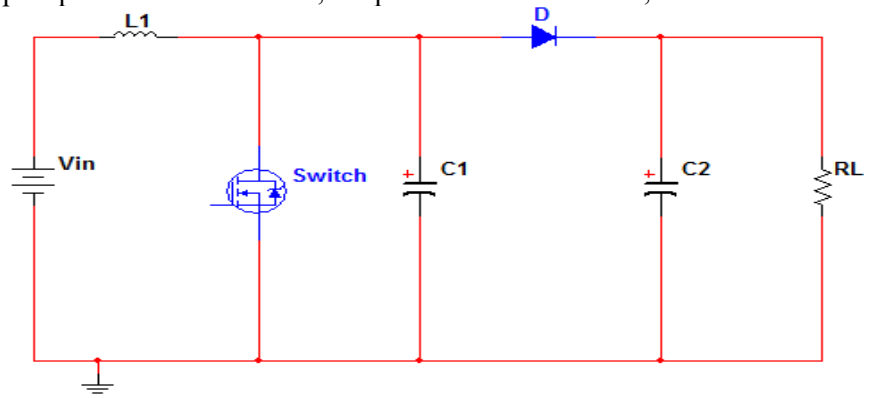


Fig. 1: Topology of the classical DC-DC converter

Algorithm

The algorithm is based on monitoring the current slope in the input inductor of the DC-DC converter. A slight deviation from the set input current value, particularly over-current, can cause the power switch to operate under unhealthy conditions. A low input inductor current can also critically affect the switch, leading to converter malfunction. The algorithm is summarized in table 1.

Table 1: Algorithm table

Input inductor current slope	Switching pattern of the power switch	Switching Pattern of the converter
$I_{Input} = 12$	0	CCM

$I_{Input} > 12$	1	DCM
$I_{Input} < 12$	1	DCM

Mathematical Equations

The mathematical model of the proposed converter, as designed in figure 1, is expressed as follows:

$$L\frac{di}{dt} = V_{IN} \quad (1)$$

Equation (1) represents the input inductor dynamics.

$$C_1\frac{dV}{dt} = -\frac{V_{C2}}{R} \quad (2)$$

Equation (2) describes the relationship between the two capacitances.

$$L\frac{di}{dt} = -V_{C2} + V_{IN} \quad (3)$$

Equation (3) relates the input inductor, input voltage, and output voltage.

$$C\frac{dV_{C1}}{dt} = i - \frac{V_{C2}}{R} \quad (4)$$

Equation (4) represents the relationship between the input and output capacitors.

The nonlinear relationships among the converter variables are given by:

$$L\frac{di}{dt} = -(1 - V_D)V_{C1} + V_{IN} \quad (5)$$

Equation (5) relates the inductor current, diode voltage and input voltage.

$$C\frac{dV_{C1}}{dt} = (1 - V_{Switch})i - \frac{V_{C2}}{R} \quad (6)$$

Equation (6) describes the relationship between capacitor C1, switching voltage and output capacitor C2.

Results and Discussion

Result

The following diagrams represent the inductor signals (L_2) of the converter under different conditions.

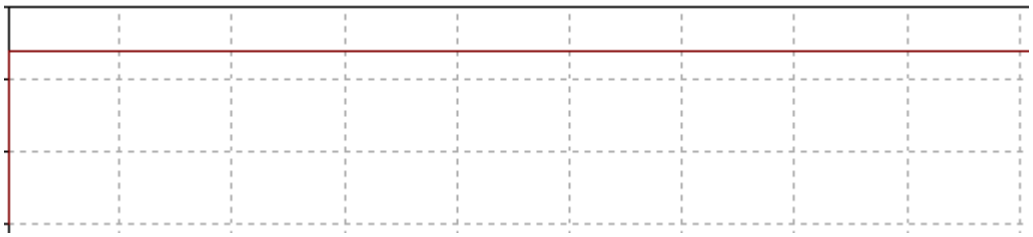


Fig. 2: Inductor current under normal condition in the power switch

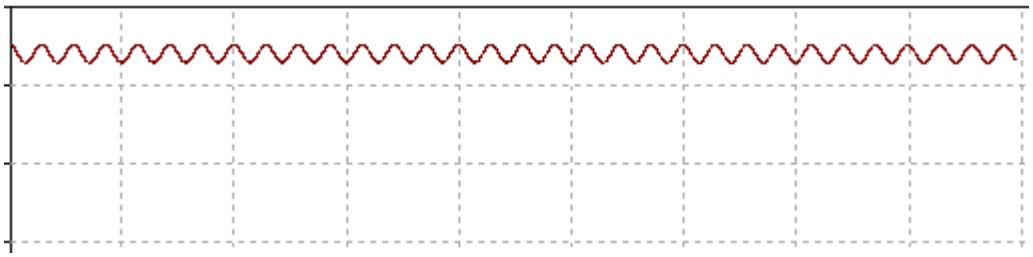


Fig. 3: Inductor-current under a slight faulty condition in the power switch

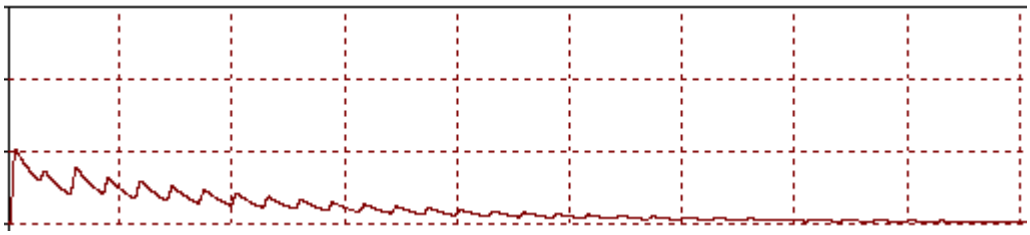


Fig. 4: Inductor-current under a critical faulty condition in the power switch



Fig. 5: Experimental setup

Table 2: Data obtained from laboratory

Components	Values
Input Inductor	2000 µH
Input Voltage	12.00 A
Input Current	24.00 V
Over Current	12.01 A
Output Voltage	96.00 V
Diode	0.90 V
Switching Frequency	40 kHz
Capacitors	2000 µF

Discussion

Simulation

To evaluate the algorithm's performance, MATLAB/Simulink was used to simulate various fault conditions in the power switch. As outlined in table 1, the current input was set to different values. The simulations employed a classical boost converter from the DC-DC converter family, integrated with the control algorithm within the simulation framework.

Experiment

An experimental setup was established to validate the conditions set in the simulation conditions. The setup involved assembling a classical DC-DC converter on a breadboard using a digital and analog trainer, as shown in figure 5. A digital oscilloscope captured over-current conditions. When the current remained within the threshold value (figure 2), the signal appeared sharp, indicating a healthy power switch. When the input inductor current slightly exceeded the threshold (figure 3), the signal resembled a pulse or sinusoid, indicating over-current. Similarly, when the input current fell slightly below the

threshold (figure 4), the signal appeared critically distorted, indicating a slow and declining power switch condition.

Conclusion

This paper presented an algorithm for failure detection of power MOSFETs in non-isolated boost DC-DC converters for PV power systems. The proposed method offers a more effective solution for maintaining healthy operation of power MOSFETs compared to traditional approaches. The fault detection timing has been significantly improved, which can reduce or prevent permanent damage to power MOSFETs. Future work may incorporate adaptive thresholds or filtering techniques to mitigate noise effects.

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