Journal of Nano- and Electronic Physics
Vol. **16** No 3, 03029(5pp) (2024)

Журнал нано- та електронної фізики
Том **16** № 3, 03029(5сс) (2024)

OPEN ACCESS

REGULAR ARTICLE

Measurement of Very Small Variation of Effective Resistance of MOSFET Deputed in Active Microgrid Inverter Operation

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(Received 13 April 2024; revised manuscript received 19 June 2024; published online 28 June 2024)

Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) are essential components of conventional power electronic converters used in microgrid (MG) inverter systems because of their efficiency, quick switching, and compact size. Microgrid inverters (MGIs) are vital to distributed energy systems (DESs), converting DC electricity from renewable sources into AC. An H-bridge inverter (HBI) in MG operation permits bidirectional power flow, enabling both grid-tied and independent operation. A MOSFET fault in SPHBI may cause a change in the MOSFET's effective resistance (MER). Reliability, safety, and performance of the MG system can all be negatively impacted by MOSFET failures in an H-bridge inverter. An effective fault detection system should be included in the MGI to lessen the impact of MOSFET failures. An approach to detecting a prompt MOSFET switch failure (MSF) in a single-phase H-bridge MG inverter associated with a photovoltaic (PV) system is presented in this article. To identify MSF, the SPHBI's output current was analyzed using the Fast Fourier Transform (FFT). For varying fault levels, the effects of MSF on the DC component (DCC), fundamental current component (FCC), Total Harmonic Current Distortion (THCD), and subharmonics (SHs) have been studied. Based on the best-fit attributes, an attempt has been made to successfully recognize the MSF that also enables the measurement of MER during MSF. Furthermore, an algorithm for MSF detection has been suggested.

Keywords: Fast Fourier Transform (FFT), Fault identification, H-bridge inverter (HBI), Microgrid (MG), MOSFET, PV system.

DOI: 10.21272/jnep.16(3).03029 PACS number: 85.30.Tv

1. INTRODUCTION

MGs are significant in the power system since they can increase resilience, integrate renewable energy, improve efficiency, and provide localized solutions for a multitude of applications and scenarios. MG is made up of distributed energy systems (DESs) [1], including renewable energy sources, energy storage systems [2], and advanced control systems. MGs can improve energy reliability and safety by lowering their reliance on centralized power plants and conventional fossil fuels by integrating PV systems [3].

Domestic microgrids (DMGs) [4, 5] are becoming more widely available due to technological developments and growing support for DESs. With DMG, households can continue to be linked to the main power grid but yet generate, store, and manage their energy. Power electronic converters [6], which offer the flexibility and control necessary to effectively manage a variety of energy sources and loads within a confined and frequently dynamic energy system, are crucial parts of MGs.

Voltage source inverters (VSIs) are used in most applications [7]. The integration of renewable energy sources and the smooth transition between grid-tied and islanded modes of operations are made possible by the flexibility and control that HBIs offer in MG applications. Compared to a VSI, HBI has numerous features [8].

The number of output phases in an inverter might vary. Perhaps the most often utilized inverters are single-phase and three-phase versions [9]. For various switching devices, VSIs employ a pulse width modulation (PWM) approach to create the continually changing analog signals effect [9]. Power semiconductor switches, such as MOSFETs, IGBTs, and BJTs, are typically used in inverters to achieve PWM to obtain the output in AC [9].

Fast switching speeds of MOSFETs enable inverters

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to operate at high frequencies. This high switching frequency aids in lowering the weight and size of the inverter's parts while also increasing power conversion efficiency. So, fault-free operation of the inverter is very much needed. Compared to other inverter components, power MOSFETs [10] have a significantly higher failure rate. Power components like MOSFETs and IGBTs are responsible for 21 % of converter failures [11, 12].

An efficient diagnostic technique for short circuit fault (SCF) in a current source inverter (CSI) is suggested by X. Guo et al. in [13]. The authors in [14] introduced a single OCF in the matrix converter system's (MCS) bidirectional switch. The OCF in the CSI was presented by M. T. Fard et al. in [15]. S. F. Zarei et al. [16] described a short circuit failure (SCF) identification approach for an islanded inverter. S. S. Ghosh et al. in [12, 17] demonstrated the IGBT switch's failure identification process in the voltage source converter (VSC). In 2020, J. Zhang et al. presented a unique technique for identifying OCF in wind power converters (WPCs) [18].

Regardless, minimal attempts have been made to detect MOSFET switch failure (MSF) in a single-phase H-bridge inverter (SPHBI) in MG operation. An innovative method for identifying MSF in SPHBI is presented in this article. The Fast Fourier transform (FFT) [19, 20] has been employed for determining the MSF. In electrical signal analysis, FFT [19, 20] can be potentially utilized to identify faults.

The output current of the SPHBI has been evaluated in this article to determine MSF. Several features, including the DC component (DCC), fundamental component (FDC), total harmonic current distortion (THCD), and sub-harmonics (SHs) of the SPHBI's output current, have been observed using the FFT to diagnose the MSF.

The following is an outline of the article. Section 2 illustrates the PV system connected to SPHBI. The issue statement is presented in Section 3. Section 4 has provided an overview of the failure assessment process. In Sections 5 and 6, respectively, specific outcomes and an MSF detection algorithm have been discussed. Comparative studies have been illustrated in Section 7. Section 8 provides a summary of the conclusions.

2. GRID-TIED MOSFET-BASED SPHBI

The main grid-tied DMG PV system, which consists of a Maximum Power Point Tracking (MPPT)-driven DC/DC boost converter (DDBC), a DC-link, a bidirectional DC/DC converter (BDC), a battery storage system, household electric loads and an SPHBI, is schematically shown in Fig. 1. The DMG's PV system is connected to a 66 kV grid and has a rating of 3.5 kW. To harvest the maximum power possible from the PV system, the DDBC employs the MPPT control. The value of the residential loads is 10 kW.

To determine the existence of MSF in the SPHBI, the output current of the SPHBI has been closely observed under both normal and at different MSF percentages.

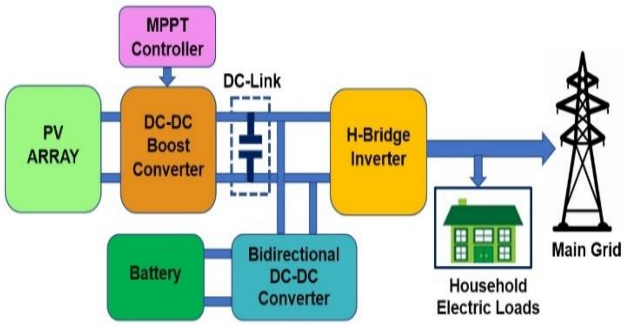

Fig. 1 – Schematic diagram of the main grid-tied domestic MG PV system, an MPPT-driven DC/DC boost converter, a DC-link, a bidirectional DC/DC converter, a battery storage system, household electric loads and an SPHBI

3. PROBLEM DESCRIPTION

In this investigation, the DMG's MOSFET-based SPHBI is connected to the PV system and the utility grid. Fault investigation considers the MSF of the SPHBI. An unforeseen issue is the MSF in SPHBI. An SPHBI's MSF can cause many problems with the device's functionality as well as variations in the effective resistance value of the MOSFET. The issue is referred to as one that causes the circuit's path to open after a certain percentage of MSF (% MSF). The MOSFETs can be stressed to the point of failure by overcurrent, overvoltage spikes, voltage transients, undervoltage, or overheating situations. Wear and ageing of MOSFETs over time can result in a drop in performance and a higher chance of failure.

The performance of the entire system, including the inverter, can be negatively impacted by MSF. Fast and precise fault detection should be incorporated into MOSFET-based inverters to lessen the impact of MSF.

Thus, in this work, an effort was made to identify MSF in SPHBI and to determine the progressive change in the MER value within the SPHBI during the MSF.

4. FFT-ORIENTED FAULT DETECTION

The Fourier Transform (FT) and FFT [17, 19, 20] are effective techniques for electrical signal analysis, especially when it comes to problem identification and diagnostics. An analysis of a signal's frequency components is made possible by FFT, which converts a time-domain signal into its frequency-domain representation. The FFT has a faster rate than the FT [17]. So, FFT may be used in real-time monitoring systems to analyze electrical signals continuously.

In this investigation, the output current of the SPHBI is closely analyzed to discover MSF. Several metrics relating to the SPHBI's output current, such as the DCC, FDC, THD, and SHs, have been tracked based on the FFT to recognize the MSF.

4.1 FFT-Oriented Pattern Synthesis

FFT analysis has been performed on the acquired SPHBI's output current signal at typical working situations as well as during different MSF percentage levels (%MSF).

Fig. 2 displays the collected output current of the SPHBI. The FFT window of the collected SPHBI's output current is displayed in Fig. 3. Fig. 4 illustrates the SPHBI's output current signal spectrum.

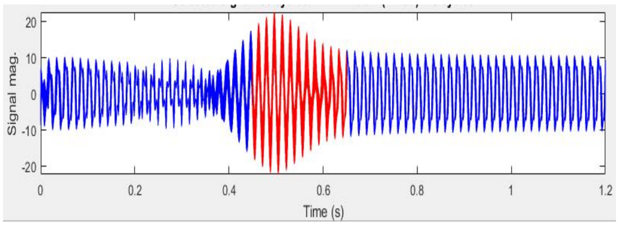

Fig. 2 – Collected SPHBI's output current signal

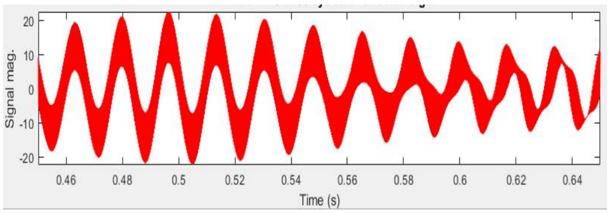

Fig. 3 – FFT window of the collected SPHBI's output current

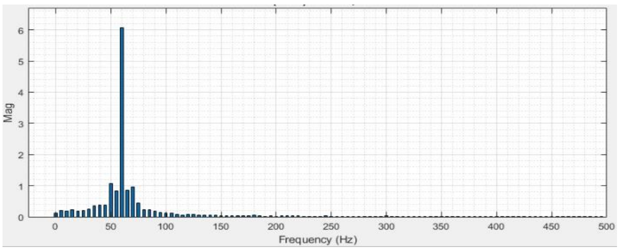

Fig. 4 – SPHBI's output current signal spectrum

4.2 Retrieval of Low-frequency Characteristics

4.2.1 Evaluation of DC Components (DCC)

For various percentage fault values of the MSF (%MSF), the DCC of the collected SPHBI's output current has been recovered using FFT-based analysis.

It may be inferred from Fig. 5 that there is no direct relationship between the DCC and MSF. Therefore, MSF in the SPHBI cannot be identified using this attribute.

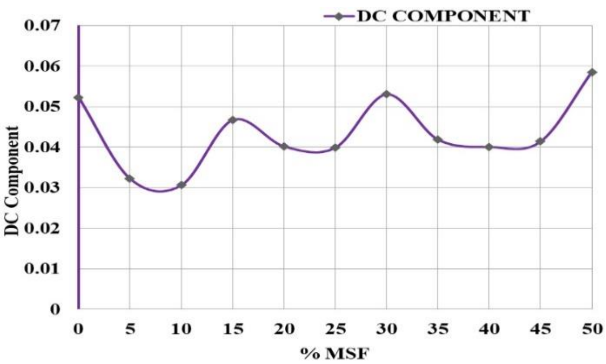

Fig. 5 – DCC versus %MSF

4.2.2 Evaluation of the FDC

FFT is implemented to the collected SPHBI's output signal to obtain its fundamental frequency component.

Fig. 6 shows the FDC values, which were calculated from the SPHBI's output current for different %MSF values.

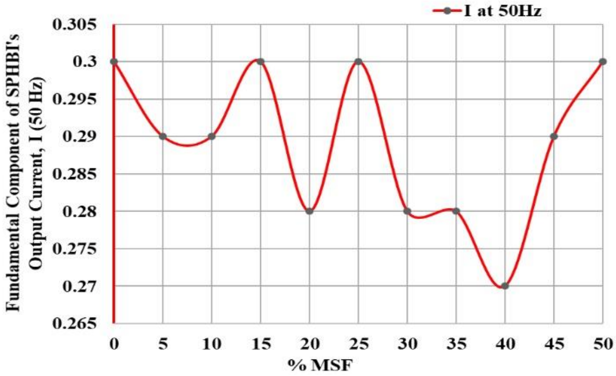

Fig. 6 – FDC versus %MSF

A graphic inspection of Fig. 6 makes it abundantly evident that there is an improper correlation between the different %MSF values and the FDC of the SPHBI's output current. Therefore, it is not viable to utilize this characteristic to detect MSF in the SPHBI.

4.2.3 Evaluation of the THCD

A signal's harmonic content is quantified by THD [17, 19, 20]. A current signal's THD is known as Total Harmonic Current Distortion (THCD).

THCD may be expressed using the following:

$$THCD(\%) = \frac{\sqrt{I_2^2 + I_3^2 + ... + I_n^2}}{I_1} \times 100 \qquad (1)$$

where, I_1 is the fundamental frequency's RMS value and the RMS values of each harmonic element are I_2, I_3, …, I_n. Fig. 7 illustrates the THCD values that were obtained for the investigation of MSF at different fault levels of MSF in SPHBI.

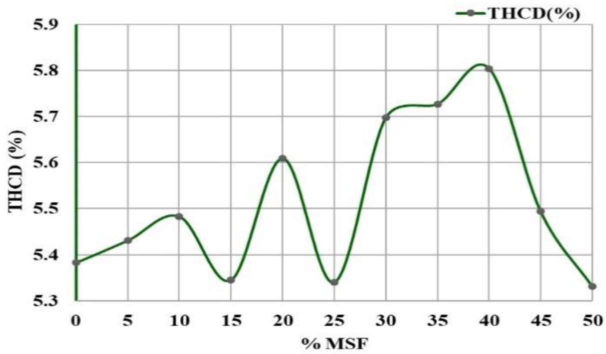

Fig. 7 – THCD(%) versus %MSF

As the percentage of MSF in the SPHBI rises to 10%, it shows that the THCD(%) value also increases. But following that, the THCD(%) number gradually decreases as %MSF rises to 15 %. Then, the value of THCD(%) increases after 15 % of MSF and continues to do so until the MSF value becomes 20 %. Consequently, the graphical analysis of Fig. 7 lacks strong support for the MSF diagnosis.

4.2.4 Evaluation of Subharmonics of Current

Sub-harmonics (SHs) have been extracted from the recorded SPHBI's output current. Each subharmonic component of the acquired signal has been closely inspected for different % MSF values. As the amount of % MSF increases, all sub-harmonic values change simultaneously, as seen in Fig. 8.

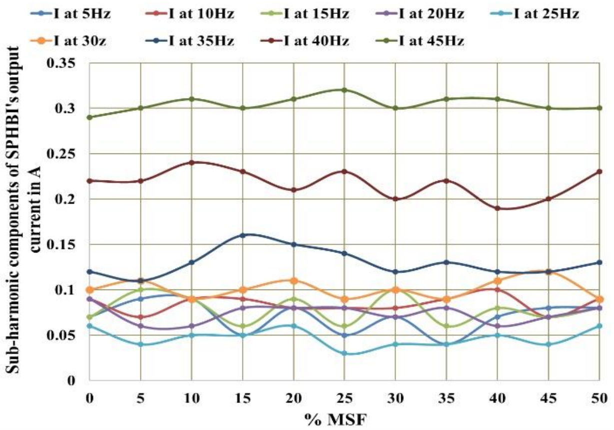

Fig. 8 – SHs versus %MSF

5. SPECIFIC RESULTS

Several metrics, including the FDC, THCD, and SHs of the SPHBI's output current, were monitored using FFT-based signal processing in the first phase of this work. Nevertheless, these evaluations are unable to produce any useful findings that might be used for the identification of MSF in SPHBI. Concurrently, the mean values (MNV) and standard deviation values (STDV) for the variance in values of all the SHs for different %MSF have been obtained as presented in Fig. 9.

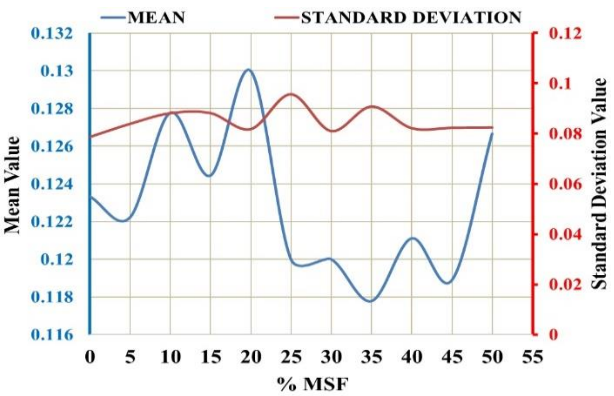

Fig. 9 – MNV and STDV of the SHs versus %MSF

It is evident from the graphical analysis of Fig. 9 that only the SHs' STDV rises linearly as MSF increases to 15%. It is therefore illustrated that the prompt identification of MSF (up to 15% of MSF) in DMG's single-phase SPHBI is merely accomplished by continually observing the SHs' STDV.

6. MSF DETECTION ALGORITHM

An MSF recognition algorithm is proposed as follows:

(a) At the very start, acquire the SPHBI's output current.
(b) Determine STDV of the subharmonic components of SPHBI's output current.
(c) Analyze the STDV of the SHs.
(d) Find MSF, if it presents.

7. COMPARATIVE EVALUATION

A comparison of various types of inverter failure detection techniques with the recommended approach is shown in Table 1.

Table 1 – Comparative Evaluation

Ref.	Determining Faults	Capability of % Fault Identification
[14], [15], [18]	OCF in MCS, CSI, and WPC	No
[13], [16]	SCF in CSI and islanded inverter	No
Proposed approach	MSF in SPHBI	Yes

8. CONCLUSION

During ideal and flawed circumstances, a statistical assessment employing FFT on the SPHBI's output current has been accomplished in this work to diagnose MSF in DMG's single-phase SPHBI and the various parameters' values were seen to change.

The specific findings also revealed that the recommended approach allows for the computation of the %MSF as well as the calculation of the MER value.

Consequently, it has been learned that this FFT-based fault-finding technique efficiently identifies MSF (up to 15% of MSF) in SPHBI by constantly monitoring the STDV of the SHs.

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Вимірювання малої варіації ефективного опору MOSFET під час активної роботи інвертора в мікромережі

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Польові транзистори метал-оксид-напівпровідник (MOSFET) є важливими компонентами звичайних силових електронних перетворювачів, які використовуються в інверторних системах мікромережі (MG) завдяки їх ефективності, швидкому перемиканню та компактному розміру. Мікромережеві інвертори (MGI) є життєво важливими для розподілених енергетичних систем (DES), перетворюючи електроенергію постійного струму з відновлюваних джерел у змінну. *H*-мостовий інвертор (HBI) у режимі MG забезпечує двонаправлений потік електроенергії, забезпечуючи як прив'язану до мережі, так і незалежну роботу. Несправність MOSFET у SPHBI може спричинити зміну ефективного опору MOSFET (MER). На надійність, безпеку та продуктивність системи MG можуть негативно вплинути збої MOSFET в *H*-мостовому інверторі. Ефективна система виявлення несправностей повинна бути включена в MGI, щоб зменшити вплив збоїв MOSFET. У цій статті представлено підхід до виявлення швидкої відмови перемикача MOSFET (MSF) в однофазному *H*-мостовому інверторі MG, пов'язаному з фотоелектричною (PV) системою. Щоб ідентифікувати MSF, вихідний струм SPHBI був проаналізований за допомогою швидкого перетворення Фур'є (FFT). Для різних рівнів несправності було вивчено вплив MSF на компонент постійного струму (DCC), фундаментальний компонент струму (FCC), повне гармонійне спотворення струму (THCD) і субгармоніки (SHs). На основі найкращих атрибутів була зроблена спроба успішно розпізнати MSF, що також дозволяє вимірювати MER під час MSF. Крім того, запропоновано алгоритм виявлення MSF.

Ключові слова: Швидке перетворення Фур'є (FFT), Ідентифікація несправностей, *H*-мостовий інвертор (HBI), Мікромережа (MG), MOSFET, Фотоелектрична система.