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A Novel Power Cepstrum Based Differential Protection Scheme For LVAC Microgrid

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Abstract – AC microgrids have become a promising solution in the transition toward renewable energy, addressing climate change and the rising global demand for electricity. They enhance the flexibility, efficiency, and resilience of power distribution networks. However, to fully optimize the benefits of microgrids, it is essential to implement efficient protection systems capable of rapidly detecting faults. This paper proposes a power cepstrum based current differential protection scheme for fault detection in LVAC microgrid. The method utilizes the positive sequence current measured at the line ends. Fault detection is achieved by analyzing the difference in the power cepstrum obtained from both ends. The power cepstrum is derived by applying a logarithm to the Fast Fourier Transform (FFT) of the current signal, followed by an inverse FFT, with the final result obtained by taking the square and modulus of the transformed signal. This process ensures high sensitivity and reliability while helps in setting same threshold for fault detection in both grid-connected and islanded modes of operation. The proposed scheme can detect the fault under both operating modes of microgrid upto 6 ohm, and doesn't maloperate for measurement error and time synchronization error. It also remains stable for different system transients and has high accuracy and fast fault detection (maximum 17.7 ms). The proposed technique is implemented and tested on the 4- bus low voltage AC microgrid and simulated in MATLAB to assess the effectiveness of the proposed technique.

Keywords**:** Differential protection, Power cepstrum, Fast Fourier Transform, Microgrid, Fault detection.

1. Introduction

Concerns about climate change and the rising demand for power have driven the growth of Distributed Generators (DG), which are integrated into distribution systems through microgrids. However, this integration poses significant challenges to conventional protection schemes due to bidirectional power flow, the intermittent nature of Renewable Energy Sources (RESs), and different fault currents in Grid-Connected mode (GCM) and Islanded Mode (IM) [1]. Various protection techniques have been proposed in the literature based on local measurements, such as [2] used a monitoring function to observe the inverter current for fault detection in IM. In [3], faults are detected based on power flow variations, while Singh *et al.* [4] employed fuzzy logic on current to detect faults in both modes. Support vector machine approach was used in [5] to detect faults based on voltage and current data. However, these methods fail for varying fault resistance or during transient events. Differential protection is generally preferred over local measurement-based methods due to its high selectivity and better performance in fault detection [1]. Various differential protection scheme is recommended for fault detection of AC microgrid such as, Gururani *et al.* [6] proposed a Hilbert-Huang transform based current differential protection scheme. Similarly, [7] used downsampling and empirical mode decomposition to estimate line current differences, while [8] and [9] employed S-transform and Discrete wavelet transform, respectively. However, these methods are computationally complex and time consuming, and do not account for time synchronization errors. In [10], the use of superimposed negative sequence impedance is proposed for fault identification, but this scheme fails for three phase fault. Soleimanisardoo *et al.* [11] used frequency injection after fault occurrence to detect the faulty feeder in IM, while Mahfouz *et al.* [12] used impedance angle differences for fault identification. Zhao *et al.* [13] applied cosine similarity to voltage traveling waveform to detect faults. However, methods described in [11]-[13] did not consider the effect of varying fault resistance.

Therefore, to address the limitations discussed in the literature, this article proposes a power cepstrum based differential protection technique. In this method, the current signal is transformed into the frequency domain, allowing high-frequency and low-frequency components to be processed separately before being reverted to their original form. Additionally, the approach involves taking the square and modulus of the transformed signal, which enhances sensitivity for low-voltage AC (LVAC), *i.e.*, up to 6 Ω fault resistance and ensures accurate and reliable fault detection, compared to traditional protection scheme. Furthermore, it helps in setting same fault detection threshold for both GCM and IM, therefore able to work in different configurations and improving overall system reliability.

2. Proposed Methodology

In this work, power cepstrum transform based current differential protection technique is proposed to detect fault in LVAC microgird. Cepstral analysis is a special case of homomorphic filtering. A homomorphic technique refers to a method that employs a nonlinear transformation to convert a signal into a different domain, where linear operations are easier to apply. After processing the signal in this transformed domain using linear applications, an inverse nonlinear transformation is applied to return the processed signal to its original domain. It is defined as the power spectrum of the log power spectrum [14], and mathematically represented as (1).

Complex spectrum = $C_C(\tau) = f^{-1}\{\log(f\{x(t)\})\}$ (1)

Where $f\{x(t)\} = A(f)e^{j\varphi(f)}$, where A represents the magnitude and φ represents phase of the spectrum

$\log\{f\{x(t)\}\} = \log A(f) + j\varphi(f)$ (2)

$C[n] = f^{-1}\{\log(|f\{x[n]\}|)\}$ (3)

$C_{px} = |f^{-1}\{\ln\{f(x(n))\}\}|^{2}$ where f, f^{-1} and C_{px} represents FFT, inverse FFT and power spectrum respectively (4)

The three-phase current is measured at both ends of the line, and the positive sequence current is derived using the Fortescue theorem [1]. The current signal x(t) is then converted into the frequency domain using the Fast Fourier Transform (FFT). Following this, the logarithm of the FFT-estimated current signal is calculated using (2). This logarithmic transformation simplifies the analysis by converting multiplicative relationships into additive ones, effectively separating high-frequency components from low-frequency components. In power systems, this separation is crucial for distinguishing fundamental components from fault-induced components in the frequency domain. Next, the transformed signal undergoes the Inverse Fast Fourier Transform (IFFT), using (3), yielding the cepstrum of the signal. The cepstrum is calculated at two ends of the protected line, and the power cepstrum is obtained by squaring the modulus value of the cepstrum and expressing it in decibels (dB) using (4). The proposed power cepstrum scheme is designed on the difference in power cepstrum obtained at both ends of the line utilizing positive sequence current, and for external fault and transient conditions, the current remains the same at two ends of the line. Therefore, the absence of a fault in the line means zero difference in the power cepstrum. However, if an internal fault occurs in the line, the difference will not be zero, and it must exceed a predefined threshold. However, the measurement error and time synchronization error may result in the maloperation of the scheme; therefore, a pre-defined threshold is provided for this scheme. The threshold is decided by considering the current transformer measurement error of 5% as per IEC standard 61869-2 [15] and by proving a time delay of 3 ms between line ends, along with numerous simulations performed in both GCM and IM. The threshold for the proposed detection scheme is selected as 0.56 dB. The test bed of LVAC microgrid for the power cepstrum scheme and its flow chart for the proposed technique is shown in Fig.1 and Fig. 2. respectively.

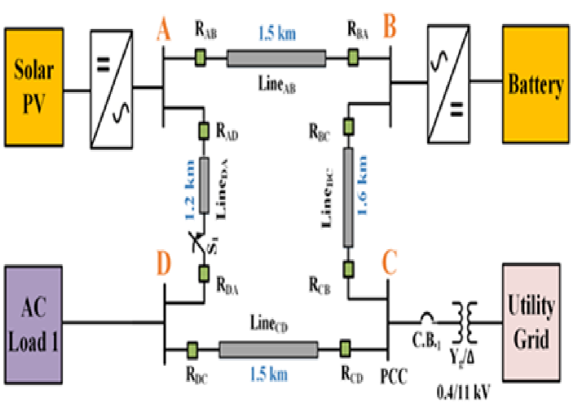
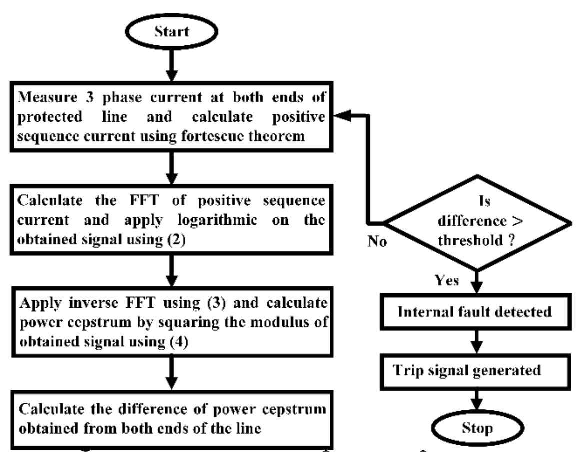


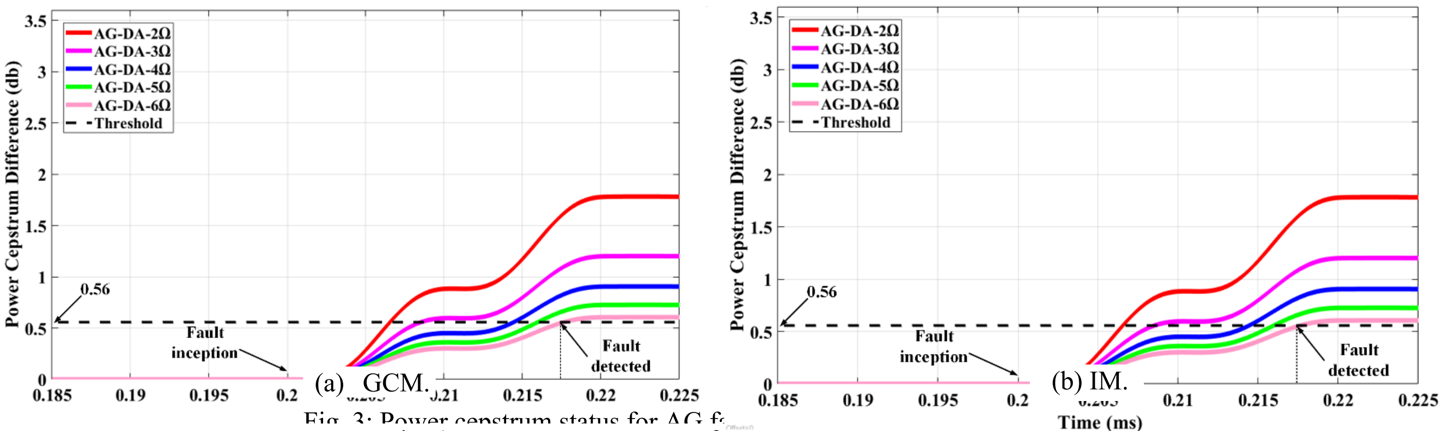
Fig. 1: Test bed for the power cepstrum scheme.



3. Result and Discussion

The proposed power cepstrum scheme is tested on 4 bus LVAC microgrid (ring configuration) in MATLAB, where Solar PV(100 kW), Battery Energy Storage System (140 kW), and AC load(200 kW) are connected at bus A, B and D respectively, and the grid is connected to bus C through a step-down transformer (11/0.4 kV). In GCM mode, both DGs are operated in

PQ mode, and the grid maintains the voltage and frequency of system, while in IM mode, BESS is operated in V-f mode and providing voltage and frequency, while Solar PV is operated in PQ mode [1]. The sampling frequency is chosen as 64 samples per cycle, considering accuracy and cost factors, and it is generally preferred by most protective relays [1].



(a) GCM. (b) IM.

Fig. 3: Power cepstrum status for AG f [illegible]

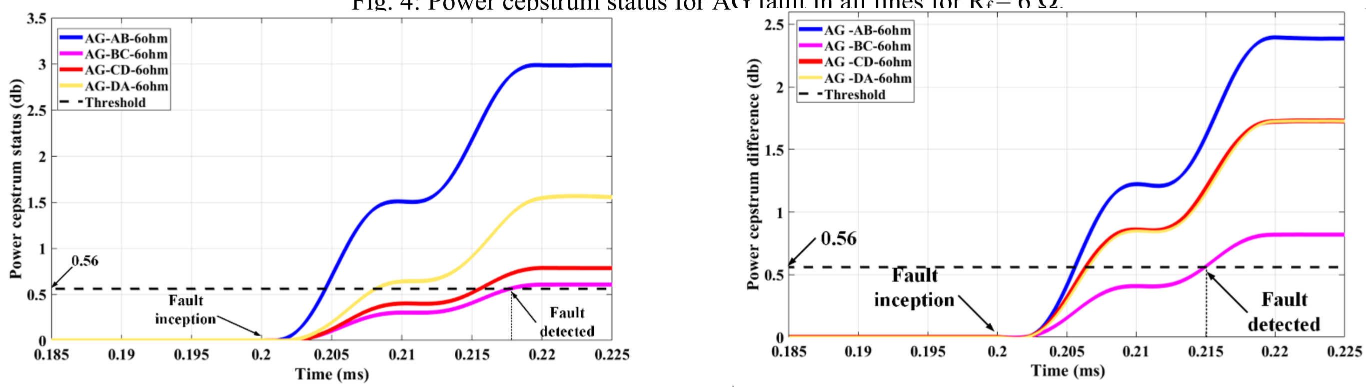


Fig. 4: Power cepstrum status for AG fault in all lines for $R_f = 6\ \Omega$.

(a) GCM. (b) IM.

To test the sensitivity of the scheme, a midpoint AG fault was simulated at t=0.2 s in line$_{DA}$, and the power cepstrum is shown for different fault resistance in both GCM and IM in Fig. 3 (a) and Fig. 3 (b), respectively. It is observed from the result that the proposed scheme can detect the fault in both GCM and IM. As fault resistance increases, the Power cepstrum magnitude decreases, which can be perceived from the result; however, the proposed power cepstrum scheme can detect the fault in both modes upto 6 Ω, which shows its high sensitivity. The cepstrum scheme doesn't mal-operate for the transient conditions such as switching of 3 phase load, outage of DG, islanding, and capacitive load, as it compares the difference of power cepstrum obtained from two ends of line, which is the same in the case of external fault and transient conditions, since the positive sequence current remains the same at the line ends, thus provides high accuracy. Most of the local measurement based protection scheme designed for AC microgrid fails for these conditions. However, in differential protection, measurement error and time synchronization error also result in maloperation of the scheme; therefore, the proposed scheme considers their effect in the threshold selection. To test the reliability of the scheme, it is tested in all the lines by creating a midpoint AG fault of $R_f = 6\ \Omega$ in all the lines for both GCM and IM, and results are depicted in Fig. 4 (a) and Fig. 4 (b), respectively. It is perceived from the result that the proposed scheme successfully detects the fault in all lines in both GCM and IM. The maximum fault detection time taken by the scheme is 17.7 ms, while it requires 5-6 ms for $R_f = 1\Omega$, which demonstrates fast operating capability of the power cepstrum scheme. It can also detect simultaneous faults and can succesfully detect fault in radial ntwork configuration. The cpstrum scheme is also verified for different fault locations by varying the line length from 10% to 90% of line length. The scheme can successfully detect both unsymmetrical and symmetrical faults in both modes; however, due to space constraints, these results are not shown in the article.

4. Conclusion

In this paper, a power cepstrum based differential protection scheme for 4 bus LVAC microgrid is presented for fault detection. The method involves analyzing the power cepstrum, obtained by applying the inverse FFT to the logarithm of the Fast Fourier Transform (FFT) of the positive sequence current. The proposed method is able to detect internal faults under both operating modes of LVAC microgrid. The scheme shows high sensitivity by detecting fault upto 6 ohm in GCM and IM of LVAC microgrid. It is independent of fault location and also provides high speed operation (17.7 ms). Moreover, the scheme is robust, showing no maloperation during system transients and remains insensitive to measurement and time synchronization errors. The efficacy of the proposed method was validated through MATLAB simulations, and the results confirm its accuracy and reliability under various operating conditions.

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