Enhancing Microgrid Protection: Wavelet Response Analysis for Islanded and Grid-Connected Modes

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***Abstract*—Microgrid systems have emerged as a viable solution to address the challenges associated with conventional power grids, such as reliability, resiliency, and sustainability. The protection of microgrids plays a crucial role in ensuring their safe and efficient operation. This paper presents a novel approach to enhance microgrid protection by applying wavelet response analysis for current measurements. The proposed technique utilizes a differential technique for fault identification in both islanded and grid-connected modes. The proposed enhanced microgrid protection scheme provides an innovative and robust solution for ensuring the reliable fault detection of microgrids in both islanded and grid-connected modes of operation. Simulation results highlight the application of wavelet response analysis offering a comprehensive and efficient approach to detect and mitigate power system abnormalities, contributing to microgrid systems' overall stability and resilience. The proposed technique can effectively identify abnormal conditions by implementing wavelet transform to analyze current waveforms through differential relaying techniques distinguishing between short circuit faults, external disturbances, and tap loads. Simulation studies were conducted on a representative 4-Bus benchmark microgrid model to evaluate the performance of the protection scheme. Results demonstrate the effectiveness and superiority of the proposed scheme in accurately identifying symmetrical and asymmetrical faults, effectively segregating tap loads, and contributing to the reliability and resilience of microgrid systems.**

***Index Terms*—Microgrid, distribution grid, protection, wavelet transform, differential relay, islanded, grid-connected.**

I. INTRODUCTION

Microgrid systems have gained significant attention as a promising alternative to traditional power grids, offering improved reliability, resiliency, and integration of renewable energy sources [1]. These self-contained energy systems can operate in both islanded mode, where they function independently from the main power grid, and grid-connected mode, where they are synchronized with the utility grid. However, with the increased complexity and integration of diverse energy resources such as solar photovoltaic (PV) systems, ensuring the protection of microgrids becomes a critical aspect of their efficient and reliable operation [2].

Microgrid protection involves the detection and isolation of faults and abnormal conditions within the system to prevent further damage and ensure an uninterrupted power supply. Traditionally, protection schemes for conventional distribution power grids have relied on time-domain analysis techniques, such as overcurrent and directional relays [3]. However, these conventional methods may not be sufficient to address the unique challenges and dynamic characteristics of microgrids [4]. In recent years, advanced signal processing and analysis techniques have shown great potential for enhancing the performance of microgrid protection systems. Wavelet transform, a powerful mathematical tool, has gained attention in various fields for its ability to capture both time and frequency information simultaneously [5]. By decomposing signals into different scales, wavelet transform enables the identification of transient events and abnormal patterns such as faults, that may be missed by traditional protection techniques.

This paper introduces an enhanced microgrid protection scheme utilizing wavelet response analysis for both islanded and grid-connected modes with differential protection techniques. The objective is to develop a comprehensive and efficient approach for detecting and mitigating faults and power quality disturbances in microgrids. By leveraging the wavelet transform, the proposed scheme enhances sensitivity and selectivity, thereby improving reliability and resiliency. The analysis focuses on current waveforms, extracting relevant features through wavelet responses at different scales to identify abnormal conditions, faults, and disturbances in the microgrid. Additionally, a thresholding technique ensures reliable and timely detection of power issues in both modes. Simulation studies on a detailed microgrid model confirm the superiority of the proposed scheme over conventional methods. These findings support the development of more effective protection strategies for future microgrid deployments, facilitating their widespread integration into power grid infrastructure.

This document is organized as follows; Section II shows the importance of microgrid protection, Section III identifies the problem in conventional protection schemes, Section IV shows the microgrid system used for the studies, and proposes the relay model developed, Section V presents thorough simulation studies and discussion of results, and Section VI closing remarks and conclusions proposing future work opportunities.

II. IMPORTANCE OF MICROGRID PROTECTION

Microgrid systems encompass distributed energy resources (DERs) like solar panels, wind turbines, energy storage systems, and control mechanisms, enabling operation as an islanded system or interconnected with the utility grid in grid-connected mode [6]. These systems offer numerous advantages, including reduced transmission losses, increased renewable energy utilization, improved energy efficiency, and improved resilience against grid disturbances [8].

While microgrid systems present a groundbreaking solution to enhance power grid dependability and resilience, effective protection mechanisms remain a crucial challenge. Traditional methods designed for centralized power grids may not suit the complexities of microgrids with high DER penetration. Addressing this research gap requires developing innovative, comprehensive, and efficient protection schemes adaptable to both islanded and grid-connected modes, capable of detecting, identifying, and isolating faults.

Moreover, the integration of renewable energy sources and evolving microgrid topologies with bi-directional power flow demand advanced protection solutions. The urgency to develop comprehensive and effective protection strategies arises from the need to cater to the specific requirements of islanded and grid-connected modes while utilizing current measurements for fault analysis.

III. PROTECTIONS, DRAWBACKS, AND OPPORTUNITIES

In the domain of distribution systems and microgrids, researchers have proposed two distinct protection schemes. The first is the non-adaptive protection scheme, known as the conventional protection system for distribution systems. In contrast, the second type is the adaptive protection scheme, which presents an innovative and intelligent approach to safeguarding distribution systems [7]. The limitations of conventional methods in detecting faults and disturbances effectively within microgrids drive the exploration of alternative approaches.

A. Traditional and Adaptive Protection

Conventional microgrid protection schemes typically rely on traditional techniques used in centralized power grids, including overcurrent relays, directional relays, reclosers, and fuses. Yet, these methods may not fully address the unique challenges of microgrids, such as bidirectional power flow and the presence of multiple distributed energy resources [3].

Adaptive protection schemes offer optimized settings tailored to specific operating conditions, resulting in reduced relay operating time. Real-time monitoring using Supervisory Control and Data Acquisition (SCADA) and integrated energy systems (IES) have been common, but they have encountered issues like time delays and measurement errors. Phasor Measurement Units (PMUs) offer advantages over SCADA, as they provide higher accuracy and time stamping for data with a higher sampling rate (48 samples/cycle) compared to conventional SCADA systems, which typically measure every 2 to 4 seconds [9]. PMUs use Global Positioning System (GPS) as a reference source, providing synchronized sampling accuracy of about 1 microsecond using a phase-locked oscillator [10]. The real-time phasor calculations obtained are referred to as Synchrophasors, as they are based on an absolute time reference [11].

B. Discrete Fourier Transform

The widely used algorithm for estimating phasors in PMUs is the Discrete Fourier Transform (DFT). PMUs can measure voltage and current waveforms, as well as fundamental frequency, Rate Of Change Of Frequencies (ROCOF), and Total Vector Error (TVE) [12]. Although DFT exhibits excellent harmonic suppression for stationary signals, it has limitations when the system's operating frequency deviates from the nominal 60Hz or 50Hz. In such cases, the integral period sampling condition may not be satisfied, leading to frequency aliasing and spectral leakage errors in parameter estimation. To address these drawbacks, the Recursive Discrete Fourier Transform (RDFT) algorithm has been introduced, offering benefits such as easy implementation, real-time stability, and accurate phase and frequency estimations [13].

RDFT can be used to detect, monitor, and analyze the presence of the third harmonic in the system [11]. However, it has been observed that RDFT's response may be biased, impacting the scheme's effectiveness, particularly when dealing with Inverter-Based Resources (IBr's) generating off-nominal frequencies or unbalanced faults contribution during unsymmetrical faults [14]. Measuring current/voltage phase angles with conventional recursive DFT is challenging, even with frequency deviations [15].

C. Wavelet Transform

The wavelet transform is a powerful mathematical tool enabling time-frequency analysis of signals, akin to Fourier transformations. While the Fourier transform extracts frequency details from the signal, it loses information about the frequency's precise location within the signal. In contrast, wavelets achieve the same convergence rates while providing efficient non-linear approximations and better adaptivity to unknown smoothness. Essential properties of wavelets include their ability to filter, ”disbalance,” and ”whiten” signals, as well as to detect self-similarity within a signal [16].

Distinguished from the smooth and predictable sine waves forming the basis of Fourier analysis, wavelets exhibit irregularity and asymmetry. They serve as alternatives rather than replacements for standard Fourier methods [17]. In wavelet analysis, signals are broken down into shifted and scaled versions of the original (or mother) wavelet, similar to how Fourier analysis decomposes signals of different frequencies [17]. However, it's important to acknowledge its limitations, especially when dealing with signals that comprise a linear combination of harmonics, which is a common occurrence in power systems. In such cases, some caution is warranted in the application of wavelets.

Wavelets are particularly well-suited for capturing transient events and abrupt changes in signals. Still, their effectiveness in analyzing signals with harmonic components may be limited. Harmonic-rich signals may lead to wavelet coefficients that are not as informative or well-localized in the time-frequency domain, potentially making it challenging to distinguish specific fault-related information events from harmonic noise. To address this concern, a careful selection of the decomposing wavelet must be done. Since the choice of wavelet directly influences the dependence structure within the transformed time series. [16]. For protecting microgrids, considering hybrid approaches that combine wavelet analysis with other techniques like Fourier analysis can prove to be highly advantageous. This combination allows for more effective handling of signals that contain both transient and harmonic components. These approaches can provide a more comprehensive and adaptable solution for detecting faults in special cases.

The Discrete Wavelet Transform (DWT) of signal x involves passing it through filters, such as a low-pass filter with impulse response g resulting in a convolution of the two (1). Simultaneously, the signal is decomposed with a high-pass filter. The outputs generate detail coefficients (from the high-pass filter) and approximation coefficients (from the low-pass filter) as seen in Fig. 1. It is important that the two filters are related to each other known as a quadrature mirror filter.

$$y[n] = (x * g)[n] = \sum_{k=-\infty}^{\infty} x[k]g[n-k] \tag{1}$$

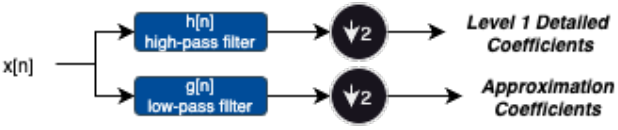


Fig. 1: One-level filter bank analysis

Nyquist's rule allows discarding half of the samples due to the removal of half the frequencies in the signal [18]. Subsampling and further processing with new low-pass (2) and high-pass (3) filters create a binary tree filter bank, enhancing frequency resolution and approximation coefficients.

$$y_{\text{low}}[n] = \sum_{k=-\infty}^{\infty} x[k]g[2n-k] \quad (2)$$

$$y_{\text{high}}[n] = \sum_{k=-\infty}^{\infty} x[k]h[2n-k] \quad (3)$$

DWT is widely used in image processing, signal analysis, and pattern recognition. It has been used in the past to enhance earthquake detection. [19]. In power systems, it has shown promise for voltage and current waveform analysis, transient event identification, and accurate disturbance detection. Due to its ability to capture time and frequency information simultaneously, DWT is well-suited for analyzing non-stationary signals in microgrids.

Prior studies have utilized wavelet transform in power systems for fault detection, localization, classification, power quality monitoring, and analysis. This research aims to enhance microgrid protection through wavelet response analysis, building on previous studies and contributing to the field's advancement.

IV. MODEL AND PROTECTION SCHEME

The study aims to address this research gap by introducing an enhanced protection scheme that improves fault detection accuracy and line tripping. By leveraging wavelets for response analysis, the proposed scheme aims to achieve reliable fault detection, optimized identification of tap loads, and effective handling of asymmetrical faults in microgrids using differential techniques [20].

A. Microgrid Model

The microgrid model employed in this study is a 4-Bus system designed in network topology seen in Fig.2 representing a small village. Bus 3 and Bus 4 are dedicated solely to different types of loads, while Bus 1, and Bus 2 incorporate both distributed energy resources (DERs) and independent loads. In this setup, each inverter shares loads, contributing to load balancing within the microgrid. Additionally, a Point of Common Coupling (PCC) connection is established at Bus 3 to facilitate switching between grid-connected and islanded modes. This configuration enables the microgrid to operate autonomously in islanded mode and seamlessly synchronize with the utility grid in grid-connected mode when needed, providing a versatile benchmark testbed for the proposed protection scheme. All disturbances, faults, and tap loads are tested in Line 1. The inverter control system in the model follows the voltage source converter (VSC) type, which includes droop control, fault limiters, voltage restoration, and frequency restoration [21], [22]. The most important values for the microgrid parameters are listed below on Tab.I.

B. Relay Model

This paper introduces a novel relay model based on differential protection with wavelet analysis for detecting short circuit faults in microgrids operating in both grid-connected and islanded modes. The model utilizes discrete wavelet transformations (DWT) for analyzing discrete data sets, akin to the fast Fourier transformation (FFT) applied to discrete measurements [23]. The choice of wavelet is critical for optimal microgrid protection [17], ensuring timely fault tripping to prevent grid and equipment damage.

The relay model employed in this research implements the differential protection technique enhanced by wavelet analysis. The focus of this technique is to ensure efficient fault detection and localization within the microgrid. The relay utilizes three-phase current measurements at both ends of the protection zone, enabling precise fault identification and analysis. The incorporation of wavelet analysis further enhances the sensitivity and selectivity of the protection scheme, enabling reliable fault detection even under dynamic and non-stationary conditions. By combining the differential relay technique with wavelet analysis, the proposed protection system aims to ensure the secure and reliable operation of the microgrid, thereby contributing to its overall stability and resilience.

TABLE I: 4-Bus Microgrid Parameters

Main Components	Parameter Specification
Grid Feeder (MV) **Distribution Line (MV)**	$4.1kV$, $50Hz$
PCC (LV) & Load (LV)	$240V$, $50Hz$
Distributive Generation (LV)	$240V/120V$, $50Hz$
DC Link **Distributive Energy Resource** **Grid Forming (LV)**	$750V$ $30kW, 240V/120V$ VSC, $50Hz$
Inverter Switching Frequency	$5000Hz$
Inverter LCL Filter	$L = 0.0073H$ $C = 0.00027631F$ $L = 0.000485H$
Transformers (Y-Y) (MV/LV)	$30kVA$, $4.1kV/240V$, $50Hz$
Distribution Line (L) **Short Type Line**	$4.1kV$, $500m$ $R = 0.0805 Ohm/km$ $X = 0.0950 Ohm/km$
Protection Type	$Wavelet\ Differential$

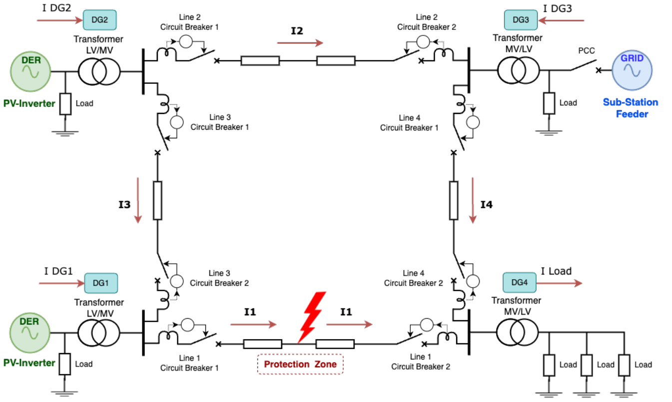


Fig. 2: 4-Bus Microgrid Model

By utilizing wavelet analysis, transient events and fault signatures can be accurately captured, enabling precise fault detection and localization. The adoption of Daubechies wavelets is particularly effective in detecting sudden transitions [24], making it a suitable choice for the proposed relay model leading to improved reliability.

1) Wavelet Daubechies: The Daubechies wavelet family comprises different wavelets with distinct properties, such as the number of vanishing moments. The choice of a specific Daubechies wavelet depends on signal characteristics and study objectives. For three-phase current wave signals, Daubechies wavelets are generally well-suited due to their ability to analyze signals with sharp transitions and discontinuities, making them ideal for periodic sine wave signals [16].

Three-phase current waveforms in power systems exhibit continuous and periodic behavior, and Daubechies wavelets, known for their compact support and orthogonality properties, efficiently represent signals with abrupt changes and sudden transitions, commonly found in sine three-phase current waveforms [23]. These wavelets strike an optimal balance between time and frequency localization, accurately representing harmonic components and capturing transient events [16], making them valuable for detecting disturbances in current waveforms, an essential aspect of grid protection.

After careful analysis, the most suitable wavelet for the study is identified as the Daubechies 3 (db3) wavelet. Db3 offers an excellent trade-off between simplicity and effectiveness in representing signal features. With three vanishing moments, it is computationally efficient and requires less memory compared to higher-order wavelet. Db3 can effectively capture abrupt changes and discontinuities in signals, making it a practical choice for real-time implementation. Its moderate time and frequency localization properties enable the detection and representation of transient fault events, making it suitable for fault detection tasks. The high-pass and low-pass decomposed coefficients are listed in Tab.II [25].

TABLE II: Filter Decomposition Daubechies 3 (db3)

Filter Type	**Decomposition Coefficients**
High-Pass	$[-0.3327, 0.8069, -0.4599, -0.1350, 0.0854, 0.0352]$
Low-Pass	$[0.0352, -0.0854, -0.1350, 0.4599, 0.8069, 0.3327]$

2) Differential Wavelet Relay: The differential relay technique operates by comparing currents I1 and I2 at both ends of the protected line (or protection zone) for accurate fault detection and localization, as illustrated in Fig. 3. Through the utilization of DWT, this technique aims to enhance sensitivity and precision in fault detection by analyzing high-frequency components in the current signals. Our relay model adopts the wavelet db3, striking a favorable balance between computational efficiency and signal representation accuracy. This makes db3 a practical and effective choice for fault detection in the proposed differential technique.

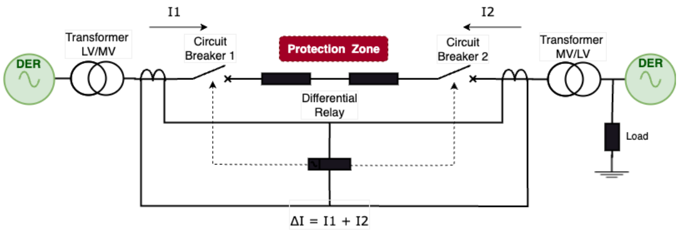


Fig. 3: Microgrid Differential Relay Technique

C. Relay Protection Scheme and Operation

The acquired three-phase current signals undergo Discrete Wavelet Transform (DWT), decomposing them into approximation coefficients and detail coefficients. The relay technique focuses on analyzing the detail coefficients obtained from the db3 wavelet decomposition. These coefficients contain high-frequency variations and carry crucial information about faults and transient events in the current signals. To enhance fault-related information while reducing noise, denoising techniques are employed. The thresholding technique retains significant fault detail coefficients while discarding irrelevant components, reducing false tripping and alarms.

In the differential relay scheme, the denoised detail coefficients are compared between both ends of the protected line to detect variations in the current signal. Significant events or faults are identified by setting a threshold value of $|0.6|$ for the level-1 detail coefficients obtained from the db3 wavelet decomposition. If both ends of the protection zone detect abrupt variations above this threshold, the relay trips the line, indicating a fault occurrence. The choice of the db3 wavelet aligns well with its capability to capture transient and fault events, making it suitable for microgrid protection.

The proposed relay technique's effectiveness is demonstrated through extensive simulations, validating its ability to detect faults accurately. Fig. 4 shows the protection block diagram illustrating the proposed fault detection principle. The simulation section validates the proposed relay technique and proves its efficacy towards short circuit faults.

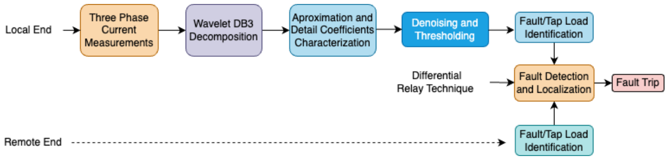
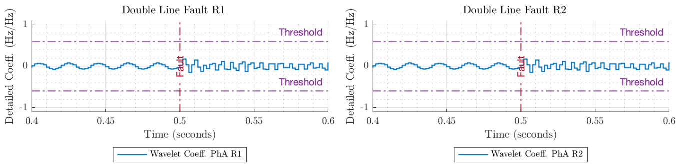


Fig. 4: Proposed Fault Detection Principle

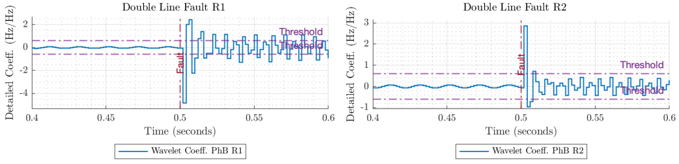
V. SIMULATION RESULTS

All simulations and modeling were done in Matlab/Simulink. By combining the Wavelet Daubechies 3 (db3) and the differential relay technique, our proposed approach significantly enhances fault detection and localization capabilities. The db3 wavelet effectively captures high-frequency variations and transient events, while the differential relay technique focuses on the detail coefficients, ensuring sensitivity to fault occurrences. This synergy enables precise and reliable fault detection, even in complex power system scenarios, leading to faster fault clearance and improved power system protection. As a result, our model accurately identifies faults and distinguishes them from tap loads, preventing wrongful line tripping in both grid-connected and islanded modes of operation, effectively meeting the protection requirements.

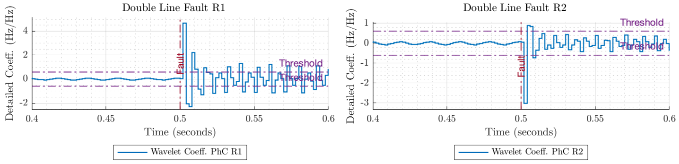
To evaluate the performance of our enhanced protection scheme, we conducted simulations on the microgrid model under various fault scenarios and operational conditions, including grid-connected and islanded modes. The simulations covered various types of faults, such as phase-to-phase (LL), double-phase-to-ground (LLG), three-phase (LLL), single-phase-to-ground (LG), and Tap Load. The proposed threshold value was used to analyze the magnitude of detail coefficients and identify fault events in an Islanded Grid and Grid Connected, as shown in Fig.5 - Fig.10. The results demonstrate that the proposed approach effectively detects both symmetrical and asymmetrical short-circuit faults, as the db3 wavelet adeptly captures high-frequency variations in the current signals, enabling precise fault identification on a per-phase basis.



(a) L-L R1 Coefficients Phase A (b) L-L R2 Coefficients Phase A

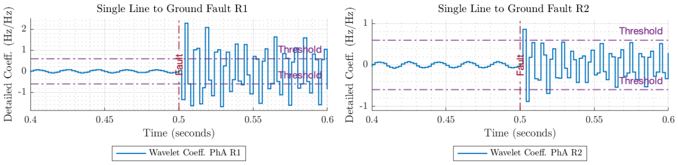


(c) L-L R1 Coefficients Phase B (d) L-L R2 Coefficients Phase B

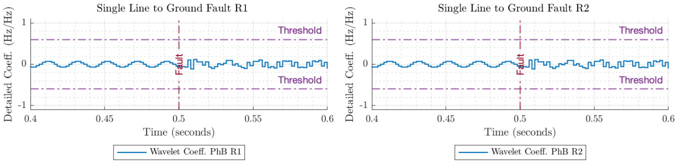


(e) L-L R1 Coefficients Phase C (f) L-L R2 Coefficients Phase C

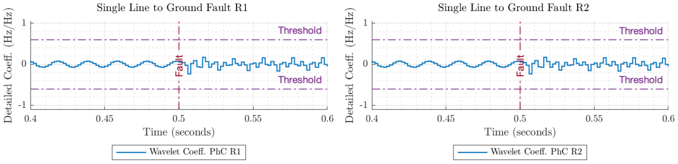
Fig. 5: L-L Wavelet Detailed Coefficients - Islanded



(a) L-G R1 Coefficients Phase A (b) L-G R2 Coefficients Phase A

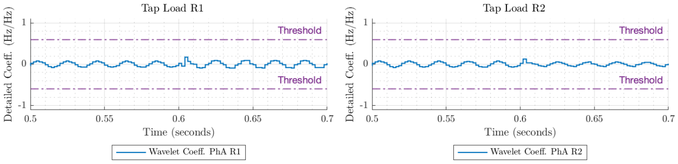


(c) L-G R1 Coefficients Phase B (d) L-G R2 Coefficients Phase B

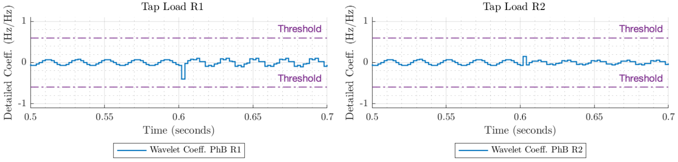


(e) L-G R1 Coefficients Phase C (f) L-G R2 Coefficients Phase C

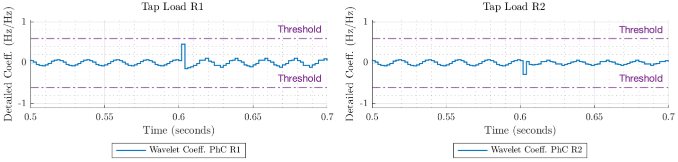
Fig. 6: L-G Wavelet Detailed Coefficients - Islanded



(a) Tap-Load R1 Coeff. Phase A (b) Tap-Load R2 Coeff. Phase A

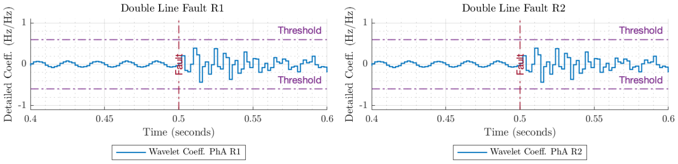


(c) Tap-Load R1 Coeff. Phase B (d) Tap-Load R2 Coeff. Phase B

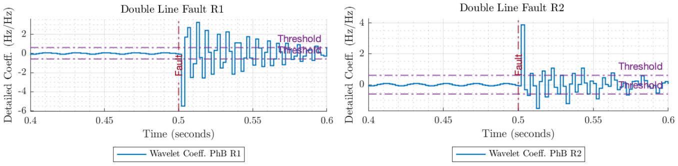


(e) Tap-Load R1 Coeff. Phase C (f) Tap-Load R2 Coeff. Phase C

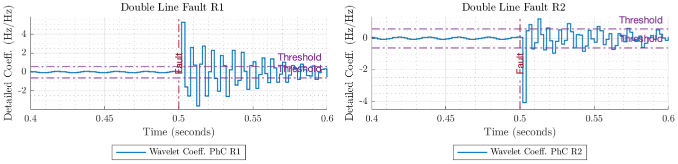
Fig. 7: Tap Wavelet Detailed Coefficients - Islanded



(a) L-L R1 Coefficients Phase A (b) L-L R2 Coefficients Phase A

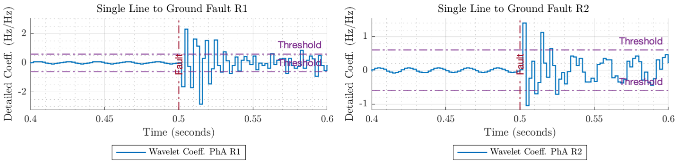


(c) L-L R1 Coefficients Phase B (d) L-L R2 Coefficients Phase B

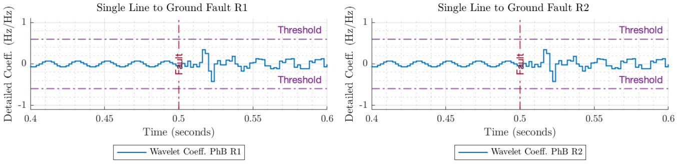


(e) L-L R1 Coefficients Phase C (f) L-L R2 Coefficients Phase C

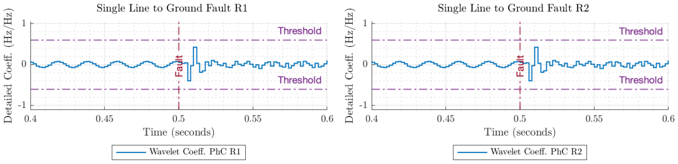
Fig. 8: L-L Wavelet Detailed Coefficients - Grid-Connected



(a) L-G R1 Coefficients Phase A (b) L-G R2 Coefficients Phase A



(c) L-G R1 Coefficients Phase B (d) L-G R2 Coefficients Phase B



(e) L-G R1 Coefficients Phase C (f) L-G R2 Coefficients Phase C

Fig. 9: L-G Wavelet Detailed Coefficients - Grid-Connected

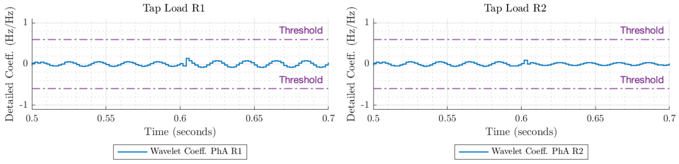
Our simulations confirm the superior performance of the enhanced protection scheme, accurately detecting and localizing faults within the microgrid. Furthermore, the relay's response time and stability during fault events were evaluated, showcasing its quick and accurate fault detection capabilities. The threshold value can be adjusted to suit specific power system characteristics and desired fault detection sensitivity, offering flexibility in the protection scheme. Tab.III and Tab.IV show the detailed coefficients in Islanded and Grid Connected.

VI. CONCLUSION

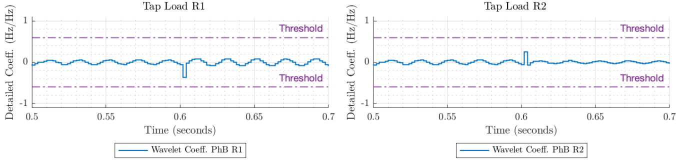
To fill the research gap, we introduced an innovative microgrid protection approach with Wavelet response analysis and Daubechies Wavelets. The proposed relay model, integrating wavelet analysis and the efficacy of differential relay, has demonstrated superior fault detection performance for both symmetrical and asymmetrical short circuit faults in islanded and grid-connected modes.

Simulation results have highlighted the remarkable accuracy, efficiency, and fault detection capabilities of the proposed technique, surpassing those of traditional protection methods. The Wavelet Daubechies 3 (db3) combined with the differential technique proves to be a promising tool for microgrid protection, providing improved fault detection while accurately segregating tap loads and reducing false tripping occurrences. In future work, we will present a compelling comparison of the sensitivity and selectivity of our technique compared to conventional methods of fault detection. The insights from this study contribute to better protection schemes for microgrids, ensuring stable and secure operation during faults.

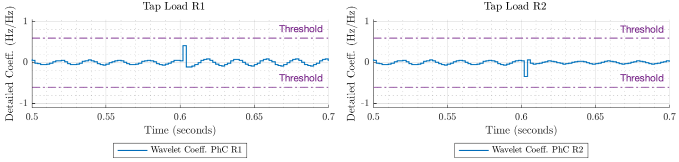
The choice of the db3 wavelet, carefully selected for its balanced characteristics encompassing computational efficiency and the ability to capture abrupt changes and transient events, has further reinforced the efficacy of the proposed relay model in enhancing microgrid protection and overcoming the limitations of conventional methods. The thresholding coefficient has proven effective in detecting short-circuit faults, regardless of their symmetry, leading to rapid and reliable fault identification, thereby ensuring a robust detection scheme. The proposed approach is powerful for fault detection in microgrid systems.



(a) Tap-Load R1 Coeff. Phase A (b) Tap-Load R2 Coeff. Phase A



(c) Tap-Load R1 Coeff. Phase B (d) Tap-Load R2 Coeff. Phase B



(e) Tap-Load R1 Coeff. Phase C (f) Tap-Load R2 Coeff. Phase C

Fig. 10: Tap Wavelet Detailed Coefficients - Grid-Connected

TABLE III: Islanded Mode Wavelet Detailed Coefficients

Phase Response	**Grid Disturbance Type (Hz/Hz)**				
	S-L-G	***L-L***	***L-L-G***	***L-L-L***	***Tap***
Phase A L.	2.2818	0.1734	0.1655	1.2637	0.1668
Phase B L.	0.1109	2.4200	3.2374	2.6886	0.1053
Phase C L.	0.1693	4.6706	5.1088	5.1204	0.4549
Phase A R.	0.8607	0.1726	0.1648	0.6602	0.1263
Phase B R.	0.1104	2.8558	2.6141	2.6096	0.1546
Phase C R.	0.1687	0.8993	1.2238	1.2046	0.0801

(a) Positive Detailed Coefficients

Phase Response	**Grid Disturbance Type (Hz/Hz)**				
	S-L-G	***L-L***	***L-L-G***	***L-L-L***	***Tap***
Phase A L.	−1.695	−0.152	−0.208	−1.090	−0.091
Phase B L.	−0.116	−4.831	−4.398	−4.385	−0.405
Phase C L.	−0.239	−2.294	−2.745	−2.699	−0.146
Phase A R.	−0.879	−0.152	−0.207	−0.550	−0.078
Phase B R.	−0.116	−0.935	−1.103	−0.917	−0.073
Phase C R.	−0.238	−3.015	−3.255	−3.257	−0.281

(b) Negative Detailed Coefficients

TABLE IV: Grid-Connected Mode Wavelet Detailed Coefficients

Phase Response	**Grid Disturbance Type (Hz/Hz)**				
	S-L-G	***L-L***	***L-L-G***	***L-L-L***	***Tap***
Phase A L.	2.2692	0.1681	0.1621	1.2705	0.1664
Phase B L.	0.1066	2.3667	3.1869	2.5953	0.1033
Phase C L.	0.1653	4.6611	5.0470	5.0766	0.4535
Phase A R.	0.8119	0.1673	0.1614	0.6026	0.1222
Phase B R.	0.1064	2.8476	2.6420	2.6316	0.1569
Phase C R.	0.1648	0.8602	1.1636	1.1675	0.0789

(a) Positive Detailed Coefficients

Phase Response	**Grid Disturbance Type (Hz/Hz)**				
	S-L-G	***L-L***	***L-L-G***	***L-L-L***	***Tap***
Phase A L.	−1.623	−0.139	−0.228	−1.238	−0.099
Phase B L.	−0.107	−4.817	−4.438	−4.411	−0.411
Phase C L.	−0.234	−2.250	−2.675	−2.696	−0.153
Phase A R.	−0.868	−0.139	−0.227	−0.519	−0.078
Phase B R.	−0.106	−0.914	−1.076	−0.872	−0.074
Phase C R.	−0.233	−3.003	−3.218	−3.224	−0.278

(b) Negative Detailed Coefficients

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