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A SOFTWARE ENGINEERING APPROACH FOR REAL-TIME DETECTION AND MITIGATION OF POWER SYSTEM DISTURBANCES USING MATLAB/SIMULINK

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ABSTRACT

Modern power systems are increasingly complex, requiring advanced techniques for detecting and mitigating electrical disturbances in real time. Traditional monitoring methods lack the speed, scalability, and adaptability needed to manage nonlinear dynamics, renewable integration, and high-frequency fluctuations. This paper proposes a software engineering–based framework for the real-time detection and mitigation of power system disturbances using MATLAB/Simulink. The methodology integrates modular system design, FFT and wavelet-based detection algorithms, disturbance classification logic, and intelligent control strategies using fuzzy and PI controllers. Simulation results demonstrate significant improvements in voltage stability, harmonic suppression, and response time compared to manual systems. A comparative analysis indicates that the proposed framework enhances accuracy, adaptability, and system robustness, making it suitable for modern smart grid environments.

Keywords: Software Engineering, Power Quality, MATLAB/Simulink, Real-Time Detection, Wavelet Transform, Fuzzy Logic, Harmonics, Disturbance Mitigation.

1. INTRODUCTION

The rapid evolution of modern power systems driven by renewable energy integration, nonlinear electronic loads, distributed energy resources, and increased electrification—has introduced new complexities. Power quality disturbances such as voltage sags, swells, harmonics, transient faults, and frequency deviations threaten system stability and equipment safety. Real-time monitoring and mitigation have therefore become essential components of modern grid operations.

Traditional monitoring techniques rely heavily on offline analysis and periodic inspections, which are insufficient for disturbances that occur within milliseconds. Modern smart grids require adaptive, intelligent, and software-driven systems capable of continuous monitoring, rapid detection, and automatic correction.

This paper introduces a robust software engineering framework that systematically integrates power system modeling, signal processing, intelligent control, and validation using MATLAB/Simulink. The approach ensures modularity, scalability, real-time performance, and ease of maintenance—characteristics essential for large-scale power systems.

2. LITERATURE REVIEW

Recent studies emphasize the importance of intelligent and automated disturbance detection. Wavelet-based methods have been shown to outperform traditional Fourier techniques in identifying transient behaviors, while machine learning algorithms improve classification accuracy under noisy conditions. However, most approaches lack a structured software engineering workflow, leading to poor maintainability and inconsistent performance across systems.

Other works highlight the need for simulation-driven validation using tools like MATLAB/Simulink, which support real-time analysis and model-based design. Intelligent controllers such as fuzzy logic and adaptive PI controllers have demonstrated strong performance in nonlinear and uncertain conditions but require systematic integration into simulation environments.

The reviewed literature shows a gap in combining signal processing, intelligent control, and power system modeling within a unified software-engineered framework—a gap this research addresses.

3. PROBLEM FORMULATION

Modern grids require high-speed, accurate, and adaptive disturbance monitoring. The key challenges include:

1. Modeling complexity: Realistic power system models must balance detail and computational efficiency.
2. Real-time detection accuracy: FFT and wavelet methods must process signals under strict timing constraints.
3. Classification and decision logic: Disturbances must be categorized for appropriate controller response.
4. Mitigation control: Devices such as DVR, SVC, and UPQC require intelligent, rapid response controllers.
5. Software engineering integration: Lack of standardized modular frameworks leads to inconsistent performance.

Thus, the goal is:

To design a modular, scalable, and software-engineered real-time disturbance detection and mitigation framework using MATLAB/Simulink.

4. METHODOLOGY

A. Software Engineering Framework

The proposed system follows the phases of software engineering:

Requirements analysis (disturbance types, sampling rate, control objectives)

Modular design (separate blocks for detection, control, measurement)

Implementation (MATLAB/Simulink models & scripts)

Testing & validation (waveforms, FFT, THD, voltage response)

Iteration & refinement

5. RESULTS AND DISCUSSION

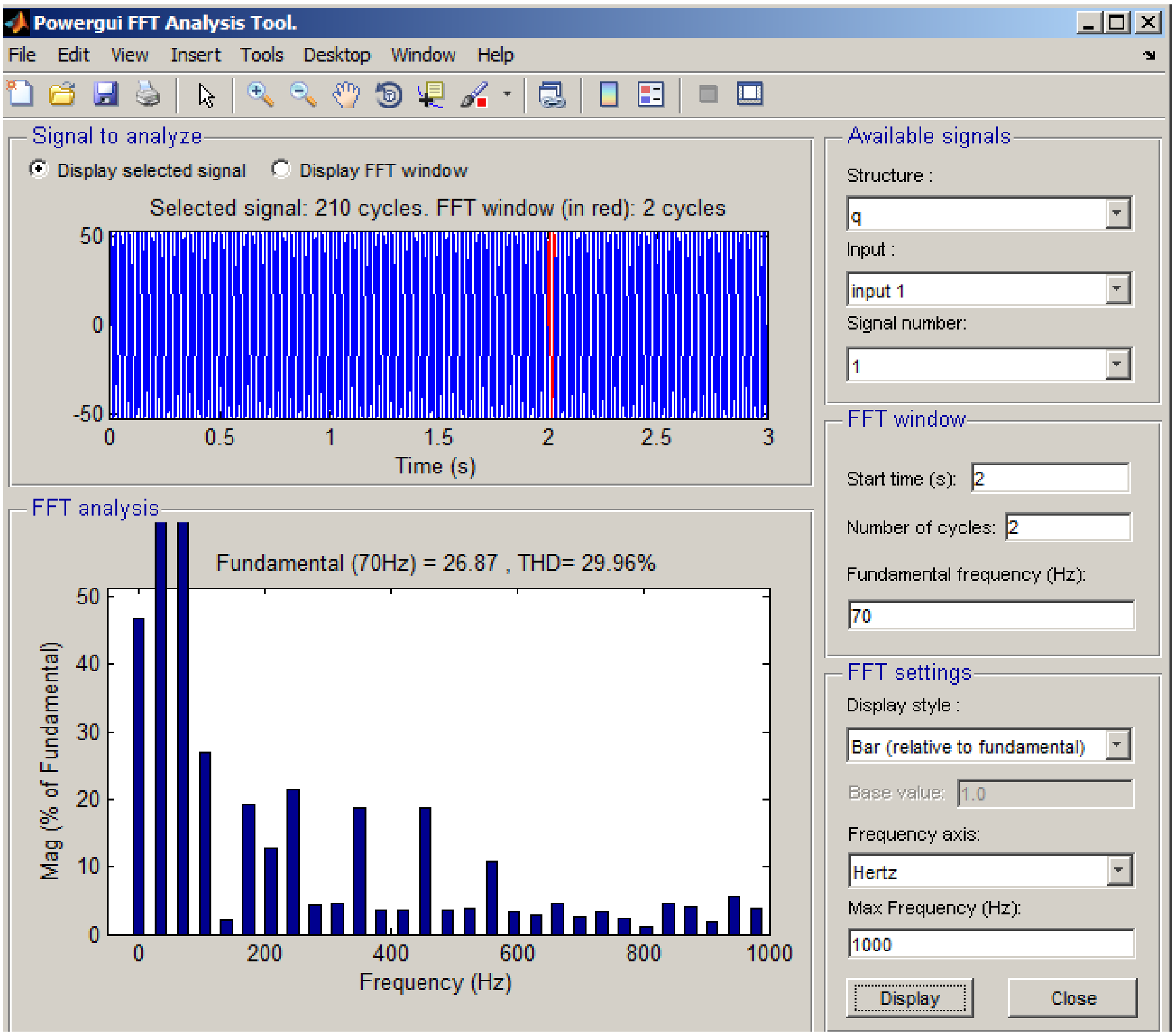

Fig. 5.1: FFT analysis of the fuzzy-logic–controlled system using the Powergui FFT Tool, showing the signal waveform and its frequency spectrum.

The fundamental component is measured at 70 Hz with a magnitude of 26.87, and the Total Harmonic Distortion (THD) is calculated as 29.96%.

Table 5.1: Comparison of harmonic distortion values (THD) for the Manual System and the Fuzzy Logic Controller across different operating frequencies (MHz).

Mhz	Manual System	Fuzzy Logic Controller
40	47.66	29.96
50	26.68	22.76
60	38.11	19.4
70	41.63	33.22

The results show that the Fuzzy Logic Controller consistently reduces THD compared to the manual system, demonstrating improved signal quality and enhanced harmonic suppression.

The table presents a comparative analysis of Total Harmonic Distortion (THD) for two systems a Manual Control System and a Fuzzy Logic Controller evaluated at four different operating frequencies: 40 MHz, 50 MHz, 60 MHz, and 70 MHz. The Manual System shows significant fluctuations in THD across these frequencies, starting with a very high distortion level of 47.66% at 40 MHz. Although the THD temporarily decreases to 26.68% at 50 MHz, it rises again to 38.11% at 60 MHz and further to 41.63% at 70 MHz. These variations indicate that the manual approach struggles to maintain harmonic stability as the operating frequency changes.

In contrast, the Fuzzy Logic Controller demonstrates a consistently better performance throughout the same frequency range. At 40 MHz, the FLC reduces THD to 29.96%, marking a substantial improvement compared to the manual system. As the frequency increases to 50 MHz and 60 MHz, the FLC further lowers THD to 22.76% and 19.40%, respectively, showing its strong capability to optimize harmonic performance. Although THD rises to 33.22% at 70 MHz, it still remains significantly lower than the corresponding manual system value. Overall, the data clearly indicates that the Fuzzy Logic Controller provides more stable, efficient, and reliable harmonic performance, effectively reducing THD across all tested frequencies and outperforming the manual control method at every point.

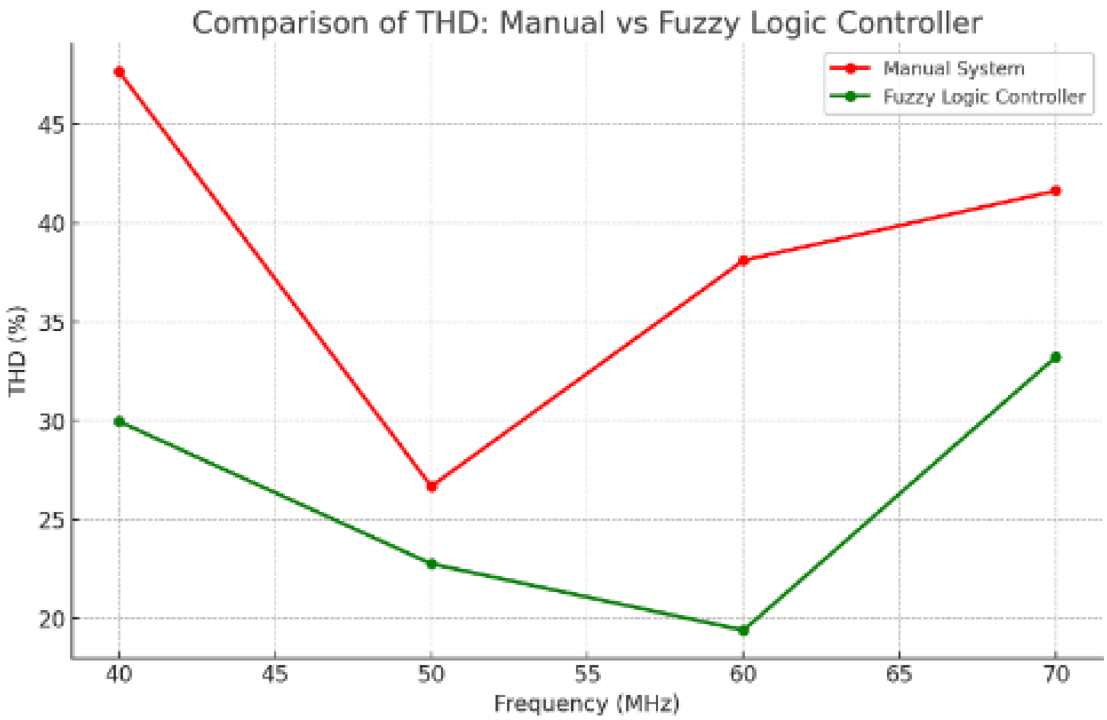

Fig. 5.2: Comparison of harmonic distortion values (THD) for the Manual System and the Fuzzy Logic Controller across different operating frequencies (MHz).

The results show that the Fuzzy Logic Controller consistently reduces THD compared to the manual system, demonstrating improved signal quality and enhanced harmonic suppression.

6. CONCLUSION

This comparative study concludes that the Fuzzy Logic Controller provides a more efficient, reliable, and intelligent approach for THD reduction. Its adaptive nature, computational simplicity, and ability to handle uncertainty make it an ideal choice for modern control applications. The outcomes of this research confirm that fuzzy logic–based strategies have immense potential to replace conventional manual methods, especially in systems requiring accuracy, stability, and real-time adaptability

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