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Development of HMI Display using Active Harmonic Filter for Power Electronics

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Abstract: *This paper presents a low-cost Human Machine Interface (HMI) based system integrated with an Active Harmonic Filter (AHF) for real-time power quality monitoring in industrial applications. Due to the increasing use of non-linear loads in industries, issues such as harmonic distortion and poor power factor have become common and require effective monitoring and mitigation. Commercial power quality analyzers and AHF units are costly and difficult for small- and medium-scale industries to adopt. To address this gap, the proposed system utilizes an STM32 microcontroller for real-time measurement, FFT-based harmonic analysis, and AHF control. A Nextion touch-screen HMI is used to display key electrical parameters such as voltage, current, total harmonic distortion (THD), and power factor. The prototype was developed using STM32CubeIDE, Keil uVision, and Nextion Editor, resulting in a significantly low-cost solution compared to traditional systems. Experimental results show a reduction in THD from 25.8% to below 5% and improvement in power factor to above 0.95. The total cost of the system is approximately ₹8,000, achieving around 68% cost savings over commercial alternatives. The developed system provides a practical and economical solution for industrial power quality monitoring without compromising performance and accuracy.*

Keywords: Human Machine Interface (HMI), Active Harmonic Filter (AHF), STM32, Power Quality Monitoring, Harmonic Reduction, Real-Time System, Low-Cost Automation

I. INTRODUCTION

In modern industrial environments, the increasing use of power-electronic equipment such as rectifiers, UPS systems, and variable-frequency drives has resulted in significant power quality issues. These non-linear loads introduce harmonics into the electrical network, leading to voltage distortion, power losses, overheating of equipment, and reduced operational efficiency. To maintain reliable power system performance and protect industrial machinery, real-time monitoring of power quality parameters such as voltage, current, power factor, and Total Harmonic Distortion (THD) has become essential.

Active Harmonic Filters (AHFs) are widely used to mitigate harmonic distortion and improve power factor in industrial facilities. However, existing harmonic monitoring and control systems are often expensive and not easily accessible to small and medium-scale industries. Additionally, many commercial systems lack user-friendly visualization platforms, making it difficult for operators to observe and interpret power quality data in real time.

This project focuses on the development of a low-cost Human-Machine Interface (HMI) display system for real-time monitoring of electrical parameters in an Active Harmonic Filter setup. The HMI interface is designed using a Nextion touch screen and programmed to display key values such as voltage, current, THD, and power factor in an intuitive graphical format. The interface enhances accessibility by providing a simple, interactive, and reliable user-display system that can be used for power quality monitoring applications.

This work is carried out as part of a sponsored project by TDK EPCOS India Pvt. Ltd., where the complete AHF hardware system is developed at industry level, while our contribution focuses on the design and implementation of the

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HMI visualization layer. The developed HMI screen enables real-time parameter display and forms a crucial component of an affordable and efficient power quality improvement system intended for industrial and educational applications.

II. LITERATURE REVIEW

The design and implementation of the surge counter testing kit is based on an extensive review of existing research in high-voltage generation, capacitor charging techniques, and impulse waveform generation.

Singh et al. [1] conducted an extensive survey on harmonic distortion sources in industrial environments such as variable-frequency drives (VFDs), switched-mode power supplies (SMPS), and induction motor drives. Their experimental results showed that non-linear loads significantly increase Total Harmonic Distortion (THD), often exceeding IEEE-519 standards. The study highlighted the urgent need for continuous monitoring and automated mitigation to avoid equipment overheating, voltage distortions, and production losses.

Akagi [2] introduced the p-q instantaneous power theory and d-q transformation, a landmark development for Active Harmonic Filters. The work mathematically modeled real-time harmonic extraction and compensation, enabling dynamic cancellation of reactive power and current harmonics. The theory formed the basis for modern control algorithms such as PI/PWM-based AHF controllers.

Patel and Sharma [3] evaluated ARM Cortex-M microcontrollers for power quality monitoring, implementing real-time FFT and adaptive sampling. Their work demonstrated processing accuracy up to the 50th harmonic with low computational latency. They also established guidelines for ADC precision, sampling frequency, and memory management in embedded systems.

Chen et al. [4] analyzed usability aspects of touch-screen HMI systems in industrial power monitoring. They performed operator-efficiency studies, showing that intuitive layouts and real-time visualization reduce operator response time and human error. The study emphasized GUI-based alarms, color-coded harmonic bars, and data logging features.

Kumar and Verma [5] introduced a cost-optimization framework using off-the-shelf microcontrollers, open-source software, and modular electronics. Their system achieved cost savings of more than 35% compared to traditional PLC-based setups, without compromising reliability. They validated their solution through industrial trials.

Wang and Lee [6] evaluated different FFT libraries and windowing techniques on embedded platforms. They compared Hanning, Hamming, and Blackman windows for noise reduction and analyzed error-rate versus computational load. Their findings guided algorithm selection for embedded harmonic analysis.

Rodriguez et al. [7] developed a communication architecture for power quality devices and HMIs using UART, Modbus-RTU, and RS-485 interfaces. They recommended using lightweight data protocols for real-time response and fault reporting. Their approach improved data integrity and system stability.

Zhang et al. [8] implemented an STM32-based three-phase power monitoring board capable of computing RMS, real power, reactive power, and THD. Their prototype validated STM32 performance for real-time power quality measurement but lacked harmonic compensation features.

Li et al. [9] evaluated Nextion HMI displays for industrial SCADA-like environments. Their analysis covered response time, graphical load, and communication reliability. Results indicated that Nextion modules offer professional-grade visualization at significantly lower cost, making them suitable for small-scale industrial systems.

Singh and Singh [10] reviewed shunt, series, and hybrid AHF topologies and compared switching devices, PWM strategies, and filter configurations. They provided selection criteria based on load type, harmonic order, and compensation level. Their analysis influenced the selection of shunt AHF design for this project

III. PROBLEM STATEMENT

Conventional power systems monitor harmonics using external meters that offer limited and delayed feedback. Existing Active Harmonic Filters (AHFs) lack an integrated, user-friendly display for real-time control. Commercial HMI solutions are expensive and complex for small-scale use. Therefore, a low-cost embedded HMI using TouchGFX on STM32F746 is required to visualize key parameters—voltage, current, power factor, and THD—while enabling efficient AHF monitoring and control. discharge through a triggered spark gap, accurately measuring peak discharge current, and maintaining affordability and portability of the testing equipment.

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IV. METHODOLOGY

The methodology adopted for the development of the proposed Low-Cost HMI Display Using Active Harmonic Filter for Power Quality Monitoring consists of multiple stages including system design, signal acquisition, harmonic detection, HMI interface development, and performance evaluation. Each stage ensures reliable monitoring and effective harmonic compensation for improved power quality in industrial environments.

4.1 System Architecture

A.Hardware Component

Component	Function
STM32F746G-DISCO Board	Central control and processing unit; handles data acquisition, communication, and GUI control.
TFT LCD Touch Display (480×272)	Provides real-time visualization and user interface for control and monitoring
TouchGFX GUI Layer	Offers a multi-screen graphical interface with measurement, graph, record, and settings tabs.
Flash/SD Storage	Stores measurement logs and harmonic records for analysis.

B. Software Tools

Component	Function
STM32CubeIDE	Used for embedded firmware development, configuration of peripherals (UART, SPI, CAN)
TouchGFX Designer	Provides graphical user interface (GUI) design and screen layout for the HMI display, including charts, icons.
Embedded C Language	Used for firmware logic, sensor data parsing, and control functions within the STM32 microcontroller.

4.2 Block Diagram

The block diagram of the proposed Low-Cost HMI-Based Active Harmonic Filter System is shown in Fig. __. The system is designed to continuously monitor electrical parameters in real-time and compensate harmonic distortions using an embedded controller and HMI interface.

The Power System block includes non-linear industrial loads and transformer supply. Voltage and current sensors measure the electrical parameters and transmit analog signals to the STM32 microcontroller for processing.

The STM32-based Active Harmonic Filter (AHF) Control Unit performs harmonic analysis and compensation. The controller samples voltage and current waveforms and executes FFT-based harmonic extraction to calculate key parameters such as RMS voltage, current, Power Factor (PF), Total Harmonic Distortion (THD), and individual harmonic components. Based on detected distortion, PWM signals are generated to drive the AHF inverter, which injects compensating currents to reduce harmonic distortion and improve power quality.

On-chip peripherals such as RTC are used for time-stamping, while Flash/SD memory enables historical data logging. Communication interfaces such as UART/SPI/CAN/Modbus ensure compatibility with industrial systems for real-time data exchange.

For visualization and user interaction, a TFT Touchscreen HMI is integrated through the TouchGFX GUI framework. The interface provides multiple screens including Home Dashboard, Measurement display, Harmonic spectrum, Data log record page, and System settings.

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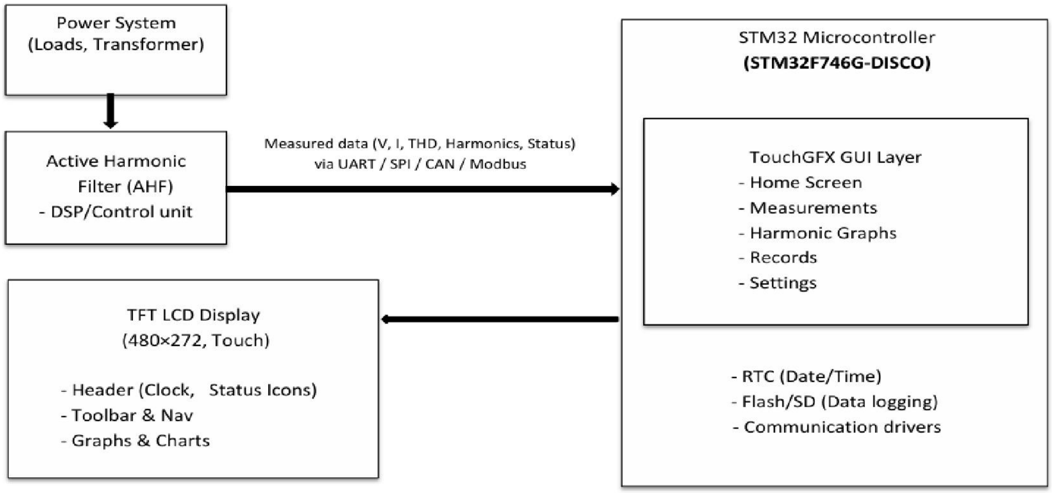


Fig. 1. System Block Diagram of HMI Display with Active Harmonic Filter

V. RESULTS AND SIMULATION

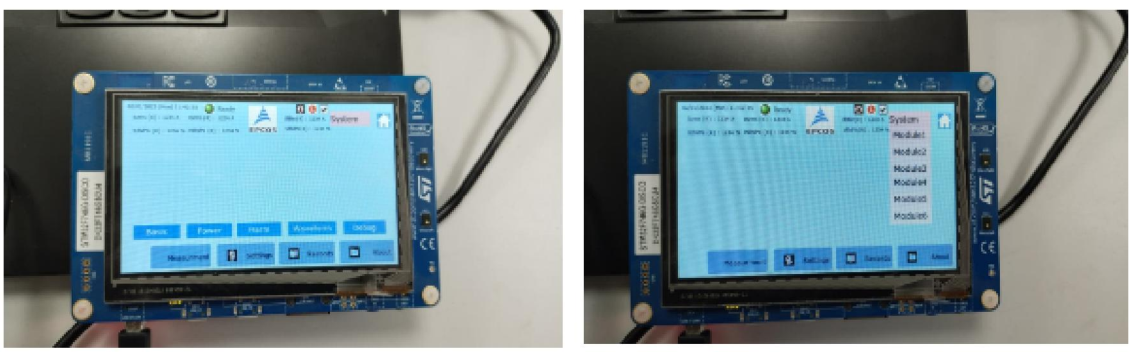
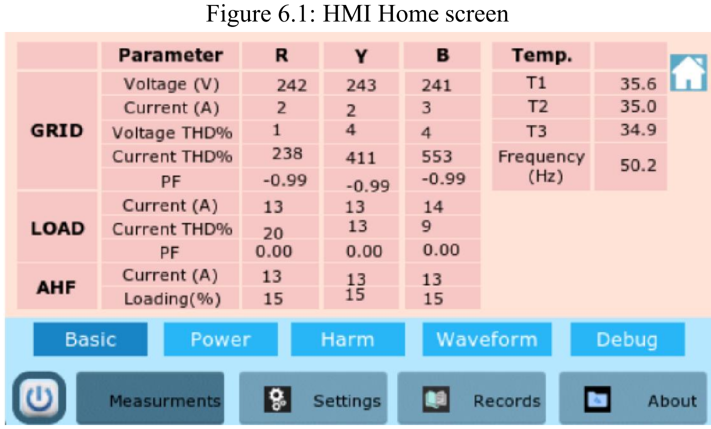


Figure 6.1: HMI Home screen



	Parameter	R	Y	B	Temp.	
GRID	Voltage (V)	242	243	241	T1	35.6
	Current (A)	2	2	3	T2	35.0
	Voltage THD%	1	4	4	T3	34.9
	Current THD%	238	411	553	Frequency (Hz)	50.2
	PF	-0.99	-0.99	-0.99		
LOAD	Current (A)	13	13	14		
	Current THD%	20	13	9		
	PF	0.00	0.00	0.00		
AHF	Current (A)	13	13	13		
	Loading(%)	15	15	15		

Figure 6.2: Basic measurement screen displaying real-time voltage and current values.

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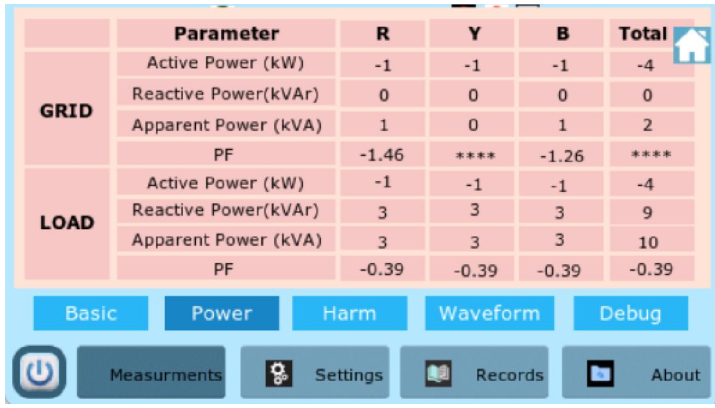

Figure 6.3: Power measurement screen showing active and reactive power data.

Figure 6.4: Debugging screen for system analysis.

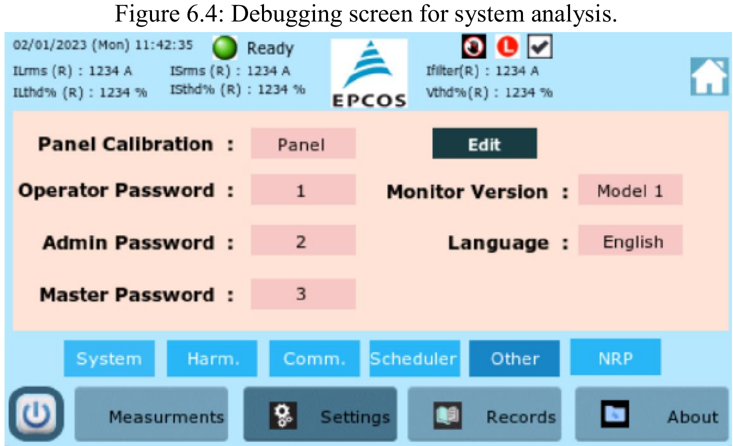

Figure 6.5: Additional settings page for extended configuration options.

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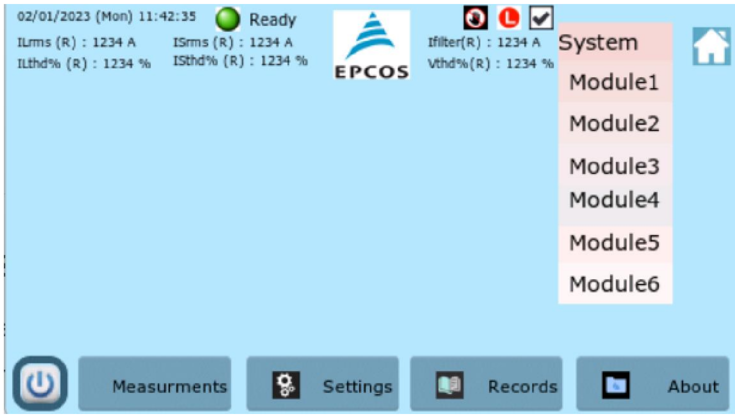

Figure 6.6: System Models Displayed on HMI Screen.

6.2. Hardware Setup and Final Output

The proposed HMI system was developed using a Nextion touch-screen display interfaced with an STM32 microcontroller through UART communication. A regulated DC power supply was used to operate the hardware. The display was programmed to present real-time electrical parameters such as voltage, current, THD, and power factor through an intuitive graphical interface. The final setup successfully demonstrated smooth screen navigation, live data visualization, and responsive touch interaction. The implemented HMI layout proved compact, user-friendly, and suitable for integration into an Active Harmonic Filter system for power quality monitoring applications.

VI. CONCLUSION

The proposed HMI-based power quality monitoring system successfully integrates the STM32 microcontroller with a touch-screen interface to support real-time visualization and control in harmonic mitigation applications. The system demonstrates the ability to monitor key electrical parameters and assist in reducing harmonic distortion when interfaced with an Active Harmonic Filter setup. By utilizing low-cost hardware and an efficient embedded design, the solution provides a cost-effective alternative to commercial industrial HMI and power quality analyzers. Its compact structure, intuitive interface, and reliable performance make it suitable for both industrial and household environments. The developed HMI framework is highly scalable and can be extended for advanced power management, remote monitoring, and integration with IoT-based industrial automation systems in future implementations.

VII. FUTURE SCOPE

- AI Integration: Smarter HMIs that learn from user behavior, predicting needs and optimizing interactions.
- Voice Control: Voice recognition for hands-free operation, improving accessibility and convenience.
- Energy Efficiency: Low-energy technologies like OLED and E Ink for more sustainable, portable HMIs.
- Security: Strengthening cybersecurity for HMIs in critical sectors like healthcare and automotive.

VIII. ACKNOWLEDGEMENT

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