

# An Advanced Iot System For Monitoring And Analyzing Chosen Power Quality Parameters In Microgrid Solutions

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**Abstract-** Nowadays, the electric power sector is accomplishing many essential improvements on power networks to respond to power supply reliability and energy consumption demand as well as to exploit effectively distributed generators integrated into the networks. The smart grid, a new modern solution for future power networks, uses digital technologies and Internet of Things (IoT) solutions to intelligently respond and adapt to changes in the power networks. This paper develops a new design of IoT-based network architecture applied for measuring, monitoring, and controlling substations on low-voltage distribution networks. In this proposed system, transmitting and receiving measurement data from the substations is based on the IoT platform via the LoRaWAN and WiFi communication technologies. This aims to increase the reliability and accuracy of the communication system. Once access permissions for the system are established, network operators and managers can easily monitor all electrical measurement parameters and control circuit breakers at the substations using smartphones or personal computers. The obtained experimental results in this paper show that the proposed system is a low-cost and feasible design for applying to future power networks.

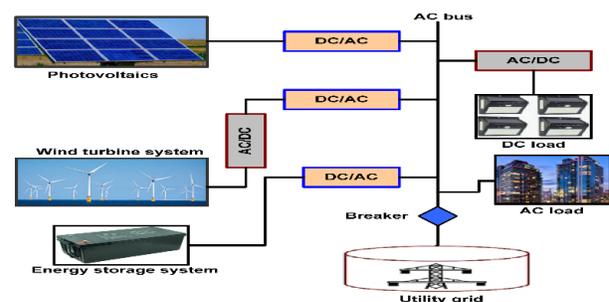
**Keywords-** energy management, Internet of Thing (IoT), micro-grid, power quality (PQ), ThingSpeak cloud.

## I. INTRODUCTION

Power quality (PQ) is commonly defined as the power grid's capability to supply a clean and stable power flow, as a constantly available PQ. The power flow should have a pure sinusoidal waveform within specified voltage and frequency tolerances. Deviations from these ideal Power quality (PQ) issues are becoming increasingly common as modern electrical systems incorporate a growing number of nonlinear and sensitive loads, which introduce disturbances into the grid. The effects of degraded PQ can cause substantial financial setbacks for industries and the overall economy. A study conducted by the Electric Power Research Institute

reported that major industrial plants in the United States incur losses exceeding **\$100 billion annually** due to electrical issues, including power quality fluctuations and voltage anomalies. Ensuring high PQ performance helps both consumers and power utilities reduce energy losses and operational costs. To address these challenges effectively, it is essential to perform continuous monitoring of incoming electrical variables and disturbances originating from nonlinear equipment. PQ monitoring supports equipment protection and aids in selecting appropriate mitigation measures to enhance PQ performance in micro-grid environments.

With the advancement of Industry 4.0, the Internet of Things (IoT) has emerged as a transformative technology whose applications extend across numerous domains such as healthcare, smart homes, building automation, environmental monitoring, power systems, transportation, and more. In the electrical sector, IoT has become a critical enabler in systems such as Supervisory Control and Data Acquisition (SCADA), smart metering, building automation,



public lighting networks, and smart grids, and is especially valuable for measuring, supervising, and managing power quality parameters. For example, a data visualization approach utilizing wireless sensor networks (WSNs) was presented in earlier research, where sensor nodes collected environmental data such as humidity and temperature for monitoring purposes.

Due to the rapid expansion of IoT technologies, several developed nations have implemented advanced metering infrastructures, automated metering systems, or intelligent energy meters to record and monitor household energy usage in real time. These systems allow consumers to track and understand their electricity consumption patterns instantly, enabling better energy management and financial savings. In recent years, many researchers have designed innovative solutions combining sensors, communication modules, and information systems to monitor and analyze both distributed energy generation and consumption. One study demonstrated the use of communication technology linking smart grids with residential systems to optimize energy usage. Another work developed an IoT-based remote energy monitoring system for scheduling, managing, and optimizing power consumption in homes and smart grids. A specialized IoT-big data platform aimed at improving energy efficiency in micro-grids by collecting, organizing, and sharing energy-related information was also introduced. Further, an advanced semantic-based energy management architecture was deployed in modern buildings. Additional research used cloud computing to design monitoring systems that allow users to access, control, and supervise system metrics remotely. IoT-enabled technologies for real-time monitoring of smart metering infrastructure using internet communication and LabVIEW software were also demonstrated.

Several researchers have explored intelligent techniques for micro-grid energy management. One study proposed a particle swarm optimization (PSO)-based management approach. A smart monitoring unit was designed in another work using Arduino Nano V3.0 to measure electrical parameters such as voltage and current. To create a more automated and intelligent indoor communication network, another study introduced a smart home management model employing IEEE 802.15.4 and ZigBee-based sensor networks.

Beyond the role of IoT in intelligent energy management, power quality (PQ) remains a critical concern within electrical distribution systems because inadequate PQ can severely disrupt industrial operations and commercial activities. As a result, numerous studies in recent years have explored the use of IoT-based solutions to improve PQ performance. For instance, the work reported in [24] introduced a smart sensing network developed using field-programmable gate array (FPGA) architecture for PQ supervision in electrical installations. A real-time PQ assessment framework integrating IoT, computing platforms, and big data analytics was described in [25]. Another study [26] demonstrated an IoT-driven energy monitoring approach that communicated with digital meters through the Modbus

protocol to classify different PQ conditions. In modern industries, many types of equipment demand high PQ stability during production to maintain product accuracy and reliability, especially for devices that are highly vulnerable to electrical disturbances. Consequently, continuous and structured PQ monitoring is essential for effective control and management [27]. Time synchronization of smart-meter readings using the Precision Time Protocol (PTP) was adopted in a recent method for enhancing distribution system monitoring and improving state estimation accuracy [28].

Addressing current operational needs, this paper presents an improved IoT-based framework designed to measure and evaluate selected PQ indices in real time within a micro-grid environment. The proposed setup incorporates three PZEM-004T sensing modules interfaced with an Arduino WeMos D1 R1 microcontroller, and offers the following key capabilities:

- (i) it enables real-time monitoring and evaluation of specific PQ parameters at multiple nodes of a micro-grid, while simultaneously archiving these readings into an online historical database;
- (ii) it supports large-scale data storage through a dedicated web server;
- (iii) it provides the flexibility to conduct PQ monitoring and analysis under both online and offline conditions;
- (iv) it is compact, economical, and easy to deploy.

The structure of this paper is arranged as follows: Section 2 outlines the materials and methodology, covering both the hardware setup and embedded software designed to achieve efficient real-time PQ assessment in micro-grids. Section 3 discusses the experimental findings and their interpretation. Section 4 concludes the work by summarizing the key outcomes.

## II. MATERIAL AND METHOD

### Hardware implementation

This paper presents an enhanced IoT-driven platform designed for real-time monitoring and evaluation of selected power quality (PQ) parameters, as illustrated in Fig. 1. The energy monitoring unit is composed of three PZEM-004T measurement modules, an Arduino WeMos D1 R1 microcontroller, and a set of four relay components. The PZEM-004T, manufactured by Peacefair Electronic Technology Co., Ltd., features an 8-pin configuration: two pins supply operating power for the sensor, two pins enable serial communication, and the remaining four pins serve as voltage and current input terminals. The device functions on

the operating principle of a current transformer (CT) and is suitable for single-phase electrical networks at 50 Hz or 60 Hz. This module incorporates a non-invasive CT along with the SD3004 energy-measurement SoC chip, allowing it to accurately capture key single-phase electrical metrics such as voltage, frequency, current, active power, power factor, and consumed energy at the monitoring points. The CT provides sensing capability through its specified ratio of 100 A to 100 mA.

The PZEM-004T is recognized as an economical and modern power-monitoring sensor that supports the measurement of several PQ indicators, including voltage, current, frequency, active power, and power factor [29]. Current measurement is achieved by simply passing the conductor through the circular opening in the CT's magnetic core.

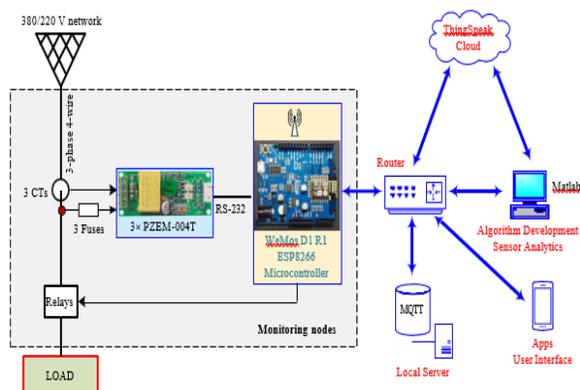


Fig. 1. The proposed ThingSpeak platform-based system overview

The PZEM-004T sensor provides its output through transistor–transistor logic (TTL) serial communication instead of analog voltage signals like earlier sensor models; therefore, no external signal-conditioning circuitry is required. Using the dedicated PZEM004T software library [30], measurement values can be obtained directly and efficiently. Furthermore, findings reported in [29] indicate that the PZEM-004T is an economical and highly reliable sensor, outperforming other commonly used devices for monitoring PQ-related electrical parameters. To transmit the collected data from the PZEM-004T modules to the ThingSpeak cloud platform, an Arduino WeMos D1 R1 microcontroller is employed. It interfaces with the PZEM-004T units via an RS-232 communication link and uses an integrated ESP8266 module for wireless connectivity. The microcontroller is programmed through the Arduino IDE, enabling it to gather readings from the three PZEM-004T modules and upload them to the ThingSpeak web server over Wi-Fi. The data-transfer interval is approximately twenty minutes, after which users can remotely observe and interpret PQ information from any location using an internet-enabled

personal computer or mobile device. A real-world photograph of the developed prototype is shown in Fig. 2.

At present, PQ evaluation plays a crucial role in improving electrical energy efficiency. The PQ at a monitoring point can be characterized primarily by voltage quality and frequency quality. Frequency quality serves as a system-wide indicator and is regulated by generating stations; measured frequency values must remain within the acceptable operating limits defined for normal system performance [1]. In addition, the most recent edition of the international standard IEC 61000-4-30: Edition 3 [31] specifies the exact methodologies and algorithms that PQ measurement instruments must follow when assessing parameters such as system frequency, supply voltage levels, voltage flicker, dips, swells, interruptions, unbalance, and harmonic distortion for both current and voltage. In this study, the upgraded IoT-based architecture is developed around a hardware configuration in which the PZEM-004T serves as the primary sensing element for capturing several PQ parameters outlined in IEC 61000-4-30.

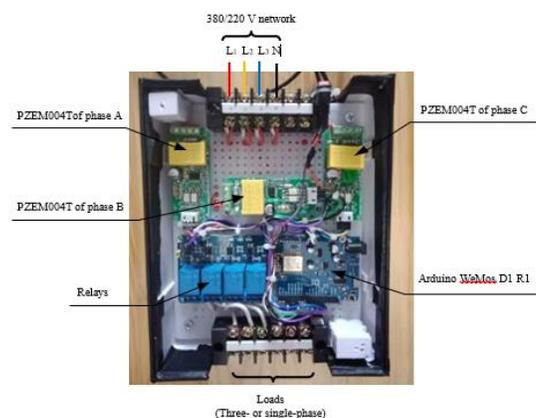


Fig. 2. The real image of the advanced IoT system

The system is capable of measuring, monitoring, and analysing several key PQ parameters, including supply voltage magnitude, current, power frequency, active power, and power factor. The next subsection describes the development of the embedded software programmed into the Arduino WeMos D1 R1 microcontroller, which enables the execution of these system functions.

### Embedded software

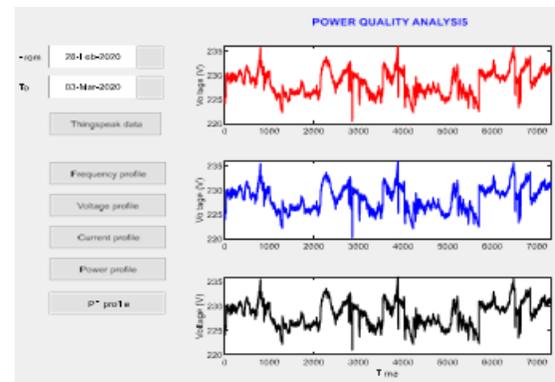
In the proposed IoT-based framework, three PZEM-004T units function as sensing devices to capture selected PQ parameters at the designated monitoring location. The acquired measurements are transferred to the Arduino WeMos D1 R1 microcontroller through a defined communication protocol using command-based data exchange. To extract and

process the readings from each PZEM-004T module, a program developed in the Arduino IDE is written and uploaded to the WeMos D1 R1 microcontroller. Additionally, a dedicated algorithm is implemented on the microcontroller to transmit the collected data to the web server and enable real-time PQ visualization on the ThingSpeak cloud platform, as depicted in Fig. 3.

In the developed IoT framework, the PQ measurement data captured at the monitoring location is transmitted to the ThingSpeak cloud platform through a communication protocol. The system employs the Message Queuing Telemetry Transport (MQTT) protocol to facilitate data exchange between the ESP8266 module and the ThingSpeak server. To upload all measured parameters from the monitoring point to the cloud, the Arduino WeMos D1 R1 microcontroller is programmed using the Arduino IDE. The programming procedure follows the guidelines of international standards IEC 61000-4-30 [31] and EN 50160 [32], which specify the essential voltage characteristics at end-user terminals in low- and medium-voltage distribution networks under normal operating conditions. In terms of PQ evaluation, RMS voltage must be calculated using a 10 ms window for detecting rapid voltage variations or a 200 ms window for statistical analysis. Since the proposed system is intended for long-term monitoring of selected PQ parameters rather than the detection of fast events such as swells, dips, or interruptions, the commands for measuring RMS voltage and current (listed in Table 1) are executed over an interval of 10 cycles (200 ms).

The PQ measurement results recorded at the monitoring node are made accessible remotely through dedicated ThingSpeak channels. These channels are configured to visualize variables such as frequency, current, voltage, active power, and power factor. Consequently, three separate channels—PQM1, PQM2, and PQM3—are created to support the monitoring and analysis of PQ at the observation point, as illustrated in Fig. 4. The specific measurement variables associated with each channel are summarized in Table 2.

All measurement data collected during the monitoring period is stored on the ThingSpeak cloud. For analytical purposes, a Matlab-based program is developed to retrieve and process the stored PQ information. The Matlab commands used for extracting data from ThingSpeak in the proposed system are listed in Table 3. Furthermore, a graphical user interface (GUI) for PQ analysis is created using Matlab's GUIDE tool, with a sample shown in Fig. 5. This interface allows users to select custom start and end times for the analysis.



### III. CONCLUSIONS

This study introduces an enhanced IoT-based monitoring framework that integrates embedded hardware with the ThingSpeak cloud platform to evaluate selected power quality (PQ) parameters within micro-grid environments. The system is built around three PZEM-004T sensing modules interfaced with an Arduino WeMos D1 R1 microcontroller to carry out data acquisition and processing tasks. Key PQ indicators—namely voltage, current, frequency, active power, and power factor—are continuously measured at the monitoring node and logged in real time through dedicated ThingSpeak channels. These channels provide online visualization of the time-series behavior of each parameter. Beyond real-time display, all recorded data are stored on the ThingSpeak cloud server, and a custom Matlab-based graphical interface is developed to support further PQ evaluation. Using this interface, users can examine voltage and frequency histograms over the monitoring window, enabling detailed assessment of PQ performance in low-voltage distribution systems.

The proposed solution demonstrates its capability to acquire, supervise, and interpret the five PQ parameters most frequently encountered in 380/220 V networks. It offers consumers convenient access to PQ information from any internet-connected computer or mobile device, allowing them to verify the quality of the electrical supply they receive. Furthermore, long-term storage of the monitored PQ data ensures availability for future diagnostics, reporting, or system optimization.

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