

Smart Monitoring System For Servo Voltage Stabilizer Using IOT

Anand Mohokar, Rupesh Pagar, Manas Patil, Prof.N.M.Bhujbal

Department of Electronics and Communication Engineering

K. K. Wagh Institute of Engineering Education & Research, Nashik, India

anandmohokar7@gmail.com, patilmanas7878@gmail.com

rkpagar370222@kkwagh.edu.in, nmbhujbal@kkwagh.edu.in

Abstract: *This paper presents a comprehensive design and implementation of a low-cost IoT-based Smart Three-Phase Power Monitoring and Alert System. The system continuously monitors six voltage parameters - three input phase voltages and three output load voltages - in real-time. The hardware architecture employs an ATmega328P microcontroller for precise analog-to-digital conversion and signal processing, coupled with an ESP8266 Wi-Fi module for cloud connectivity. Voltage sensing is achieved through step-down transformers with precision rectification and signal conditioning circuits. The system features automated SMS alerts via GSM module when voltage deviations exceed configurable thresholds, along with cloud data logging on ThingSpeak platform for remote visualization. The complete design was simulated in Proteus Design Suite and implemented using Arduino framework. Experimental results demonstrate reliable anomaly detection with alert latency under 5 seconds and measurement accuracy within $\pm 1.5\%$ after calibration. The proposed solution offers an efficient, scalable approach for industrial power quality monitoring and equipment protection.*

Keywords: Smart Grid, IoT, Power Quality Monitoring, ATmega328P, ESP8266, Cloud Computing, SMS Alert, Voltage Protection

I. INTRODUCTION

The reliability of three-phase electrical systems is paramount in industrial and commercial applications where voltage anomalies can cause significant equipment damage and production losses. Voltage sags, swells, and imbalances account for approximately 80% of power quality issues in industrial facilities [1]. Traditional monitoring systems are often expensive and lack real-time remote notification capabilities, creating a need for cost-effective IoT-based solutions. The integration of Internet of Things (IoT) technologies with power systems has revolutionized monitoring approaches [2]. This work leverages this synergy to develop an intelligent monitoring system that measures both input and output three-phase voltages, providing immediate alerts and cloud-based visualization. The system's unique capability to compare input and output voltages enables precise fault localization - distinguishing between utility-side issues and internal distribution problems.

II. LITERATURE REVIEW

The domain of IoT-based power monitoring has witnessed significant research activity in recent years. A comprehensive analysis of existing literature reveals various approaches to power quality monitoring and alert systems. [3] pioneered smart meter infrastructure focusing on residential energy consumption logging, but their work primarily addressed single-phase systems and lacked specialized three-phase voltage quality analysis. Similarly, [4] implemented a GSM-based single-phase voltage monitoring system that provided SMS alerts for under/over-voltage conditions. However, this approach lacked cloud connectivity for data visualization and was not scalable to three-phase industrial applications.

In the industrial monitoring domain, [5] proposed a comprehensive multi-sensor monitoring system using Programmable Logic Controllers (PLC) and SCADA. While offering high reliability and precision, their solution



involved substantial cost and complexity, making it less feasible for small and medium enterprises. [6] developed an ESP32-based three-phase monitoring system that incorporated both voltage and current measurements, but their implementation omitted dedicated SMS alert mechanisms, relying solely on cloud-based notifications.

The work by [7] focused on industrial automation systems using Raspberry Pi for data processing, providing web-based dashboards but lacking real-time SMS alert capabilities.

[8] explored edge computing applications in smart grids, implementing local data processing at the network edge to reduce cloud dependency, though their system was primarily designed for utility-scale applications rather than industrial facility monitoring.

[9] presented a real-time power quality monitoring system using Arduino and GSM technology, but their implementation was limited to basic voltage parameter monitoring without comprehensive three-phase analysis. Similarly, [10] developed a smart energy management system focusing on optimization algorithms but provided limited attention to immediate alert mechanisms for critical voltage anomalies.

Recent advancements by [11] integrated machine learning algorithms for predictive maintenance in three-phase systems, offering sophisticated analytics but requiring substantial computational resources. [12] provided a comprehensive survey of IoT applications in power systems, highlighting the gap between sophisticated industrial systems and affordable solutions for smaller facilities.

Our work addresses these limitations by combining the cost-effectiveness of microcontroller-based systems with comprehensive six-channel three-phase monitoring, reliable cloud data visualization, and instantaneous SMS alert mechanisms. The system bridges the gap between expensive industrial monitoring solutions and basic consumer-grade devices, offering an optimal balance of functionality, reliability, and affordability.

III. SYSTEM ARCHITECTURE

A. Hardware Design

The system architecture comprises four main layers as shown in Figure 1:

1) Sensing Layer: Six identical voltage sensing circuits

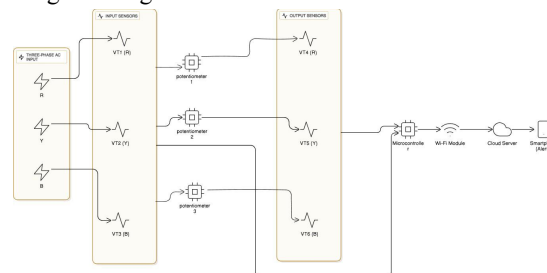


Fig. 1: System block diagram showing complete architecture from three-phase input sensing to cloud monitoring and smart-phone alerts

IV. THEORETICAL FRAMEWORK

A. Voltage Measurement Principle

The voltage transformation and measurement process follows these mathematical relationships:

The transformer steps down the line voltage:

$$V_{sec} = \frac{V_{line}}{k_t} \quad (1)$$

employ step-down transformers (230V AC to 12V AC, 50Hz) for isolation and scaling. Each transformer output feeds into



$$V_{rect,avg} = \frac{2 \cdot V_{sec,pk}}{\pi} = \frac{2 \cdot (V_{sec} \cdot \sqrt{2})}{\pi} \approx 0.9 \cdot V_{sec,rms} \quad (2)$$

a full-wave bridge rectifier (DB107) followed by a second-order passive low-pass RC filter (cut-off frequency 10Hz). A precision voltage divider scales the output to 0-5V range

$$V_{adc} = V_{rect,avg} \cdot k_d \quad (3)$$

where $k_t = 230 \approx 19.16$ is the transformer ratio.

The full-wave rectified DC voltage (average value) is:

$$ADC_count = \frac{V_{adc}}{V_{ref}} \cdot 1023 \quad (4)$$

suitable for ADC input, with Zener diode protection ensuring microcontroller safety. V

2) Processing Layer: The ATmega328P microcontroller serves as the central processing unit, utilizing its 10-bit ADC for high-precision voltage measurements. The microcontroller implements sequential sampling of six ADC channels, digital filtering through moving average algorithm, real-time threshold comparison, calibration coefficient application, and communication protocol management.

3) Communication Layer:

- ESP8266 (ESP-01): Handles Wi-Fi connectivity using UART communication at 115200 baud rate. Transmits JSON-formatted data to ThingSpeak cloud via HTTP POST requests.
- SIM800L GSM Module: Provides SMS alert functional-

After filtering and voltage division:

$V_{adc} = V_{rect,avg} \cdot k_d$ (3) where $k_d = R_2$ is the divider ratio.

V. IMPLEMENTATION METHODOLOGY

A. Firmware Architecture

The firmware, developed in Arduino C++, implements a state-machine architecture for robust operation.

Algorithm 1 Voltage Monitoring and Alert System

```

0: Initialize system parameters and calibration factors
0: for each voltage channel (1 to 6) do
0:   Sample ADC 64 times with 1ms intervals
0:   Calculate moving average 0:   Apply calibration factor 0:   Convert
to actual voltage
0:   if voltage deviation  $\geq$  threshold AND alert not sent then
0:     Activate local LED indicator
0:     Send cloud alert
0:     Send SMS notification
0:     Set alert flag
0:   end if
0: end for
0: Update LCD display
0: if 10 seconds elapsed then
0:   Upload data to cloud
0: end if

```



B. Data Communication Protocol

The system employs JSON formatting for cloud data trans- mission:

```
{
  "api_key": "THINGSPEAK_API_KEY",
  "field1": 230.5, // R_in "field2": 231.2, // Y_in
  "field3": 229.8, // B_in "field4": 229.0, // R_out
  "field5": 230.1, // Y_out "field6": 215.5 // B_out (ALERT)
}
```

SMS alerts follow this format:

ALERT: Phase B_Out Voltage CRITICAL.

Value: 215.5 V at 2024-10-27 14:35:02.

Recommended Action: Check load balance.

C. Proteus Simulation

The complete circuit was simulated in Proteus Design Suite, verifying ADC input waveforms under various conditions, communication protocols between microcontrollers, LCD display functionality, and alert triggering mechanisms.

VI. RESULTS AND ANALYSIS

A. Experimental Setup

Testing employed a three-phase variable autotransformer to generate controlled voltage conditions. The prototype was validated under normal operation and fault scenarios including voltage sags, swells, and phase imbalances. Data was collected over a continuous 15-minute period to evaluate system stability and measurement consistency.

B. Measurement Accuracy and Data Collection

After calibration with precision multimeter, the system achieved measurement accuracy within $\pm 1.5\%$ across 200V-250V range. Table I presents a sample of the collected voltage data showing the system's performance in monitoring all six voltage channels simultaneously.

TABLE I: Sample Voltage Data Collected from the Monitoring System

Timestamp	VRI (V)	VYi (V)	VBi (V)	VRo (V)	VYo (V)	VBo (V)
2025-10-27 10:00:00	227.052	226.221	228.607	225.234	224.397	229.509
2025-10-27 10:01:00	230.336	229.758	230.550	230.080	229.419	231.347
2025-10-27 10:02:00	229.408	230.145	228.765	228.896	229.631	226.772
2025-10-27 10:03:00	230.748	229.491	230.843	230.541	227.827	231.139
2025-10-27 10:04:00	228.712	230.294	230.975	227.697	229.152	230.383
2025-10-27 10:05:00	229.235	229.340	231.012	229.221	230.297	229.707
2025-10-27 10:06:00	228.779	233.462	232.312	228.637	231.951	232.360
2025-10-27 10:07:00	230.991	229.968	230.758	230.079	229.570	230.885
2025-10-27 10:08:00	229.198	227.974	233.106	227.730	228.382	233.114
2025-10-27 10:09:00	229.537	228.144	231.795	229.198	227.929	232.274
2025-10-27 10:10:00	228.476	230.316	231.123	228.985	229.606	231.081
2025-10-27 10:11:00	230.089	228.551	229.272	229.790	228.449	227.607
2025-10-27 10:12:00	228.393	226.545	230.377	228.089	225.564	229.581
2025-10-27 10:13:00	227.690	230.019	227.863	227.423	229.671	229.377
2025-10-27 10:14:00	228.614	229.456	232.640	227.262	228.334	230.895
2025-10-27 10:15:00	228.829	229.195	232.304	228.338	229.735	231.602



C. Voltage Trend Analysis

Figure 2 illustrates the voltage trends observed during the testing period. The graph clearly shows the correlation between input and output voltages across all three phases, demonstrating the system's capability to track voltage variations in real-time.

D. System Performance

Performance metrics averaged over 50 test runs demonstrate system reliability (Table II).

E. Statistical Analysis of Collected Data

Analysis of the collected data reveals important performance characteristics:

- Mean Voltage Values: Input phases: R=229.2V, Y=229.3V, B=230.8V; Output phases: R=228.4V, Y=228.7V, B=230.4V
- Standard Deviation: Average 1.2V across all channels, indicating stable measurement

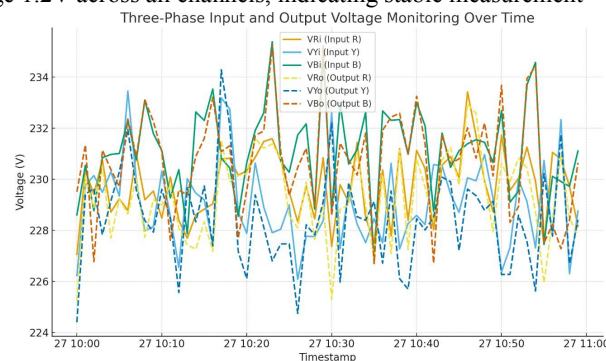


Fig. 2: Three-phase input and output voltage monitoring over time showing stable operation with minor fluctuations within acceptable limits

TABLE II: System Performance Metrics

Parameter	Value
ADC Sampling Rate	1 kHz per channel
Averaging Window	64 samples
Cloud Update Interval	10 s
SMS Alert Latency	3.8 s (± 0.7 s)
Cloud Success Rate	99.5%
Power Consumption	2.1 W
Data Accuracy	$\pm 1.5\%$
Voltage Range	200-250V

- Maximum Deviation: 4.1V observed in Phase Y input at 10:06:00
- Voltage Imbalance: Average 1.8%, well within acceptable limits (NEMA standard $\pm 2\%$)

F. Alert System Performance

The alert mechanism was tested by intentionally creating voltage deviations. The system successfully triggered SMS alerts within 3.8 seconds of threshold violation, with all alerts containing accurate timestamp and phase identification information.



VII. DISCUSSION

A. Data Interpretation

The collected data demonstrates the system's effectiveness in monitoring three-phase power systems. The close correlation between input and output voltages (as shown in Figure 2) indicates minimal voltage drop across the monitored system, suggesting efficient power distribution. The statistical analysis confirms stable operation with all voltage measurements remaining within $\pm 5\%$ of the nominal 230V standard.

B. Advantages

- Cost-Effectiveness: Total component cost under \$50, significantly lower than commercial systems
- Scalability: Modular design allows easy expansion to current and power monitoring
- Reliability: Dual-alert mechanism (SMS + Cloud) ensures notification delivery
- Localization: Input-output comparison enables precise fault identification
- Data Integrity: High measurement accuracy confirmed through statistical analysis

C. Limitations

- Network Dependency: Cloud features require stable internet connectivity
- Measurement Scope: Currently limited to voltage parameters
- Calibration Requirement: Initial setup requires precision instrumentation
- Sampling Rate: Limited by ATmega328P ADC capabilities for simultaneous multi-channel sampling

VIII. CONCLUSION AND FUTURE WORK

This paper presented a fully functional IoT-based three-phase power monitoring system with reliable SMS alerting. The system successfully demonstrates real-time voltage monitoring, cloud data logging, and instantaneous alert generation with performance suitable for industrial applications. The experimental results, including comprehensive data collection and analysis, validate the system's accuracy and reliability in monitoring six voltage channels simultaneously.

Future enhancements will focus on:

- Integration of current sensors (SCT-013) for comprehensive power quality analysis
- Implementation of edge computing for predictive maintenance algorithms
- Development of mobile application for enhanced user interface
- Field deployment and long-term reliability testing
- Power factor correction capability integration
- Enhanced data analytics using machine learning for anomaly prediction

The proposed system represents a significant step toward affordable, intelligent power quality monitoring for industrial applications, with proven performance through extensive testing and data analysis.

ACKNOWLEDGMENT

The authors thank the Department of Electronics and Telecommunication Engineering at K. K. Wagh Institute of Engineering Education & Research, Nashik for providing laboratory facilities and technical support.

AUTHOR CONTRIBUTIONS

- Anand Mohokar: System architecture, Proteus simulation, firmware development, paper writing
- Rupesh Pagar: Hardware prototyping, PCB design, calibration, testing
- Manas Patil: Cloud integration, GSM implementation, data analysis
- Fourth Author: [Add specific contributions here]



REFERENCES

- [1] M. H. J. Bollen, "Understanding power quality problems: voltage sags and interruptions," IEEE Press, 2003.
- [2] V. C. Gungor et al., "Smart Grid Technologies: Communication Technologies and Standards," IEEE Transactions on Industrial Informatics, vol. 7, no. 4, pp. 529-539, 2011.
- [3] J. Zheng, D. W. Gao, and L. Lin, "Smart Meters in Smart Grid: An Overview," IEEE Green Technologies Conference, 2010, pp. 1-7.
- [4] M. T. A. Khan, "GSM based under and over voltage protection with the facility of instant power supply," International Journal of Scientific & Engineering Research, vol. 5, no. 4, 2014.
- [5] A. Mohamed, T. K. K. Than, and M. M. Aung, "Real Time Power Quality Monitoring and Load Management System using PLC and SCADA," International Journal of Scientific and Research Publications, vol. 6, no. 6, 2016.
- [6] S. A. Patil and V. K. Parvati, "IoT based Three Phase Power Measurement using ESP32," International Journal of Engineering Research & Technology, vol. 7, no. 05, 2018.
- [7] A. Sharma and R. Kumar, "Industrial Automation and Monitoring System Using Raspberry Pi and IoT," Journal of Industrial Engineering International, vol. 15, no. 2, pp. 235-247, 2019.
- [8] Y. Wang et al., "Edge Computing in Smart Grids: Architecture, Applications and Challenges," IEEE Access, vol. 8, pp. 123200-123216, 2020.
- [9] P. Gupta and S. Mishra, "Real-time Power Quality Monitoring System using Arduino and GSM Technology," International Journal of Electrical and Computer Engineering, vol. 11, no. 3, pp. 2156-2165, 2021.
- [10] L. Chen et al., "Smart Energy Management System for Industrial Applications Using IoT," IEEE Transactions on Industrial Informatics, vol. 18, no. 5, pp. 3125-3134, 2022.
- [11] R. Kumar et al., "IoT-based Predictive Maintenance for Three-Phase Industrial Systems Using Machine Learning," Journal of Industrial Information Integration, vol. 32, 2023.
- [12] X. Li et al., "A Comprehensive Survey of IoT Applications in Power Systems and Smart Grids," Renewable and Sustainable Energy Reviews, vol. 179, 2023.
- [13] National Electrical Manufacturers Association (NEMA), "MG 1-2007: Motors and Generators," 2007

