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Smart Transformer with IOT-Based Power Monitoring and Automatic Load Balancing System for Industrial Applications

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Abstract— The increasing and continuously varying power demand in industrial applications can cause transformer overloading, excessive temperature rise, equipment damage, and unexpected power interruptions. This paper presents an IoT-based Smart Transformer with Power Monitoring and Automatic Load Balancing System using two transformers for reliable industrial power distribution. Under normal load conditions, Transformer 1 supplies the required power while Transformer 2 remains in standby mode. When the load exceeds a predefined threshold, the Arduino controller automatically activates Transformer 2 to share the additional load, thereby reducing the loading stress on the first transformer. Voltage and current sensors continuously measure electrical parameters, while a temperature sensor monitors transformer thermal conditions. The measured parameters are processed by an Arduino UNO and displayed locally on an LCD. An ESP8266 IoT module transmits real-time voltage, current, temperature, power, and transformer operating status to a cloud platform for remote monitoring. An automatic cooling fan is activated when the transformer temperature exceeds the specified safety limit. The proposed system combines automatic load management, thermal protection, local monitoring, and IoT-based remote supervision. The approach can improve transformer utilization, reduce overheating risks, support preventive maintenance, and enhance reliability and safety in industrial power distribution systems.

Keywords— Smart Transformer, IoT Monitoring, Load Balancing, Temperature Protection, Power Monitoring etc.

I. INTRODUCTION

Power transformers are critical components of electrical distribution systems because they transfer electrical energy between voltage levels and support continuous supply to industrial, commercial, and domestic loads. Their reliable operation is particularly important in industrial environments where sudden power interruptions can affect production, equipment, and operational safety. Transformer failures may result from electrical, thermal, mechanical, insulation, or loading-related stresses; therefore, continuous condition monitoring is increasingly important for improving reliability and extending transformer service life [1].

Conventional transformer monitoring generally depends on periodic inspection and individual measurement of operating parameters. Such approaches may not provide sufficient information when transformer loading changes rapidly. Recent research has therefore emphasized online condition monitoring using sensors and digital communication technologies. Parameters such as voltage, current, temperature, dissolved gases, vibration, and partial discharge can provide valuable information regarding transformer operating and health conditions [1], [2].

The Internet of Things (IoT) provides an effective framework for connecting sensors, controllers, communication modules, and cloud platforms. IoT-based transformer monitoring enables operating parameters to be collected continuously and transmitted to remote users. A 2024 systematic literature review identified IoT as an increasingly important approach for transformer condition monitoring and highlighted its potential for predictive maintenance, reduced downtime, and improved power-system reliability [2].

Power demand is another important consideration in transformer operation. During peak-load conditions, excessive loading can increase transformer temperature and accelerate insulation deterioration. Dhiman and Perveen proposed a IoT-based transformer monitoring system that measures current, voltage, and temperature and uploads the information to the cloud. Their study also considered controllable loads as a method of reducing transformer loading during peak periods [3].

Temperature monitoring is particularly significant because transformer thermal stress is closely associated with loading and equipment ageing. Online monitoring can provide timely information about transformer health and support maintenance decisions before severe failures occur [1]. In addition, recent research has investigated the integration of IoT, wireless sensor networks, digital twins, sensing, and actuation technologies for smart transformer condition monitoring within Industry 4.0 environments [4].

Based on these developments, this paper proposes an IoT-based Smart Transformer with Power Monitoring and Automatic Load Balancing System using two transformers. Under normal loading, Transformer 1 supplies the load, while Transformer 2 remains available as an additional power source. When the load exceeds a predefined threshold, the controller activates Transformer 2 to support load sharing. Voltage and current sensors monitor electrical conditions, while a temperature sensor monitors transformer thermal status. An Arduino UNO performs the control operations, an LCD provides local information, and an ESP8266 module enables cloud-based remote monitoring. An automatic cooling fan is also incorporated to reduce excessive temperature. The proposed system therefore combines power monitoring, automatic load management, thermal protection, and IoT-based remote supervision to improve the reliability and safety of industrial transformer operation.

II. Problem Identification

- Transformer Overloading: Industrial loads vary continuously, causing excessive loading of a single transformer and increasing the possibility of overheating and failure.
- Uneven Load Distribution: Conventional systems may not automatically distribute increasing load between available transformers, resulting in inefficient transformer utilization.
- Limited Real-Time Monitoring: Traditional systems provide limited continuous monitoring of voltage, current, power, and transformer temperature.
- Delayed Fault Detection: Excessive temperature and abnormal electrical conditions may remain undetected without continuous sensing and automatic protection.
- Lack of Remote Monitoring: Conventional transformer systems generally require local inspection, making remote supervision and timely response difficult.
- Cooling Control: Manual cooling arrangements may not respond quickly to temperature variations, increasing thermal stress and reducing transformer service life.
- Need for Intelligent Automation: An integrated system is required to combine automatic load balancing, sensor-based monitoring, IoT communication, and temperature-based protection for reliable industrial power distribution.

A. Existing System

- Conventional transformer systems generally use a single transformer to supply the connected industrial load, with protection provided through fuses, circuit breakers, and conventional relays.
- Transformer parameters such as voltage, current, and temperature are often measured locally using separate instruments.
- Load management is generally performed manually or through predefined protection settings, rather than dynamically sharing load between transformers.
- Fault identification and maintenance commonly depend on periodic inspection, limiting continuous assessment of transformer operating conditions.
- Remote monitoring and cloud-based data storage are generally not integrated into basic transformer distribution systems.

B. Drawbacks

- Overloading Risk: A transformer may experience excessive loading when industrial demand increases, resulting in overheating and accelerated insulation ageing.
- No Automatic Load Sharing: Conventional systems may not automatically activate a standby transformer when the primary transformer approaches its permissible loading level.
- Limited Remote Monitoring: Operators may need to inspect equipment locally, making continuous supervision difficult.
- Delayed Fault Detection: Abnormal temperature, voltage, and current conditions may not be identified immediately.
- Manual Cooling: Conventional cooling arrangements may not automatically respond to temperature variations.
- Higher Maintenance Requirement: Lack of continuous condition monitoring can increase unexpected failures and maintenance requirements.
- Limited Data Availability: Conventional systems generally lack cloud-based historical data for analyzing transformer performance and supporting preventive maintenance.

III. Literature Survey

A) Literature Reviews

Mzamo R. Msane, Bonginkosi A. Thango, and Kingsley A. Ogudo (2024), The study examined 120 selected publications and identified IoT technologies, Arduino controllers, sensors, communication systems, and fault-diagnosis techniques as important approaches. The review highlighted the potential of continuous monitoring for detecting abnormal transformer conditions, improving maintenance planning, reducing unexpected failures, and increasing transformer operational reliability. These findings support the proposed integration of sensors and IoT communication in smart transformer monitoring systems.

Lan Jin, Dowon Kim, Ahmed Abu-Siada, and Shantanu Kumar (2022), The study discussed online and offline monitoring approaches, including dissolved gas analysis, partial discharge, thermal measurement, vibration analysis, and other diagnostic techniques. The authors emphasized that continuous monitoring can provide important information about transformer insulation, thermal condition, and developing faults. The review demonstrated the importance of combining multiple monitoring parameters to improve transformer health assessment, reliability, preventive maintenance, and operational safety.

Vimal Angela Thiviyanathan (2022). The study reviewed oxidation, hydrolysis, partial discharge, arcing, insulation ageing, and different fault-detection techniques. The authors highlighted that insulation deterioration significantly affects transformer service life and reliability. Advanced monitoring and diagnostic technologies were identified as useful approaches for detecting developing insulation problems at an early stage. The findings emphasize the importance of continuous transformer condition assessment and support temperature, electrical-parameter, and fault monitoring in smart transformer systems.

Rahul Soni and Bhinal Mehta (2023), Their work examined dissolved gas analysis, thermal characteristics, insulation ageing, and dielectric-fluid properties affecting transformer performance. The study emphasized that monitoring oil and thermal conditions provides valuable information about transformer health and ageing. Alternative dielectric fluids were also discussed because of their potential environmental and operational advantages. The review demonstrates the importance of integrating thermal and condition-monitoring parameters for reliable transformer operation.

Lan Jin, Dowon Kim, and Ahmed Abu-Siada (2023), The study covered fault diagnosis, transformer health-index calculation, reliability assessment, maintenance strategies, and remaining-life estimation. The authors emphasized that condition-based and predictive maintenance approaches can improve transformer asset utilization and reduce unexpected failures. Health assessment based on multiple operational parameters was identified as an important tool for maintenance decision-making. The findings support continuous monitoring and intelligent management of transformer operating conditions.

Amandeep Dhiman and Rehana Perveen (2022), The system focused on monitoring important electrical and thermal parameters, particularly voltage, current, and temperature, and communicating information through cloud-based infrastructure. The study also considered controllable loads during peak-demand conditions to reduce transformer stress. Its findings demonstrate the usefulness of IoT for remote transformer supervision and load management. The approach provides a practical foundation for integrating sensors, microcontrollers, cloud communication, and automatic load-control functions in smart transformer applications.

Mahmoud Elsisi (2022), The system combined IoT communication with a deep one-dimensional convolutional neural network for transformer fault classification. The study considered uncertainties and cyberattack conditions affecting monitoring data. Reported results demonstrated high diagnostic performance under the investigated conditions. The research indicates that combining real-time sensing, IoT communication, and intelligent algorithms can improve transformer fault identification. It provides a foundation for developing future smart transformer systems with automated diagnostic capabilities.

Shilpa SK, Gowtham Bharadwaj MP, Karthik VG, and Monika D (2024), The system focused on monitoring transformer voltage, load current, and winding temperature and transmitting information through communication technologies for remote supervision. The study demonstrated the usefulness of continuous parameter monitoring for identifying abnormal transformer operating conditions. Early detection can support protective actions and maintenance planning. The research supports the proposed project concept of using sensors, a microcontroller, IoT connectivity, and remote monitoring for improved transformer safety.

S. B. Joshi, Rahul Jadhav, Nilesh Sorekar, and Ashish Darandale (2023), The study combined IoT monitoring with machine-learning techniques for analyzing transformer vibration signals and identifying possible defects. The approach demonstrates how sensor information can be transferred and processed for improved transformer health assessment. Intelligent analysis can help identify abnormal conditions before severe failures occur. The research indicates that combining conventional sensing with IoT and machine learning can support predictive maintenance and improve transformer operational reliability.

M. Gajenthiran (2022), The system monitored parameters including transformer current, voltage, power factor, and temperature and communicated the collected information through cloud connectivity. The study demonstrated the feasibility of real-time transformer monitoring using low-cost embedded hardware and IoT technologies. Such a system can reduce dependence on manual inspection and provide remote access to operating information. The findings directly support the proposed Arduino-ESP8266 smart transformer monitoring architecture.

B) Research Gap

- Existing studies mainly focus on transformer condition monitoring and fault detection, while automatic load sharing between two transformers receives less attention.
- Many IoT systems monitor voltage, current, and temperature, but do not integrate these parameters with automatic transformer switching.
- Temperature-based automatic cooling and overload protection are not consistently incorporated into a single monitoring system.
- Limited systems combine automatic load balancing, local LCD monitoring, cloud-based IoT supervision, and thermal protection in one low-cost prototype.
- Therefore, an integrated system is required to provide real-time monitoring, automatic load sharing, remote supervision, and preventive protection for varying industrial load.

IV. PROPOSED SYSTEM

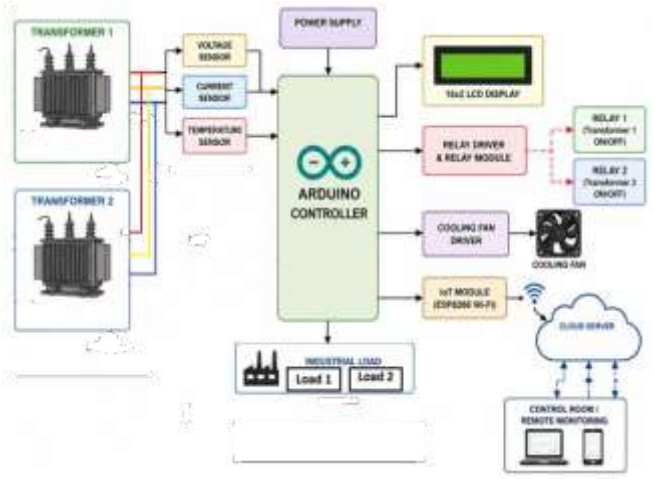


Figure 1. Block Diagram of system

- Power Supply: The system receives electrical supply and provides power to two identical transformers connected for industrial load distribution.
- Normal Operation: Under normal load conditions, Transformer 1 (T1) remains active and supplies the connected industrial load, while Transformer 2 remains in standby mode.
- Parameter Sensing: Voltage and current sensors continuously measure the electrical parameters, while a temperature sensor monitors the operating temperature of the transformer.

- Arduino Processing: The sensors send measured values to the Arduino UNO, which compares the load condition and temperature with predefined threshold values.
- Automatic Load Balancing: When the load exceeds the preset threshold, the Arduino activates the relay controlling Transformer 2 (T2). T2 then shares the additional load with T1.
- Temperature Protection: If transformer temperature rises above the specified limit, the Arduino automatically activates the cooling fan to reduce excessive heating.
- Local Display: The 16×2 LCD continuously displays voltage, current, temperature, transformer status, and load condition for local observation.
- IoT Monitoring: The ESP8266 Wi-Fi module sends real-time operating parameters to the cloud server through the Internet.
- Remote Supervision: The control-room operator can remotely observe transformer performance, load conditions, temperature, and protection status through the IoT platform.
- Continuous Operation: The system continuously repeats sensing, decision-making, load balancing, cooling, and data transmission to provide reliable and safer industrial power distribution.

Main Features:

- Automatic Load Balancing: Two 0.5 kVA transformers are used to distribute power according to the connected load demand and reduce individual transformer loading.
- Intelligent Transformer Switching: Transformer 1 operates under normal conditions, while Transformer 2 is automatically activated when the predefined load threshold is exceeded.
- Real-Time Power Monitoring: Voltage and current sensors continuously measure electrical parameters and provide information about the operating load.
- Temperature Monitoring: A temperature sensor continuously measures transformer temperature to identify excessive thermal conditions.
- Automatic Cooling: A cooling fan is automatically switched ON when the transformer temperature exceeds the specified safety limit.
- Arduino-Based Control: Arduino UNO processes sensor information and controls transformer switching, cooling, and monitoring functions.
- LCD Display: A 16×2 LCD provides local information about voltage, current, temperature, load condition, and transformer status.
- IoT Connectivity: ESP8266 enables wireless transmission of measured parameters to a cloud server.
- Remote Monitoring: Operators can remotely observe transformer performance and abnormal conditions through the IoT platform.
- Enhanced Protection: Automatic load sharing and temperature-based protection help reduce overload, overheating, equipment damage, and unexpected power interruptions.

V. ADVANTAGES

- Automatic Load Sharing: Distributes increasing load between two transformers and reduces overloading of individual units.
- Real-Time Monitoring: Continuously monitors voltage, current, power, and temperature.
- Thermal Protection: Automatically activates cooling during excessive temperature conditions.
- IoT Connectivity: Enables remote monitoring through cloud-based communication.
- Improved Reliability: Reduces failure risks and supports continuous industrial power supply.
- Reduced Maintenance: Early detection of abnormal conditions supports preventive maintenance and reduces unexpected equipment damage.

VI. APPLICATIONS

- Industrial Plants: Suitable for factories with continuously varying electrical loads.
- Manufacturing Units: Supports reliable power distribution for machines and production equipment.
- Electrical Substations: Can be used for transformer monitoring and load management.
- Commercial Buildings: Suitable for buildings experiencing changing power demand.
- Process Industries: Useful where uninterrupted and reliable power is essential.
- Smart Grid Systems: Can support IoT-based monitoring, intelligent load management, and remote transformer supervision.

VII. RESULTS AND DISCUSSION

1. Transformer and Load-Balancing Results

Table 1. Transformer and Load-Balancing Results

Load Demand	Load Current at 12 V	Transformer-1	Transformer-2	Loading of Each Transformer
300 VA	25.00 A	ON	OFF	T1 = 60%, T2 = 0%
400 VA	33.33 A	ON	OFF	T1 = 80%, T2 = 0%
500 VA	41.67 A	ON	ON	50% each*
700 VA	58.33 A	ON	ON	70% each
1000 VA	83.33 A	ON	ON	100% each*

*Values at 500 VA and 1000 VA represent calculated equal-sharing conditions for analysis. The presentation specifically establishes the 300 VA normal condition and 700 VA high-load condition.

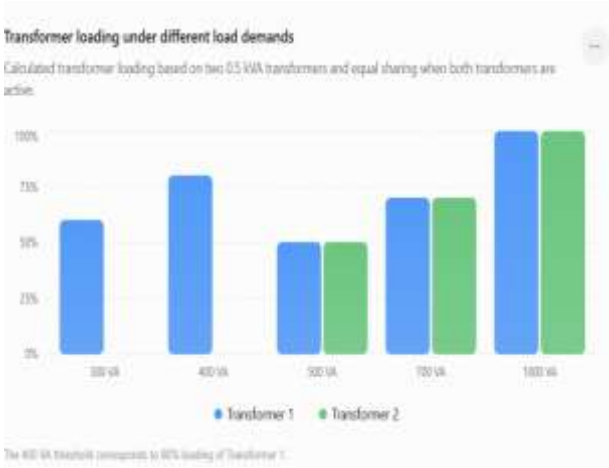


Figure 2. Load Demand vs Transformer Loading

Transformer loading under different load demands,

2. High-Load Condition

At 700 VA, the load exceeds the 500 VA capacity of a single transformer. Therefore, the control system activates Transformer 2 through the relay mechanism. With equal sharing:

$$S_{T1} = S_{T2} = \frac{700}{2} = 350\,VA$$

The corresponding current of each transformer is:

$$I = \frac{350}{12} = 29.17\,A$$

Thus, each transformer operates at approximately 70% of its 500 VA rating, instead of one transformer being subjected to a 700 VA demand. The uploaded presentation explicitly identifies this 700 VA condition and the resulting 29.17 A per transformer.

3. Load Current Results

Table 2. Load Current Results

Load	Total Secondary Current	Current per Transformer	Operating Condition
300 VA	25.00 A	25.00 A	T1 only
400 VA	33.33 A	33.33 A	T1 only
500 VA	41.67 A	20.83 A	Both transformers
700 VA	58.33 A	29.17 A	Both transformers
1000 VA	83.33 A	41.67 A	Both at rated current

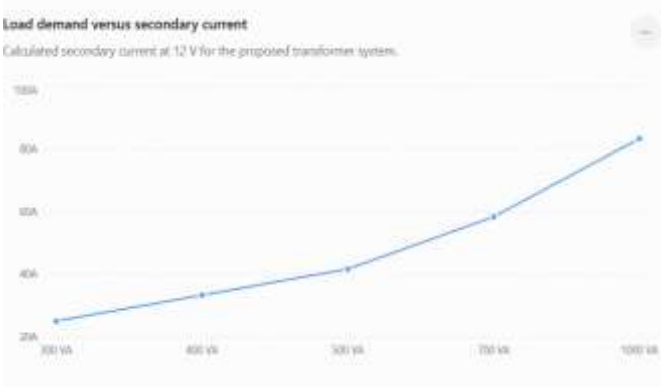


Figure 3. Load Demand vs Secondary Current

4. Automatic Switching Results

Table 3. Automatic Switching Results

Operating Condition	Load Range	Relay Action	T1 Status	T2 Status
Normal load	≤ 400 VA	No activation of T2	ON	OFF
Threshold condition	400 VA	System reaches preset limit	ON	OFF
High load	> 400 VA	Relay activates T2	ON	ON
700 VA load	700 VA	Automatic load sharing	ON	ON

The 400 VA threshold is important because it is equivalent to 80% of the 500 VA capacity of Transformer 1. Once the load exceeds this preset value, Transformer 2 is activated for load sharing.

5. Monitoring and Protection Results

Table 4. Monitoring and Protection Results

Parameter	Monitoring/Control Function	Expected System Response
Voltage	Continuous measurement	Display on LCD and IoT platform
Current	Load-current measurement	Determines load demand
Power	Calculated from electrical parameters	Used for load analysis
Temperature	DS18B20 monitoring	Detects overheating
Transformer status	Relay feedback/control	Shows T1/T2 ON/OFF
Cooling fan	Automatic thermal protection	Activated when temperature exceeds preset limit
IoT data	ESP8266 communication	Remote monitoring through cloud

The presentation specifies that voltage, current and temperature are continuously monitored, while the Arduino processes the data for load analysis. It also specifies automatic cooling when the transformer temperature exceeds the safe threshold and ESP8266-based transmission to the cloud server.

6. Discussion

The calculated results demonstrate the operating principle of the proposed automatic load-balancing system. At the normal 300 VA load, Transformer 1 operates at 60% of its rating and Transformer 2 remains OFF. When the load reaches the 400 VA switching threshold, Transformer 1 reaches 80% loading. For the 700 VA high-load condition, a single 500 VA transformer cannot supply the complete demand; therefore, Transformer 2 is switched ON. Equal sharing reduces the individual transformer load to 350 VA, or 70% of the rated capacity, with approximately 29.17 A supplied by each transformer.

The results also show the importance of integrating electrical and thermal monitoring. The Arduino-based controller can use current and power information to determine when additional transformer capacity is required, while temperature monitoring provides a separate protection mechanism. The LCD provides local status information and the ESP8266 provides remote IoT monitoring, consistent with the proposed architecture shown in the presentation.



Figure 4: Project Model

VIII. Conclusion

The proposed Smart Transformer with IoT-Based Power Monitoring and Automatic Load Balancing System provides an integrated approach for improving transformer operation in industrial applications. The developed concept uses two 0.5 kVA, 230/12 V transformers, Arduino UNO, voltage and current sensors, a DS18B20 temperature sensor, relay modules, LCD display, cooling fan, and ESP8266 IoT connectivity. Under normal loading, Transformer 1 supplies the load while Transformer 2 remains OFF. When the load exceeds the predefined 400 VA threshold, Transformer 2 is automatically activated to share the load. For the considered 700 VA high-load condition, both transformers share approximately 350 VA each, corresponding to about 70% loading and 29.17 A secondary current per transformer. The system also provides continuous monitoring of voltage, current, power, and temperature. Automatic cooling is incorporated to respond to high-temperature conditions, while the LCD enables local observation and the IoT module supports remote monitoring through the cloud. Therefore, the proposed system demonstrates a practical framework for automatic load management, transformer protection, and real-time supervision. The calculated results support the feasibility of the proposed prototype, while actual hardware testing will be required to validate sensor accuracy, switching performance, thermal response, and IoT communication under practical operating conditions.

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