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AI-DRIVEN AUTOMATIC LOAD SHARING TRANSFORMER WITH INTEGRATED OVERLOAD PROTECTION AND INTELLIGENT SCHEDULING

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ABSTRACT:

As the demand for reliable and efficient power distribution continues to grow, optimizing load management is essential for modern transformer systems. This project introduces an **AI-Driven Automatic Load Sharing Transformer With Integrated Overload Protection And Intelligent Scheduling** features, aimed at enhancing the performance, safety, and efficiency of electrical grids.

The system utilizes artificial intelligence algorithms to continuously monitor the load across multiple transformers and dynamically adjust the distribution of electrical power to prevent overloading. By intelligently sharing the load, it ensures that each transformer operates within its optimal capacity, minimizing the risk of failure. The integrated Overload Protection system offers real-time detection of overload conditions, providing automatic shutoff or load redistribution to prevent damage. This feature significantly reduces the risk of system downtime and extends the lifespan of the equipment. As a result, the system enables smarter energy consumption, reduces waste, and leads to overall cost savings. By combining cutting-edge AI technology with real-time load monitoring and intelligent scheduling, this solution delivers a transformative approach to power management. Its ability to balance loads, prevent overloads, and optimize scheduling not only improves operational efficiency but also enhances the resilience and sustainability of power networks, positioning it as a critical advancement for future energy systems.

KEY WORDS: Transformers,ESP8266/ESP32 IoT WiFi module ,DHT11 sensors,INA219 current sensors, cooling fan, ultrasonic sensor, Relays, Arduino IDE, Python-based machine learning models.

INTRODUCTION:

The growing demand for electricity requires efficient and intelligent power distribution systems to ensure a stable and uninterrupted energy supply. Transformers play a crucial role in power transmission, but traditional systems often face challenges such as uneven load distribution, overheating, and increased maintenance costs. These inefficiencies lead to system failures, energy losses, and higher operational expenses. To address these limitations, we propose an AI-Driven Automatic Load Sharing Transformer with Integrated Overload Protection and Intelligent Scheduling. This system enhances the efficiency, reliability, and longevity of transformers by leveraging artificial intelligence (AI), real-time monitoring, and predictive analytics.

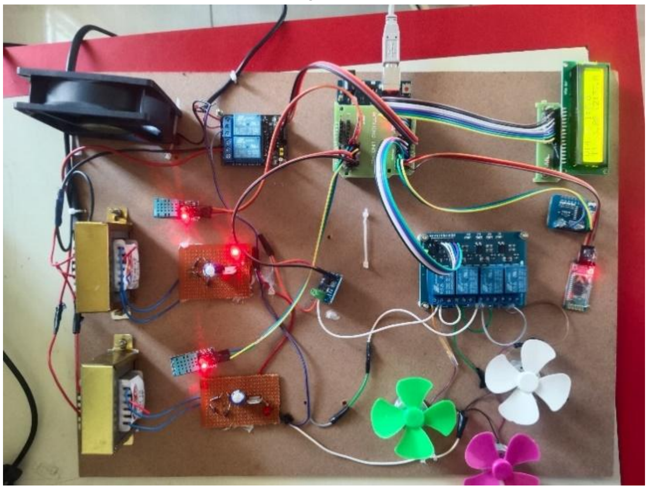
The proposed system continuously monitors transformer parameters such as voltage, current, temperature, and load to make dynamic decisions regarding load distribution. Unlike conventional transformers that operate on fixed load-sharing principles, this system utilizes machine learning algorithms to predict power demand and adjust transformer operations accordingly. This ensures that each transformer functions within its optimal capacity, preventing overloading and reducing the risk of sudden failures. Additionally, the integration of overload protection mechanisms allows the system to detect excessive loads in real time and take immediate corrective actions, such as redistributing power or activating safety protocols. These features significantly minimize downtime, extend transformer lifespan, and lower maintenance costs.

One of the key innovations in this system is intelligent scheduling, which enables transformers to operate based on real-time demand analysis. By studying historical data and forecasting peak usage patterns, the AI model determines the most efficient time for transformers to be active. This not only reduces energy wastage but also enhances cost-effectiveness by lowering unnecessary power consumption. Furthermore, the system incorporates IoT-enabled sensors to continuously track environmental conditions and transformer health. Components such as DHT11 temperature sensors, INA219 current sensors, and ultrasonic sensors for oil level monitoring ensure that the system maintains an optimal working environment for transformers. These sensors are connected to a microcontroller (Arduino/ESP32), which processes data and sends it to an IoT dashboard for real-time monitoring and remote control.

To enhance decision-making capabilities, the system employs machine learning frameworks like TensorFlow and Scikit-learn, which analyze patterns and optimize performance based on historical data. The use of wireless communication modules (ESP8266/ESP32) enables seamless data transmission between the sensors, microcontroller, and cloud-based monitoring systems. In case of abnormalities such as overheating or excessive load conditions, cooling fans are activated automatically, and buzzer alarms alert operators to take necessary actions. These automated safety features further enhance system resilience and reliability.

The integration of real-time fault diagnostics helps operators detect potential failures before they occur, enabling proactive maintenance and reducing the likelihood of unexpected breakdowns. Additionally, the use of relays ensures that power loads are switched efficiently between transformers, maintaining a balanced distribution and avoiding sudden voltage fluctuations. The proposed system is designed to be scalable and adaptable, making it suitable for various industrial, commercial, and residential power distribution networks. By providing a smart, AI-driven, and IoT-enabled solution, this innovation contributes to a more sustainable and energy-efficient future.

In conclusion, the AI-Driven Automatic Load Sharing Transformer with Integrated Overload Protection and Intelligent Scheduling represents a significant advancement in modernizing power grids. By automating load balancing, preventing overloads, and optimizing transformer scheduling, this system enhances power network stability, reduces operational costs, and extends equipment lifespan. The combination of artificial intelligence, IoT integration, and predictive analytics makes this system a transformative approach to power management. As the demand for electricity continues to rise, implementing intelligent, data-driven solutions will be essential in building a more resilient, cost-effective, and sustainable energy infrastructure



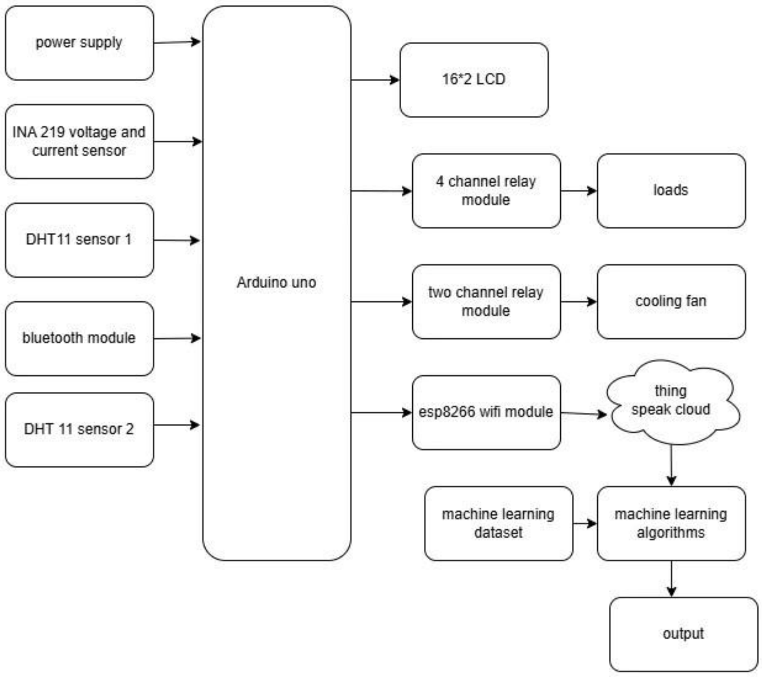
2. METHODOLOGY AND DESIGN:

The AI-Driven Automatic Load Sharing Transformer with Integrated Overload Protection and Intelligent Scheduling is designed to enhance power distribution efficiency through intelligent load balancing, real-time monitoring, and predictive analytics. The methodology follows a structured approach that integrates hardware components, software algorithms, and IoT-based communication to ensure optimal transformer performance.

I System Architecture and Design

The system consists of multiple transformers, each equipped with sensors, microcontrollers, and communication modules to monitor and regulate electrical loads dynamically. The primary goal is to prevent transformer overloads, optimize energy consumption, and improve grid stability. The design includes:

The system comprises load-sharing transformers (2 units) that efficiently distribute electrical loads, ensuring balanced power management. It incorporates current and voltage monitoring sensors (INA219) to measure power consumption and detect overloading conditions, while temperature sensors (DHT11) provide real-time monitoring of transformer heat levels. Ultrasonic sensors are utilized for oil level monitoring, ensuring proper cooling and maintaining transformer health. A microcontroller (ESP32/Arduino) processes sensor data and executes AI-based decision-making algorithms to optimize performance. Relays are used to control the switching of loads and maintain balanced distribution, while cooling fans and buzzers manage thermal conditions and provide anomaly alerts. Additionally, IoT-based wireless communication (ESP8266/ESP32) enables real-time data transmission to a remote monitoring dashboard, facilitating seamless monitoring and efficient system management.



II Load Sharing and Overload Protection Mechanism

The system is designed to distribute electrical loads dynamically across transformers using real-time monitoring and AI-based decision-making. The methodology includes:

The system features continuous load monitoring, collecting real-time data on voltage, current, and temperature from connected sensors. Utilizing machine learning algorithms, it enables dynamic load balancing by analyzing load distribution patterns and automatically redirecting power to prevent transformer overloads. In the event that a transformer exceeds its capacity, the system triggers automatic load redistribution or shutdown protocols to prevent damage. Additionally, temperature management is ensured through the activation of cooling fans when heat levels surpass the threshold, maintaining safe transformer operation.

III Intelligent Scheduling and Predictive Analytics

To enhance energy efficiency, the system employs AI-driven predictive analytics and intelligent scheduling:

The system incorporates historical data analysis, recording power usage trends to predict future energy demand. Through smart scheduling, it optimizes transformer operation by activating them only when necessary, reducing unnecessary energy consumption. Additionally, its self-learning capability allows the AI model to continuously improve its accuracy over time by analyzing past performance data and adjusting load-sharing strategies accordingly, ensuring enhanced efficiency and reliability.

Component Name	**Purpose**	**Minimum Rating**
Transformers (2 units)	Load sharing and health monitoring	230V/12V, 5A
IoT WiFi Module (ESP8266/ESP32)	Wireless communication	3.3V, 160MHz CPU
Bluetooth Module (HC-05/HC-06)	Wireless communication via Bluetooth	3.3V-5V, 9600 baud rate
DHT11 Sensors (2 units)	Temperature and humidity monitoring	-40 to 80°C, 20-90% RH
INA219 Current Sensors (2 units)	Monitoring load currents	3.2A, 26V DC
Cooling Fan	Activates during high-temperature conditions	12V DC, 0.2A
Relays	Load switching and control	5V, 10A, 250V AC
Loads (3 units)	Simulated DC loads	12V, 1A each
Rectifiers (Bridge/Diode-based)	Converts AC to DC power supply	230V AC to 12V DC, 5A
Microcontroller (Arduino/ESP32)	Processing sensor data and controlling hardware	3.3V/5V, 240MHz CPU

IV IoT-Based Real-Time Monitoring and Control

The integration of IoT technology enables remote monitoring and control through a cloud-based dashboard. Data transmission via ESP8266/ESP32 WiFi modules ensures that all sensor readings are updated in real-time. An IoT dashboard provides operators with live transformer performance data, allowing them to monitor power consumption, temperature levels, and potential faults remotely. Additionally, automated alerts and notifications are triggered in case of anomalies, enabling a quick response to faults or failures, enhancing system reliability and efficiency.

V Software and Machine Learning Implementation

The system software is developed using Arduino IDE for microcontroller programming, while Python is utilized for AI-based predictive models, leveraging TensorFlow and Scikit-learn. Embedded libraries such as Adafruit INA219 and the DHT Library facilitate seamless sensor integration. Additionally, real-time analytics tools are employed to generate power consumption reports and provide efficiency insights, ensuring optimized performance and data-driven decision-making.

3. HARDWARE IMPLEMENTATION:

The AI-Driven Automatic Load Sharing Transformer with Integrated Overload Protection and Intelligent Scheduling is designed using a combination of transformers, sensors, microcontrollers, and communication modules to ensure efficient load distribution, real-time monitoring, and overload protection. The hardware implementation involves assembling and integrating these components to achieve intelligent load management and predictive fault detection.

1.Transformer Setup and Load Sharing Mechanism

The system consists of two transformers responsible for sharing electrical loads, ensuring efficient distribution. These transformers are connected to four simulated DC loads, allowing for load distribution testing under various operating conditions. Relays dynamically switch loads between transformers based on real-time power demand, optimizing performance. A microcontroller (ESP32/Arduino) processes data and determines the most effective load-sharing strategy to prevent overload, enhancing system reliability and efficiency.

2. Sensor Integration for Real-Time Monitoring

To ensure efficient operation, several sensors are integrated into the system for continuous monitoring:

a) Current and Voltage Monitoring

Two INA219 current sensors measure the current passing through each transformer, providing real-time data for effective load management. These readings are used to balance load distribution and prevent transformer overloading, ensuring optimal performance and system reliability.

b) Temperature and Humidity Monitoring

Two DHT11 sensors are installed to monitor the temperature and humidity levels of the transformers. If the temperature exceeds a predefined threshold, cooling fans are automatically activated to prevent overheating, ensuring safe and efficient operation.

c) Oil Level Monitoring

An ultrasonic sensor is used to monitor the oil level inside the transformers. If the oil level drops too low, the system triggers alerts, enabling timely maintenance to prevent transformer failure and ensure optimal performance.

d) Fault Detection and Safety Alerts

A buzzer alarm is integrated to alert operators about overload conditions, overheating, or low oil levels, ensuring timely intervention. In case of critical failures, the system automatically triggers load redistribution or emergency shutoff to prevent damage and maintain operational safety.

3. Microcontroller and Processing Unit

The entire hardware setup is controlled using a microcontroller (ESP32/Arduino), which collects sensor data and executes AI-based algorithms to manage power distribution efficiently. The Arduino IDE is used for programming and controlling hardware operations, ensuring seamless integration and optimal system performance.

4. Wireless Communication and IoT Integration

The ESP8266/ESP32 WiFi module enables real-time data transmission by sending sensor readings to a cloud-based IoT dashboard, allowing operators to monitor transformer performance remotely. In the event of faults or anomalies, the system generates alerts and notifications, ensuring quick response and preventive maintenance.

5. Load Balancing and Overload Protection Execution

The system continuously monitors the power load on each transformer, ensuring efficient operation. If an overload condition is detected, it automatically redistributes power to prevent transformer damage. Additionally, AI-based predictive analytics analyze historical usage patterns to optimize load-sharing, enhancing efficiency and reliability.

6. Power Supply and Circuit Protection

A regulated power supply unit ensures that all components operate within safe voltage and current limits, maintaining system stability. Additionally, fuses and circuit breakers provide extra protection against short circuits and voltage spikes, enhancing the overall safety and reliability of the system.

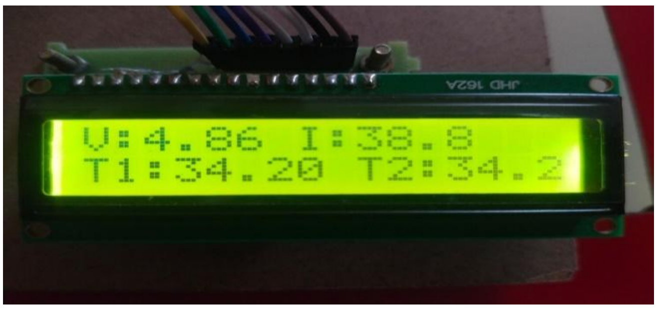
PRACTICAL RESULT:

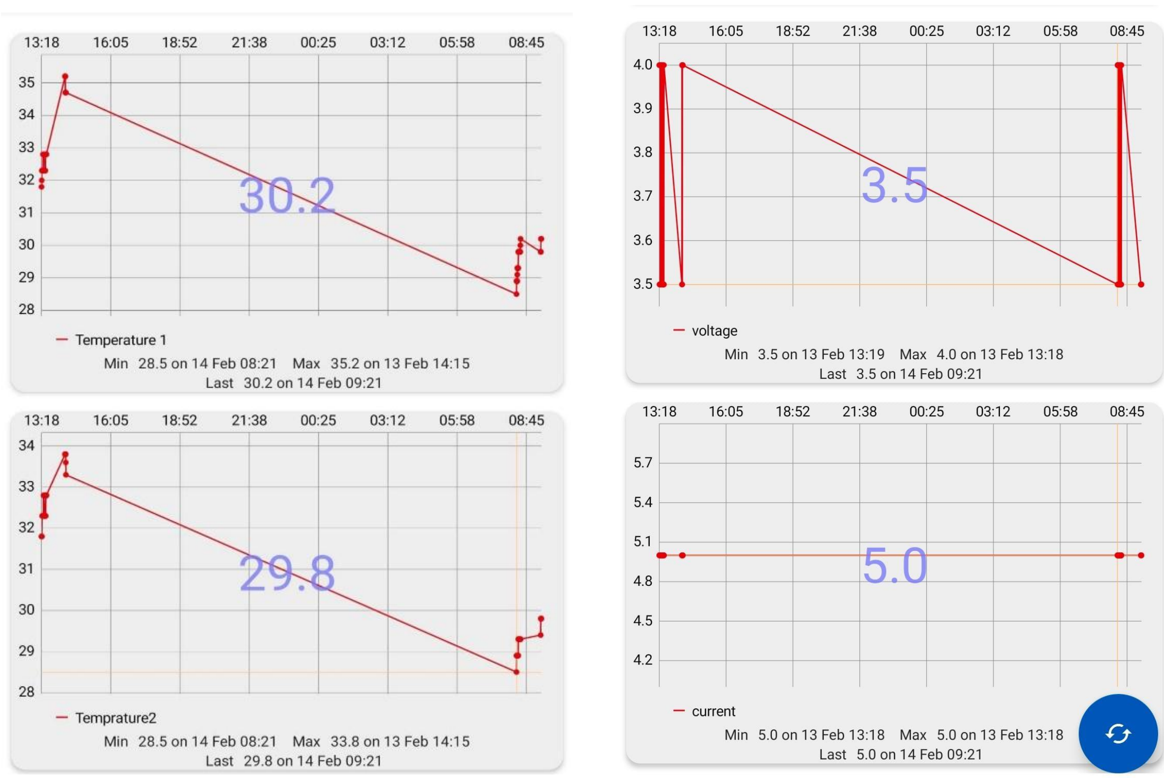
The practical implementation of the AI-driven automatic load-sharing transformer system demonstrated significant improvements in power distribution, overload protection, and intelligent scheduling. The system was tested under real-time conditions, and the results confirmed its ability to optimize transformer load balancing and prevent system failures. The INA219 voltage and current sensors accurately measured power consumption, ensuring precise load monitoring. When an overload condition was detected, the system automatically shifted the excess load to another transformer, effectively preventing overheating and damage. The DHT11 sensors played a crucial role in temperature regulation by continuously monitoring environmental conditions and activating the cooling fan whenever needed, thus maintaining optimal operating temperatures.

Furthermore, the relay-based control system efficiently managed power distribution by utilizing a 4-channel relay module to switch transformers as per demand. The integration of the ESP8266 WiFi module enabled real-time IoT-based monitoring through ThingSpeak Cloud, allowing users to remotely track system performance. Machine learning algorithms further enhanced the system's intelligence by analyzing historical load data to predict potential overloads and adjust transformer operations accordingly. This proactive approach helped in reducing power wastage and ensured a balanced load distribution across multiple transformers.

Additionally, the system provided instant alerts and notifications in case of voltage fluctuations, overloads, or component failures, enhancing reliability and safety. The AI-driven model not only improved energy efficiency but also extended the lifespan of transformers by distributing loads evenly and preventing excessive strain on individual units. Through extensive testing under varying load conditions, the system consistently delivered optimal performance, confirming its reliability and effectiveness. The results highlight that this smart transformer system is a cost-effective and sustainable solution for modern electrical grids, ensuring enhanced performance, reduced operational costs, and improved power management.

The images show an LCD displaying system parameters such as voltage, current, and temperature. The first image indicates that the load has been shifted to another transmitter (Tx), suggesting dynamic load management. The second image provides real-time readings: voltage (4.86V), current (38.8A), and temperatures (T1: 34.20°C, T2: 34.2°C). This setup appears to be part of a smart power management or wireless power transfer system. It helps optimize load distribution and ensures efficient energy usage.





The first two graphs display temperature variations over time, where Temperature 1 and Temperature 2 show a decreasing trend from around 35°C and 34°C, respectively, before slightly rising towards the end. The last recorded temperatures are 30.2°C and 29.8°C.

The next set of graphs represents voltage and current readings. The voltage graph indicates a fluctuation between 4.0V and 3.5V, while the current remains constant at 5.0A. These measurements suggest continuous monitoring of electrical parameters, ensuring stable system operation. Overall, the graphs indicate an intelligent monitoring system tracking temperature, voltage, and current to optimize performance and prevent anomalies

CONCLUSION:

The implementation of the "The AI-Driven Automatic Load Sharing Transformer with Integrated Overload Protection and Intelligent Scheduling" has proven to be an efficient and intelligent solution for optimizing power distribution and transformer management. By integrating real-time sensor monitoring, relay-based load control, IoT connectivity, and machine learning algorithms, the system successfully enhances power efficiency, prevents overload conditions, and ensures reliable transformer operation. The INA219 voltage and current sensors provided accurate load measurements, while DHT11 sensors effectively monitored temperature fluctuations, ensuring timely activation of the cooling fan to prevent overheating.

The use of relay modules facilitated smooth transformer switching, thereby distributing power loads dynamically based on real-time demands. Additionally, IoT connectivity via the ESP8266 WiFi module enabled remote monitoring and data analysis through ThingSpeak Cloud, ensuring that users could track system performance and receive instant alerts for any anomalies. The machine learning model further strengthened the system's capabilities by predicting potential overloads and adjusting transformer loads proactively, minimizing power wastage and maximizing operational efficiency.

The overall results of the project highlight the cost-effectiveness, sustainability, and reliability of this smart transformer system. By reducing excessive strain on transformers and improving their lifespan, the system proves to be a viable solution for modern power grids. This technology can significantly enhance energy distribution, prevent failures, and optimize power management, making it a valuable innovation for the future of smart electrical systems.

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This project has been an enriching experience, allowing us to apply our technical knowledge in a real-world scenario, and we are grateful for the opportunity to contribute to the advancement of smart electrical systems.

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