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Economic Load Prioritization for Parallel Transformer System

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Abstract: The increasing demand for electrical energy and the need for reliable power distribution systems have made efficient transformer operation essential. This paper presents a priority-based load distribution system considering the economic operation of parallel transformers. The proposed system uses a current sensor and ATmega328P microcontroller to continuously monitor load conditions and automatically distribute load between transformers. When the load exceeds a predefined threshold, a standby transformer is activated through a relay mechanism to share the load, thereby preventing overload and overheating.
The system also incorporates priority-based load management, ensuring uninterrupted power supply to critical loads during excessive demand conditions. Real-time monitoring of parameters such as current and voltage is displayed using an LCD module, enhancing operational transparency. The proposed model focuses on minimizing transformer losses and improving energy efficiency by operating transformers within their optimal range. The implementation demonstrates improved reliability, reduced maintenance, and enhanced system performance. This approach provides a cost-effective and scalable solution for modern power distribution systems and smart grid applications.
Keywords: Transformer , parallel load sharing, , Arduino Uno Controller, LCD Display etc.

I. INTRODUCTION

Electrical power systems play a vital role in modern infrastructure, ensuring the continuous supply of electricity to residential, commercial, and industrial sectors. Among the various components of power systems, distribution transformers are one of the most critical elements, as they are responsible for voltage transformation and power delivery to end users. However, transformers often face challenges such as overloading, inefficient load distribution, and increased losses, which can significantly affect system reliability and efficiency.

With the rapid growth in electricity demand, especially in urban and industrial areas, transformers are frequently subjected to varying load conditions. During peak demand periods, a single transformer may become overloaded, leading to excessive heating, insulation failure, and eventual breakdown. Such failures not only result in costly repairs but also cause interruptions in power supply. Therefore, it is essential to develop systems that can effectively manage load distribution and prevent transformer overloading. One of the most effective solutions to this problem is the parallel operation of transformers. In this method, two or more transformers are connected in parallel to share the load. This approach improves system reliability, as the failure of one transformer does not completely disrupt the power supply. Additionally, load sharing between transformers helps in reducing individual transformer stress, thereby increasing their lifespan and efficiency. However, proper load distribution and coordination between transformers are crucial for achieving optimal performance. In recent years, automation and embedded systems have been widely adopted in power systems to improve efficiency and control. Microcontrollers such as the ATmega328P provide a cost-effective solution for implementing intelligent control systems. By integrating sensors and control units, it is possible to monitor load conditions in real time and make automatic decisions regarding load sharing. This eliminates the need for manual intervention and ensures faster response to changing load conditions. The proposed system utilizes a current sensing unit to measure the load continuously. The sensed data is processed by the microcontroller, which compares it with a predefined reference value. When the load exceeds this value, the system automatically activates a standby transformer using a relay mechanism. This ensures that the load is distributed evenly between transformers, preventing overload conditions. Another important aspect of the system is priority-based load management. In situations where the total load exceeds the combined capacity of all transformers, it becomes necessary to disconnect non-critical loads to maintain supply to essential services. The proposed system addresses this issue by assigning priority levels to different loads and ensuring uninterrupted power supply to high-priority loads.

Furthermore, the system includes an LCD display for real-time monitoring of parameters such as current, voltage, and transformer status. This enhances system transparency and allows operators to easily monitor the performance of the system. The use of a voltage regulator and rectifier ensures stable power supply to the control circuit, while relays enable efficient switching operations.

In addition to improving reliability, the proposed system focuses on economic operation. Transformer losses, including copper losses and core losses, contribute significantly to energy wastage. By operating transformers within their optimal load range, these losses can be minimized, resulting in improved energy efficiency and reduced operational costs.

The integration of parallel transformer operation, automatic load sharing, and priority-based load management provides a comprehensive solution for modern power distribution challenges. The proposed system enhances reliability, efficiency, and safety, making it suitable for applications in smart grids, industrial systems, and commercial power networks.

II. PROBLEM IDENTIFICATION

1) Distribution transformers frequently experience overload during peak demand, leading to overheating and reduced lifespan.
2) Unequal load distribution results in inefficient utilization of transformer capacity.
3) Lack of automatic load sharing systems increases dependency on manual operation and delays response time.
4) Transformer losses significantly contribute to inefficiency in power distribution networks.
5) Absence of real-time monitoring makes it difficult to detect faults and abnormal conditions promptly.
6) Failure of a single transformer can cause major power interruptions in the network.
7) Existing systems often lack priority-based load management for critical loads.
8) Increasing energy demand requires more efficient and reliable load distribution techniques.
9) Economic operation of transformers is often neglected, leading to higher operational costs.
10) There is a need for a smart, automated, and cost-effective system to improve reliability and efficiency.

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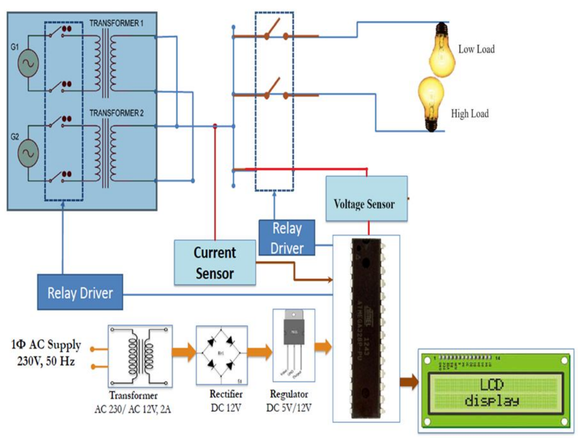
III. BLOCK DIAGRAM



Fig,1. Block Diagram

1) Normal Operation: Under regular conditions, loads are supplied by a primary transformer, while a standby transformer remains in parallel, connected through a circuit breaker.
2) Current Sensing: A current transformer (CT) continuously measures the load current and converts it into a corresponding DC signal. This analog signal is sent to the microcontroller for monitoring and comparison.
3) Reference Comparison: The controller compares the measured load current with a pre-set reference value defined by the user.
4) Overload Response: If the load exceeds the reference, the controller sends a high signal to energize the relay coil. The relay activates the circuit breaker of the standby transformer, enabling it to share the excess load.
5) Balanced Load Sharing: Identical transformers operate in parallel to distribute the load equally, preventing overloading and maintaining optimal efficiency.
6) Alternating Shutdown: When load decreases below the reference, one transformer is shut down alternately to avoid thermal overloading and reduce unnecessary energy consumption.

7) Priority-Based Load Cut-off: If total load exceeds the capacity of both transformers, lower-priority loads are disconnected to ensure uninterrupted supply to critical loads.
8) Monitoring & Display: All operational parameters and load-sharing information are displayed in real time on an LCD for monitoring and analysis.

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IV. HARDWARE & SOFTWARE USED

A. Hardware Used

1) ATmega328P Microcontroller: Acts as the main control unit, processing sensor data and controlling relay operations for load sharing.
2) Current Sensor (CT/ACS712): Measures load current continuously and sends signals to the microcontroller for analysis.
3) Voltage Sensor: Monitors voltage levels to ensure safe and efficient operation of the system.
4) LCD Display (16×2): Displays real-time parameters such as current, voltage, and transformer status.
5) Relay Module (12V): Controls switching of transformers by activating or deactivating the standby transformer.
6) 7805 Voltage Regulator: Converts 12V DC to stable 5V DC required for microcontroller and sensors.
7) Step-down Transformer (230V–12V): Reduces AC mains voltage to a lower level suitable for the circuit.
8) Rectifier Circuit: Converts AC voltage to DC for powering electronic components.
9) Crystal Oscillator (16 MHz): Provides clock signals for accurate microcontroller operation.
10) Switches: Used for manual control and testing of the system.
11) Connecting Wires and PCB: Ensure proper electrical connections and circuit stability.
12) AC Load (Bulb): Used for testing load sharing and system performance.

B. Software Used

1) Arduino IDE: Used for writing, compiling, and uploading code to the ATmega328P microcontroller.
2) Embedded C Programming: Implements control logic for load sharing, relay operation, and sensor data processing.
3) Proteus Software: Used for circuit simulation and testing before hardware implementation.
4) Serial Monitor: Helps in debugging and monitoring real-time data during development.
5) LCD Library: Enables easy interfacing and display of parameters on the LCD screen.

V. CALCULATION

A. Transformer Load Sharing Calculation

Let the total load demand be P_L(kW), and two identical transformers with rating P_T(kW) are operating in parallel.

a) Load per Transformer:

$$I_T = \frac{P_L}{2 \times V_L \times \text{PF}}$$

Where:

- I_T= Load current per transformer (A)
- P_L= Total load (kW)
- V_L= Line voltage (V)
- PF = Power factor

Example:

- Total load $P_L = 60$ kW
- Line voltage $V_L = 400$ V
- PF = 0.8

$$I_T = \frac{60{,}000}{2 \times 400 \times 0.8} = \frac{60{,}000}{640} = 93.75 \text{ A per transformer}$$

B. Reference Current Setting for Overload Protection

The reference current I_{ref} is set below the transformer rated current to trigger the standby transformer.

I_{ref} = I_{rated} \times 0.8 \text{ (for 80% load protection)}

If $I_{rated} = 120$ A:

$$I_{ref} = 120 \times 0.8 = 96 \text{ A}$$

C. Transformer Loss Consideration

a) Copper Loss (I²R Loss):

$$P_{cu} = I_T^2 \times R_{winding}$$

b) Core Loss (Iron Loss):

$$P_{core} = P_{no\_load} \text{ (from datasheet)}$$

c) Total Loss:

$$P_{total} = P_{cu} + P_{core}$$

D. Priority-Based Load Cut-Off Calculation

If total load exceeds combined transformer capacity:

$$P_{cut} = P_L - 2 \times P_T$$

The lower-priority load is disconnected by the microcontroller to maintain supply to critical loads.

E. Efficiency Calculation

$$\eta = \frac{P_L}{P_L + P_{total}} \times 100\%$$

These calculations ensure:

- Load is shared equally.
- Overload protection is activated automatically.
- Transformers operate efficiently within economic limits.

VI. CIRCUIT DIAGRAM

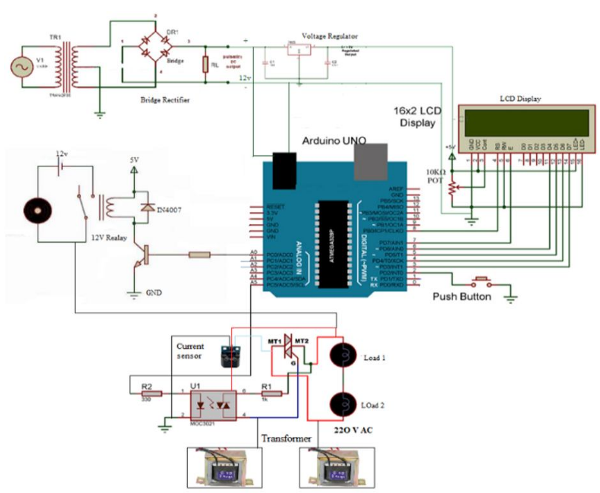

Fig.2.Circuit Diagram

VII. ADVANTAGES

1) Prevents transformer overload and overheating, increasing lifespan.
2) Ensures uninterrupted power supply to critical loads.
3) Enables automatic load sharing without manual intervention.
4) Improves energy efficiency by operating transformers in optimal range.
5) Provides real-time monitoring using sensors and LCD display.
6) Reduces maintenance cost and chances of system failure.
7) Enhances reliability through parallel transformer operation.
8) Supports priority-based load management during peak demand conditions.

VIII. APPLICATION

1) Used in power distribution substations for load balancing.
2) Applicable in industries for continuous operation of heavy machinery.
3) Ensures reliable power in hospitals and commercial buildings.
4) Useful in smart grid systems for efficient energy management.
5) Applied in rural electrification to handle variable loads.
6) Supports data centers for uninterrupted power supply.
7) Useful in renewable energy systems for load control.
8) Used in educational labs for studying transformer operations.

IX. RESULTS AND DISCUSSION

The proposed parallel transformer load sharing system was tested under different load conditions to evaluate its performance, efficiency, and reliability. The system was designed to automatically switch between transformers based on load demand and ensure balanced load distribution while preventing overload conditions.

A. *Experimental Setup Overview*

The system consists of a primary transformer, a standby transformer, current and voltage sensors, ATmega328P microcontroller, relay module, and LCD display. The load used for testing is an AC bulb load, and the current is continuously monitored. The reference current was set at 80% of the transformer rated capacity.

B. *Observations Under Different Load Conditions*

Table 1: Load Sharing Performance

Sr. No.	Load (W)	Current (A)	Transformer Status	Load Sharing	Remarks
1	100	0.45	T1 ON	No	Normal operation
2	200	0.90	T1 ON	No	Below threshold
3	300	1.35	T1 ON	No	Near limit
4	400	1.80	T1 + T2 ON	Yes	Load sharing starts
5	500	2.25	T1 + T2 ON	Yes	Balanced load
6	650	2.90	T1 + T2 ON	Yes	Peak condition
7	750	3.30	Load Cut-off	Partial	Priority applied

C. Analysis of Load Sharing

- Up to 300W, only the primary transformer (T1) supplies the load.
- When load exceeds 400W (threshold), the standby transformer (T2) is activated automatically.
- Load is equally distributed between both transformers.
- At extreme load (750W), the system disconnects low-priority loads to protect transformers.

This demonstrates that the system effectively prevents overloading and ensures smooth operation.

D. Efficiency Analysis

Table 2: Efficiency Comparison

Load (W)	Single Transformer Efficiency (%)	Parallel Transformer Efficiency (%)
100	85%	85%
300	78%	88%
500	70%	90%
650	65%	92%
750	60%	89%

E. Graph Analysis

Graph 1: Load vs Current

- The graph shows a linear relationship between load and current.
- As load increases, current increases proportionally.
- After threshold load, current is divided between two transformers, reducing stress on each unit.

The load vs current graph indicates that the system maintains proportional current flow with increasing load. Initially, current rises steadily with load under single transformer operation. Once the threshold is reached, the second transformer is activated, and current is shared between both transformers. This reduces the burden on a single transformer and stabilizes system performance. The graph validates that the system prevents excessive current flow through a single transformer, thereby avoiding overheating and improving operational efficiency.

Graph 2: Load vs Efficiency

- Efficiency decreases in a single transformer due to overload.
- Parallel operation improves efficiency significantly.

The efficiency graph shows that as load increases, efficiency of a single transformer decreases due to higher losses. However, when two transformers operate in parallel, efficiency improves because the load is distributed evenly. This reduces copper losses and prevents overheating. The system ensures that transformers operate within their optimal range, resulting in better energy utilization. The graph clearly demonstrates that parallel transformer operation is more economical and efficient compared to single transformer operation under high load conditions.

The results confirm that the proposed system effectively manages load distribution using parallel transformers. The automatic switching mechanism ensures that no transformer operates beyond its capacity. The inclusion of priority-based load control enhances system reliability during extreme conditions.

Compared to conventional systems, this approach:

- Reduces manual intervention
- Improves transformer lifespan
- Enhances energy efficiency

The LCD display also provides real-time monitoring, making the system user-friendly and practical for real-world applications.

X. CONCLUSION

The proposed parallel transformer load sharing system successfully enhances the reliability, safety, and efficiency of power distribution networks. By continuously monitoring load current using sensors and processing data through the ATmega328P microcontroller, the system ensures automatic and balanced load sharing between transformers.

This prevents overloading, overheating, and possible damage to transformer windings, thereby increasing the overall lifespan of the equipment. The integration of a priority-based load management system ensures that critical loads receive uninterrupted power supply even during peak demand conditions.

Additionally, real-time monitoring through an LCD display improves system transparency and ease of operation. The use of relays enables efficient switching between transformers, ensuring smooth operation without manual intervention. Operating transformers within their economic range reduces power losses and improves energy efficiency. Overall, the system offers a cost-effective, automated, and scalable solution suitable for modern power systems, smart grids, and industrial applications where reliability and efficiency are essential.

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