Microcontroller-Based Intelligent Transformer Tap Control System for Automatic Voltage Regulation

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ABSTRACT

Transformers play a crucial role in electrical power transmission and distribution systems because they help regulate voltage levels between generation and consumption points. In modern power networks, maintaining a stable output voltage is essential since load variations can cause voltage fluctuations that affect system performance. To address this issue, tap-changing transformers are widely used to adjust the transformation ratio and regulate the output voltage. This project presents the design and implementation of an automatic tap changer for a transformer using an ATmega328 microcontroller. The proposed system uses a current sensor to monitor load conditions and automatically adjusts the transformer tap position using a servo mechanism. The system also displays electrical parameters such as voltage, current, and power on an LCD screen. The proposed approach improves operational efficiency, reduces manual intervention, and provides better voltage regulation in comparison with conventional tap-changing techniques.

Keywords: Tap changer, transformer voltage regulation, ATmega328, Arduino, current sensor

I.   INTRODUCTION

Electrical energy has become an essential part of modern life, supporting industrial activities, communication systems, transportation, and residential needs. Transformers are key components in electrical power systems because they enable efficient transmission and distribution of electrical energy by stepping voltage levels up or down as required. In order to maintain a stable output voltage under varying load conditions, transformers are often equipped with tap-changing mechanisms that modify the turn's ratio of the transformer winding [1, 2].

A tap changer works by connecting different tapping points on the transformer winding, allowing small adjustments in the output voltage. These tapping points are usually located on the high-voltage winding side because the current flowing through it is relatively lower, which simplifies the switching process. Tap changers can operate either when the transformer is disconnected from the supply or while the transformer is energized.

Conventional mechanical tap changers have been widely used in power systems; however, they present several limitations such as electrical arcing, slower switching speed, higher maintenance requirements, and increased operational costs [3, 4]. Recent developments in electronic control systems and semiconductor switching devices have enabled the development of automated tap-changing systems that provide faster response, reduced maintenance, and improved reliability. In this project, an ATmega328 microcontroller is used to implement an automatic tap-changing system capable of monitoring electrical parameters and adjusting transformer taps accordingly. This automated system improves voltage regulation and enhances overall system performance.

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II.   LITERATURE REVIEW

Voltage regulation is an important requirement in electrical power systems to ensure that electrical equipment operates safely and efficiently. Tap-changing transformers are commonly used to regulate voltage by altering the effective turn's ratio of the transformer winding. The tap-changing process can be categorized into two main types: off-load tap changing and on-load tap changing. Off-load tap changing occurs when the transformer is disconnected from the power supply before the tap position is adjusted. In this method, the transformer is completely de-energized to prevent arcing at the switching contacts. Although this approach is simple and economical, it is not suitable for large power systems because it requires interruption of the power supply during adjustment [5-7].

On the other hand, on-load tap changing allows the tap position to be modified while the transformer remains energized and supplying power to the load. This method ensures continuous power delivery without interruption; however, it requires more complex switching mechanisms and protective circuits. Researchers have proposed different electronic and hybrid tap-changing techniques that combine mechanical and semiconductor switching devices to improve efficiency and reduce arcing effects [8-10].

The integration of microcontrollers and sensors has further improved tap-changing systems by enabling automatic control and monitoring. Microcontroller-based systems can measure electrical parameters such as current and voltage and then adjust the transformer taps accordingly. These systems offer faster response times, reduced maintenance requirements, and improved operational flexibility compared with traditional tap-changing methods.

III.   PROPOSED METHOD

The proposed system aims to automate the tap-changing process of a transformer using a microcontroller-based control unit. The design focuses on improving system reliability, reducing manual intervention, and minimizing operational costs. The system continuously monitors the electrical parameters of the load and adjusts the tap position of the transformer accordingly. In this design, the ACS712 current sensor is used to measure the load current flowing through the circuit. The sensor output is connected to the ATmega328 microcontroller, which processes the measured signal and determines whether a tap adjustment is required. Based on the processed data, the microcontroller activates the appropriate relay and controls a servo motor that physically adjusts the transformer tap position.

To simulate and verify the operation of the system, Proteus software was used for circuit simulation and Arduino program development. Additionally, Eagle software was used for designing the printed circuit board (PCB) layout. The system allows automatic control of the transformer taps, which helps maintain stable voltage levels even when load conditions change. Compared with conventional manual tap-changing systems, the proposed approach provides greater flexibility and efficiency because the system can operate automatically without requiring direct human intervention.

The circuit diagram of the proposed system is illustrated in Figure 1. The system begins with a 230-volt AC power supply that is stepped down using a step-down transformer to obtain a lower voltage suitable for electronic components. The stepped-down voltage is then passed through a rectifier circuit that converts the AC voltage into DC voltage.

To provide stable voltage levels for the control circuitry, voltage regulator integrated circuits such as 7805 and 7812 are used. These regulators supply regulated output voltages of +5 V and +12 V respectively. The +5 V supply is mainly used to power the microcontroller and other digital components, while the +12 V supply is used for relay operation. The main control unit of the system is the ATmega328 microcontroller, which is the core component of the Arduino Uno R3 platform. The microcontroller receives input signals from the ACS712 current sensor and processes them according to the programmed control algorithm. Based on the detected load conditions, the microcontroller activates relay circuits that control the transformer tap-changing mechanism.

An LCD display module is connected to the microcontroller to show real-time electrical parameters such as voltage, current, and power consumption. This display allows users to monitor system performance easily. The overall circuit is designed to ensure stable operation and efficient control of the transformer tap-changing process.
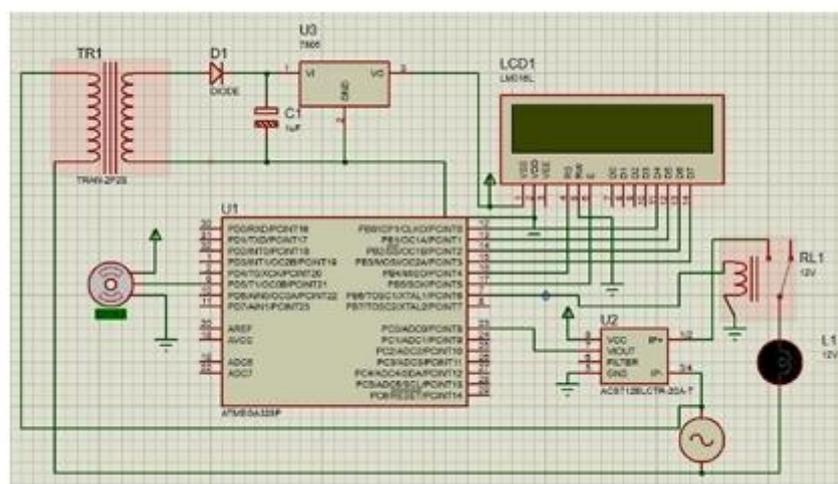

Figure 1: Circuit diagram of the automatic transformer tap-changing system.

IV.   HARDWARE IMPLEMENTATION

The hardware implementation of the proposed system is shown in Figure 2. The experimental setup consists of the transformer unit, control circuit board, microcontroller, sensor module, LCD display, and the servo motor used for tap adjustment. All components are mounted on a base platform to create a compact prototype system.

The ATmega328 microcontroller acts as the central processing unit of the system, controlling all operations based on the input signals received from the current sensor. The ACS712 sensor continuously measures the load current and sends an analog signal to the microcontroller. The microcontroller processes this signal and determines whether the transformer tap position needs to be adjusted. The servo motor connected to the transformer taps is controlled by the microcontroller to change the tap position automatically. This mechanism allows the system to maintain stable voltage output under different load conditions. The LCD display provides real-time information about system parameters, enabling users to monitor system performance effectively.

Figure 2: Hardware implementation of the automatic tap-changing transformer system

V.   RESULTS

Figure 3: LCD display showing voltage, current, and power measurement for one load condition.

Figure 4: LCD display showing measured electrical parameters for another load condition.

The experimental results obtained from the hardware prototype demonstrate the effectiveness of the proposed system. Figures 3, and 4 show the readings displayed on the LCD screen during different load

conditions. The display provides real-time measurements of voltage, current, and power consumption, allowing the system to monitor load variations accurately.

When the load conditions change, the current sensor detects the variation and sends the corresponding signal to the microcontroller. The microcontroller processes this information and determines whether the transformer tap position should be adjusted. The servo motor then moves to the appropriate tap position, ensuring that the output voltage remains within the desired range.

The experimental observations confirm that the proposed system successfully measures electrical parameters and adjusts the transformer taps automatically. This demonstrates the effectiveness of using a microcontroller-based control system for automatic voltage regulation in transformer applications.

VI.   CONCLUSION

The automatic transformer tap changer designed in this project demonstrates an effective method for maintaining voltage stability in electrical systems. By using an ATmega328 microcontroller along with a current sensing module, the system is able to monitor load conditions and automatically adjust the transformer tap position. This automation reduces the need for manual intervention and helps ensure that the output voltage remains within the desired operating range even when load variations occur. The integration of the ACS712 current sensor, relay circuits, servo motor, and LCD display enables the system to measure and display electrical parameters such as voltage, current, and power in real time. The microcontroller processes these measurements and controls the tap-changing mechanism accordingly, resulting in improved voltage regulation and system reliability. The hardware implementation and experimental results confirm that the proposed system functions successfully under different load conditions. Overall, the developed automatic tap changer system offers several advantages over conventional manual tap-changing methods, including faster response, reduced maintenance requirements, and improved operational efficiency. The proposed design can be further enhanced by incorporating advanced monitoring techniques, wireless communication, or IoT-based control for remote monitoring and automation in modern smart power distribution systems.

VII.   REFERENCES

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