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IoT Based Transformer Health Monitoring System

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***Abstract*: This paper presents the design and implementation of an IoT-based transformer health monitoring system built around a PIC16F877A microcontroller. The system continuously measures a transformer's voltage, current, frequency, winding temperature and oil level using a potentiometer-based voltage and current sensing arrangement, an optocoupler-based frequency measuring unit, an LM35 temperature sensor and an ultrasonic sensor, and displays the readings on an LCD module. When a monitored parameter moves outside its preset safe range, the microcontroller sounds a buzzer and switches a relay to trip the circuit breaker, isolating the transformer before the fault can cause further damage. An ESP8266 Wi-Fi module pushes the same readings to the Thing Speak IoT platform and a mobile app, so operating personnel can view live parameters and receive abnormal-condition alerts remotely rather than only at the local panel. The design uses low-cost, readily available components throughout, which keeps the system affordable to deploy at distribution transformers and substations where continuous human monitoring is impractical.**

***Keywords*: IoT, transformer health monitoring, PIC16F877A, ESP8266, Thing Speak, LM35 temperature sensor, relay protection, substation automation.**

1. Introduction

Distribution transformers are usually left unattended between scheduled inspections, so a developing fault overvoltage, overcurrent, overheating, an abnormal supply frequency, or a falling oil level can go unnoticed until it causes an outage or damages the unit. Continuous, automated monitoring of these parameters, with a local protective action and a remote alert, closes that gap without requiring a person to be present at the transformer.

This project implements such a monitor using a PIC16F877A microcontroller as the processing core. Voltage, current, frequency, oil-tank level and winding temperature are read by dedicated sensor circuits, converted to engineering values by the microcontroller, and shown on an LCD module at the transformer. If any reading crosses a preset limit, the microcontroller sounds a buzzer and drives a relay that opens the circuit breaker, taking the transformer off-line before the fault worsens. An ESP8266 Wi-Fi module relays the same readings to the Thing Speak IoT platform and a mobile app, so the status can be checked and abnormal-condition alerts received from anywhere with network coverage. This paper describes the hardware and software used, the interfacing of each sensor and actuator to the microcontroller, and the results obtained from the assembled system.

2. Literature Survey

Microcontroller-based protection schemes for distribution equipment typically combine a small number of analog sensing circuits for voltage and current sensing, resistive dividers or transformers are standard with a single low-cost microcontroller that compares each reading against fixed thresholds and drives a protective relay when a limit is exceeded. The PIC16F877A used in this project is a widely documented mid-range 8-bit microcontroller from Microchip's PIC16F87X family, chosen here for its on-chip analog-to-digital converter, its 8k-word flash program memory, and its low unit cost, which suit a single-board monitoring and protection design.

For the temperature channel, the LM35 precision analog temperature sensor is a common choice in this class of project because its output is linear in degrees Celsius and needs no external calibration, simplifying the analog front end. For the communication layer, the ESP8266 is a low-cost Wi-Fi module frequently paired with PIC and AVR microcontrollers to add IoT connectivity to an otherwise stand-alone embedded design, and Thing Speak is a widely used cloud platform for logging and visualizing exactly this kind of periodic sensor data and for triggering mobile notifications when a channel crosses a set threshold. The system described here follows this established pattern: local sensing and protection handled entirely by the microcontroller, with the Wi-Fi module and cloud platform added purely for remote visibility and alerting.

3. Proposed System

The system is built around a central block diagram in which the PIC16F877A microcontroller reads five sensor inputs, voltage, current, temperature, frequency and oil level and drives three outputs an LCD display, a buzzer and a relay-while an ESP8266 module provides a Wi-Fi uplink. The main functional blocks are the regulated power supply, the PIC microcontroller, the ESP8266 Wi-Fi module, the LCD display with its driver, the electromagnetic relay with its driver, the temperature sensor, the voltage sensor, the current sensor, the optocoupler-based frequency unit, the ultrasonic oil-level sensor, the buzzer with its driver, the crystal oscillator, and LED status indicators. The microcontroller continuously polls each sensor, refreshes

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the LCD, and checks every reading against its preset limit; an abnormal reading triggers the buzzer and relay locally and, through the ESP8266, a notification on the user's mobile device.

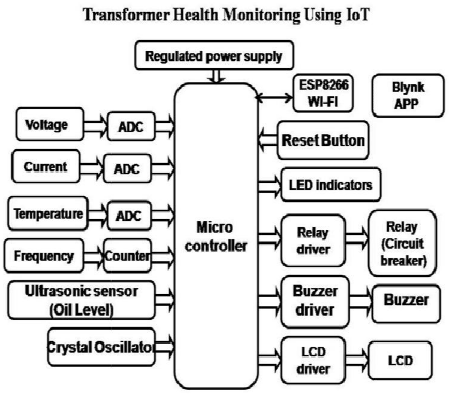

Fig. 1. Block diagram of the IoT-based transformer health monitoring system

4. Hardware Description

A. Microcontroller - PIC16F877A

The PIC16F877A is a 40-pin, 8-bit microcontroller from Microchip's mid-range PIC16F87X family, built on a Harvard architecture with separate program and data memory so that instruction fetch and data access can proceed simultaneously. It provides 368 bytes of RAM, 256 bytes of EEPROM and 8k words of flash program memory, a 35-instruction RISC instruction set, an on-chip 8-bit 5-channel analog-to-digital converter, power-on and brown-out reset, and a watchdog timer, all of which suit a low-cost, single-chip monitoring and protection application. Its five I/O ports (A–E) carry the sensor inputs and the LCD, relay, buzzer and Wi-Fi module connections used in this design.

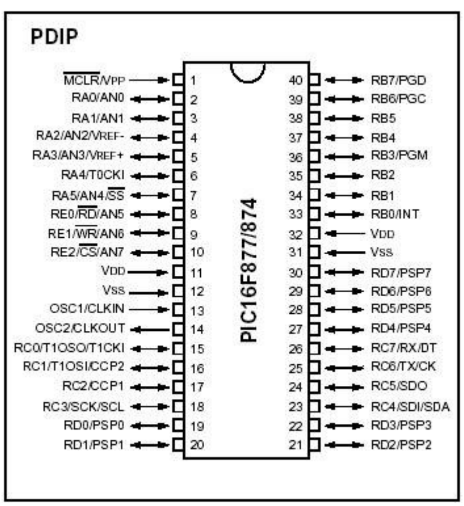

Fig. 2. Pin diagram of the PIC16F877A microcontroller (PDIP package)

B. Power Supply

A regulated power supply derived from the mains feeds the microcontroller and its peripheral circuits at the fixed DC voltage they require, with a crystal oscillator connected to the microcontroller's clock pins providing the timing reference for instruction execution and for the frequency-measurement routine.

C. Voltage and Current Sensing

In a field deployment, the voltage and current inputs are taken from step-down voltage and current transformers connected across the transmission line, scaled to a level the microcontroller's ADC can read. In this prototype, potentiometers stand in for the transformer-based sensors during bench testing: the potentiometer output is compared against fixed upper and lower bounds, and a reading outside those bounds is treated as a fault, causing the microcontroller to issue a trip signal to the relay.

Fig. 3. Commercial voltage-sensor module (a current-sensor module follows the same principle)

D. Temperature Sensing - LM35

Winding or oil temperature is measured with an LM35 precision integrated-circuit sensor, whose output voltage is linearly proportional to temperature in degrees Celsius, removing the need for a linearization step in software. The LM35 needs no external calibration, draws only about 60 µA, and is accurate to within a fraction of a degree at room temperature, which keeps the temperature channel simple and low-cost.

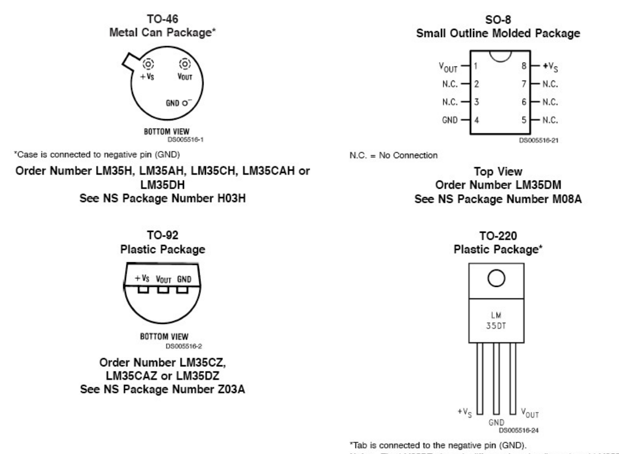

Fig. 4. LM35 temperature sensor package and pin-out options

E. Frequency Measurement Unit

Supply frequency is measured using an optocoupler stage that provides galvanic isolation between the line-connected sensing circuit and the microcontroller's low-voltage logic. The optocoupler output toggles the microcontroller's Timer0 input, and the pulse count over a fixed one-second gate time gives the line frequency in hertz.

F. Relay and Circuit Breaker Interface

An electromagnetic relay, driven from a microcontroller output through a driver stage, provides the electrical isolation needed to switch the circuit breaker with a low-power microcontroller signal. When any monitored parameter goes out of range, the microcontroller de-energizes the relay, opening the breaker and disconnecting the transformer from the line.

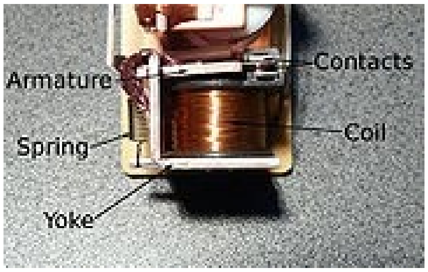

Fig. 5. Internal construction of an electromagnetic relay

G. LCD Display

A 16×2-character LCD module, interfaced to the microcontroller in the usual 4-bit or 8-bit parallel mode, displays the live voltage, current, frequency and temperature readings at the transformer, giving local personnel an at-a-glance status view without needing the mobile app.

H. Ultrasonic Sensor - Oil Level

Transformer oil level is measured with an ultrasonic distance sensor, which times the echo of a short ultrasonic pulse reflected from the oil surface to compute the distance to it. The sensor used has a rated range of roughly 3 cm to 3 m, which is more than enough resolution for tracking the oil level in a transformer tank and flagging a low-oil condition.

Fig. 6. Ultrasonic sensor module used for oil-level sensing

I. Buzzer

A buzzer, driven through a transistor driver stage from a microcontroller output, gives an audible alert at the transformer whenever a parameter goes out of range, alongside the LCD warning and the relay trip.

J. ESP8266 Wi-Fi Module

An ESP8266 Wi-Fi module, interfaced to the microcontroller's serial port, forwards the periodic sensor readings to the Thing Speak IoT platform and triggers a mobile notification when a reading is abnormal, giving remote visibility into transformer status alongside the local LCD, buzzer and relay actions.

5. Software Description

The project uses two software tools. Express PCB is used to lay out the circuit board for the sensor interface, power supply and driver stages before fabrication. The firmware is written in C using the PIC C Compiler, compiled to a .hex file, and verified in circuit simulation before being loaded onto the PIC16F877A with a hardware programmer. The compiled firmware initializes the LCD and I/O pins, then loops continuously: reading each sensor, updating the display, checking every reading against its preset threshold, and driving the buzzer, relay and ESP8266 uplink whenever a reading is out of range.

6. Working

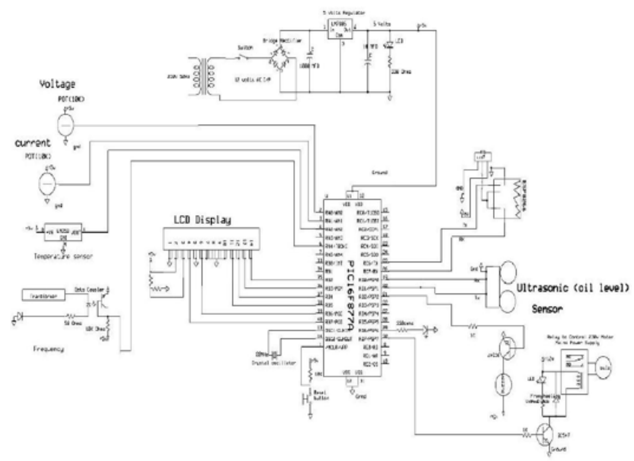

Fig. 7. Schematic diagram of the transformer health monitoring circuit, showing the sensor, microcontroller, LCD, relay and Wi-Fi interconnections

On power-up, the microcontroller initializes the LCD, closes the relay to connect the transformer to the load, and enters its main monitoring loop. In each pass it reads the voltage and current inputs, gates Timer0 for one second to measure supply frequency, reads the LM35 temperature channel and the ultrasonic oil-level sensor, and writes the voltage, current, frequency and temperature values to the LCD. Each reading is compared against a preset safe range, for example, the prototype firmware flags a high-voltage condition above roughly 240 V and a low-voltage condition below roughly 170 V. When a reading falls outside its range, the microcontroller opens the relay to trip the breaker, switches off the corresponding LED indicator, sounds the buzzer, shows a warning message on the LCD, and, through the ESP8266 module, pushes the reading to Thing Speak and triggers a mobile alert. The loop then continues, so monitoring resumes and the display, buzzer and relay all reflect the current state as soon as a parameter returns to its normal range.

7. Results and Discussion

The assembled prototype continuously measured a transformer's voltage, current, frequency, temperature and oil level, displayed the values on the LCD module, and pushed the same readings to the Thing Speak app over Wi-Fi. When a parameter was driven outside its preset range during testing, the system correctly sounded the buzzer, opened the relay to break the circuit, and sent a Thing Speak notification to the user's mobile device, confirming that the local protective action and the remote alert operate together as intended.

8. Advantages, Disadvantages and Applications

A. Advantages

- Connected devices can be switched off automatically through the relay when a fault is detected.
- Voltage, current, temperature, frequency and oil level are all monitored together and logged to the Thing Speak app.
- Live readings can be checked remotely from a mobile device from anywhere with network access.
- Visual alerts are given through the LCD display and audible alerts through the buzzer.
- The design uses low-cost components and consumes little power.
- Real-time monitoring is achieved using IoT connectivity.

B. Disadvantages

- The system does not provide feedback confirming the state of the devices it switches.

C. Applications

- Industrial transformers and switchgear monitoring.
- Monitoring and control of home appliances.
- Transformer monitoring at electrical substations.

9. Conclusion

This project integrates sensing, local display, audible and relay-based protection, and IoT connectivity into a single low-cost transformer health monitoring unit built around a PIC16F877A microcontroller. Each hardware module - power supply, sensors, LCD, buzzer, relay and ESP8266 - was selected and interfaced with a specific role in the monitoring and protection chain, and the assembled system was successfully designed, built and tested, meeting its goal of continuous, remotely visible transformer monitoring with automatic fault isolation.

10. Future Scope

Location tracking. Adding a GPS module would let the location of a monitored transformer be reported alongside its status, useful for a fleet of substations spread over a wide area.

Active thermal control. A coolant or fan-based temperature-control stage could be added to hold winding temperature within a safe band rather than only alerting once a limit is crossed.

Visual monitoring. Wireless cameras linked over GPRS/GPS could let personnel visually inspect the transformer and its surroundings from a personal computer alongside the sensor data.

Wider environmental sensing. Additional temperature sensors placed around a site could report conditions in hazardous zones back to a central PC, reducing the need to send personnel into those areas.

Scalability. The design could be extended from a single transformer to a networked fleet, with each unit's ESP8266 reporting to a shared dashboard.

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