Suggested Temperature Monitoring System for Distribution Transformers by Using Microcontroller Scheme

Amal F. Abd El-Gawad[†]

Abstract – The paper presents a monitoring system for the cooling of distribution transformers. The suggested system is controlled by a microcontroller scheme. The system is designed to control the oil temperature. It gives a solution to improve the cooling system by adding a number of fans especially for indoor transformers that are placed in badly-ventilated rooms. Also, the paper includes an alarm system with the possibility of tripping the transformer if it is necessary. The monitoring system consists of acquisition temperature sensor, and on-site unit. The hardware and software of the on-site unit are demonstrated with sufficient illustrations. Small prototype is constructed in the laboratory. Some laboratory experiments are carried out for examining the designed circuit by using Proteus Virtual System Modeling as well as for testing the prototype monitoring system. Concerning this research point, a study is carried out to evaluate the economic feasibility. The results are recorded and associated with many recommendations that may be valuable to electrical distribution (utility) companies.

Keywords: Distribution transformers, Microcontroller, Temperature, Heat sensor.

1. Introduction

For many years, there has been a good collaboration between the Electric Power and Machines Dept., Faculty of Engineering, Zagazig University, Egypt and the Electrical Distribution Company, El-Sharkia branch that is considered as the authorized utility company of Zagazig city. This collaboration may be demonstrated in scientific consultants, practical studies, student training, *et al.* At the summer of 2012, the utility company complained from a series of accidents and dramatic events in distribution transformers 11000/400 volts. Five transformers suffered from severe internal damages in their winding and other four transformers suffered from frequent tripping in rush hours. The utility company requested from the Electric Power and Machines Dept. to find a simple and economical solution. During the onsite observations, it was found that most of these transformers were indoor transformers classified as Oil Natural Air Natural Type. In addition, they were placed in badly-ventilated rooms.

Actually, for any transformer, some power is dissipated in the form of heat. For example, suppose a 10MVA transformer at a distribution substation that operates at an efficiency of 99%, then 1% loss corresponds to a staggering of 100 kW [8]. In general, smaller transformers like those on distribution poles are passively cooled by simply radiating heat away to their surroundings, sometimes assisted by radiator fans that maximize the available surface area for heat removal. Transformers with efficiencies less

than 96% produce an excessive amount of heat and usually have an unsatisfactory temperature rise.

This paper suggests adding a number of fans to improve the cooling system, especially for indoor transformers that are placed in badly-ventilated rooms. Microcontroller technology is recently one of the most important applications that serve for control [6, 13, 16]. So, the suggested system is controlled by using a microcontroller scheme. The hardware is designed to control the oil temperature. First, it is required to sense oil temperature by LM35, which is an integrated circuit sensor that can be used to measure temperature in °C with an electrical output that is proportional to the temperature. Then, the suitable action is taken according to the following four sequential stages: Fan (1) operates at 55°C, fan (2) operates at 65°C, sound or light alarm operates at 95°C, finally, trip signal is sent at 100 °C. The designed hardware is tested by Proteus Virtual System Modeling (off-line testing program). Then, it is implemented online at a small prototype that is constructed in the laboratory.

The estimated cost of the proposed system will never exceed 600 Egyptian Pounds (≈100$). The details of the hardware and all results are reported with a feasibility study for application to the distribution transformers in service.

2. Problem Description

The main source of heat generation in transformers is copper loss or I^2R loss. Although there are other factors that contribute to heat in transformers such as hysteresis

† Corresponding Author: Electrical Power and Machines Dept., Zagazig University, Egypt. (amgawad2001@yahoo.com)

and eddy current losses, the contribution of I2R loss dominates them. If this heat is not dissipated properly, the temperature of the transformer will rise continually, which may cause damages in both the paper insulation and the liquid insulation medium of the transformer [4, 7]. So, it is essential to control the temperature within permissible limit to ensure the long-life of the transformer by reducing thermal degradation of its insulation system. In electrical power transformer, external cooling system is used to accelerate the dissipation rate of heat [10, 14, 17]. There are different transformer cooling methods available for oil-immersed transformers, as follows:

- Oil Natural Air Natural Type (O.N.A.N.)
- Oil Natural Air Forced Type (O.N.A.F.)
- Oil Forced Air Natural Type (O.F.A.N.)
- Oil Forced Air Forced Type (O.F.A.F.)

The transformers under-study are following (O.N.A.N.) cooling system. So, it is suggested to be converted to (O.N.A.F.) cooling system. In the last system, cooling methods may be classified as follows:

- Manually: for which, the operator at dispatch centre decides switching on fans or not as he has a temperature gauge that shows the temperature of oil and windings.
- Using temperature sensors (indicators): for which, there is a pre-setting for temperature and the device operates automatically at the pre-setting values (specific values of temperature).

It is worth to mention that until now, the distribution utility under-study doesn't have SCADA system to communicate with the dispatch center. So, it is suggested to utilize temperature sensors (indicators).

3. Monitoring System

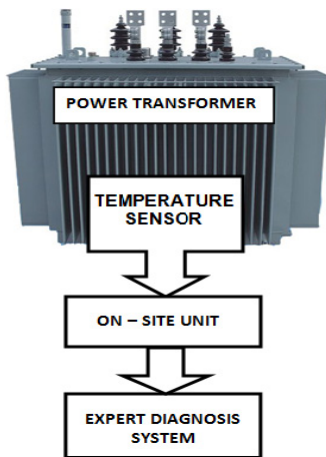The suggested monitoring system is shown in Fig. 1. It consists of successive stages. The first stage concerns the measuring of oil temperature. The second stage deals with the recorded temperature with the help of on-site unit. Finally, the prober action is taken according to expert diagnosis system. All these stages will be demonstrated in the following subsections.

3.1 Acquisition temperature sensor

LM35 is a precision integrated-circuit temperature sensor whose output voltage is linearly proportional to the Celsius (Centigrade) temperature [1]. Basic pin connection of centigrade temperature acquisition sensor is shown in Fig. 2. It has the following features:

- Calibrated directly in ° Celsius (Centigrade)
- Linear + 10 mV/°C scale factor
- 0.5°C ensured accuracy (at +25°C)
- Rated for full −55°C to +150°C range
- Suitable for remote applications
- Low cost due to Wafer-Level trimming
- Operates from 4 to 30 V
- Less than 60-μA current drain
- Low Self-Heating, 0.08°C in still air
- Nonlinearity only ±¼°C typical
- Low impedance output, 0.1 Ω for 1 mA load

3.2 Hardware of on-site unit
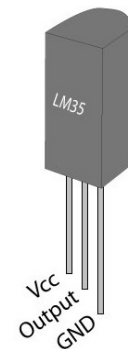
The hardware of on-site unit is shown in Fig. 3. It

Fig. 2. Basic centigrade temperature acquisition sensor
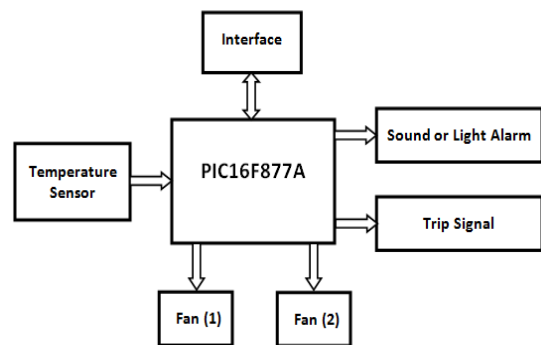
Fig. 1. The monitoring system structure

Fig. 3. The schematic diagram of on-site unit

consists of some components as will be discussed below.

3.2.1 Microcontroller (PIC16F877A)

The heart of on-site unit is the microcontroller (*PIC16F877A*) as it is easy to use and can be programmed about 1000 times [2]. It has 40 pins; from which 33 pins can be used as output or input as shown in Fig. 4.
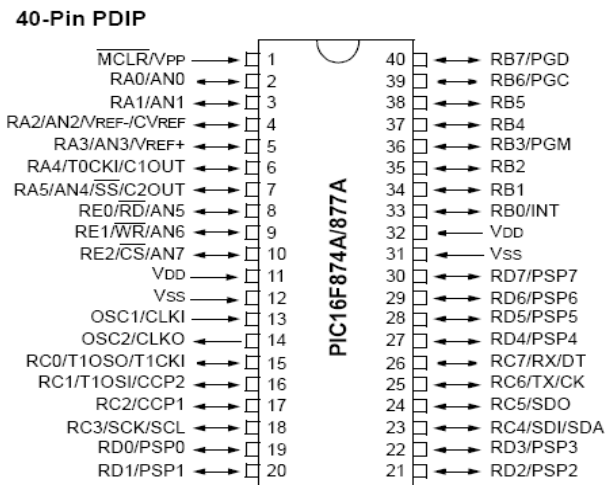

Fig. 4. The Pin diagram of (PIC16F877A)

As demonstrated at Table 1, which describes the PIC16F877A device features, the microcontroller has 5 main Input/output ports (A, B, C, D &E).

Table 1. PIC16F877A Device Features

Key Features	PIC16F877A
Operating frequency	DC-20MHz
Resets (and Delays)	POR, BOR (RWRT, OST)
Flash program memory (14-bit words)	8K
Data memory (bytes)	368
EEPROM data memory (bytes)	256
Interrupts	15
I/O ports	Ports A, B, C, D, E
Timers	3
Capture/Compare/PWM modules	2
Serial communications	MSSP, USART
Parallel communications	PSP
10-bit Analog-to-Digital module	8 input channels
Analog comparators	2
Instructions set	35 Instructions
Packages	40-pin PDIP 44-pin PLCC 44-pin TQFP 40-pin QFN

Microcontroller must be connected to oscillator on Pin No. 13 and 14. This oscillator called Crystal 4MHZ. This oscillator determines the number of orders that the microcontroller can do in one second. Micro© program is used in programming the microcontroller.

3.2.2 LCD (LCM1602A)

LCD is considered the interface tool of on-site unit. Fig. 5 shows the 16×4 character type with back light that has 16 outputs.
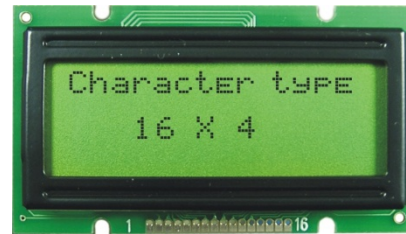

Fig. 5. The 16 x 4 character type with back light LCD

6 outputs connect to microcontroller, 6 outputs connect to voltage source and 4 outputs are not used. Fig. 6 explains LCD connection with the microcontroller.
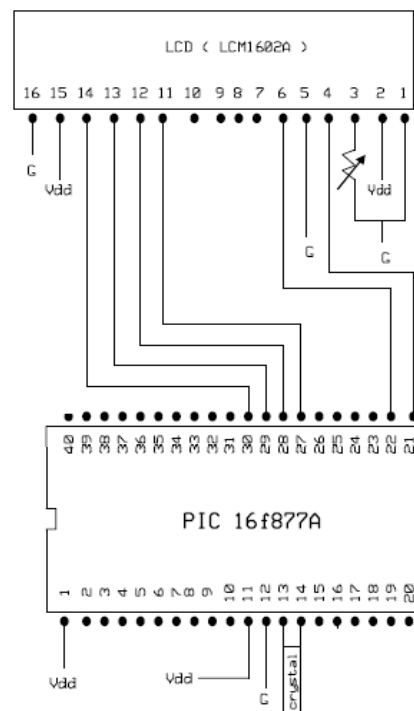

Fig. 6. LCD connection with the microcontroller

3.2.3 Accessories

The output ports of the microcontroller send control signals to energize the circuits of two fans, sound producer (alarm), and the circuit of the transformer circuit-breaker trip.

3.3 Software of on-site unit

Fig. 7 demonstrates the state diagram for on-site unit. At first, when the power is on, the initialization process
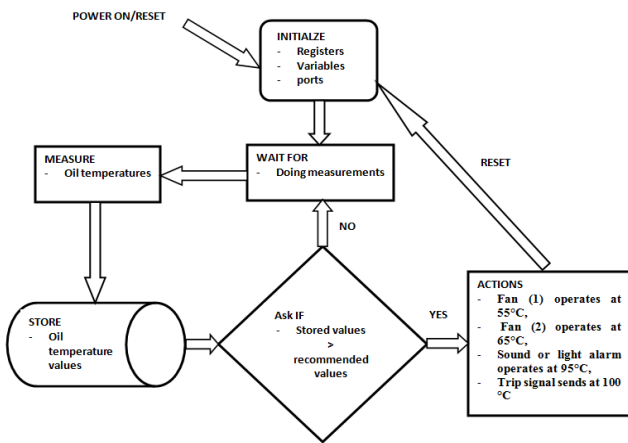
Fig.7. The state diagram for on-site unit

is started. It includes initialization of registers, variables, and ports. Then, it is required to wait to get the oil measurement. The measured value must be stored until accessing the next process that is related to comparing the stored measured value with the pre-recommended values (expert diagnosis system). If the result of the comparison reflects a negative index, it is a must to get another measurement with repeating the same mentioned procedure. If the result of the comparison reflects a positive index, some actions must be taken according to the following four stages to deal with this problem: Fan (1) operates at 55°C, fan (2) operates at 65°C, sound or light alarm operates at 95°C, finally, trip signal is sent at 100 °C. When the causes of the previous actions are removed, it is required to reset the unit and return back to the initialization process.

To execute the suggested process, Master Programmer was written and designed by using Micro© program.

4. Laboratory Experiments

Laboratory experiments are carried out to perform all the required investigations to complete the desired work correctly. Investigations include examining the designed circuit by using Proteus Virtual System Modelling (VSM) and also testing the prototype monitoring system [3, 11].

4.1 Examining the designed circuit by using Proteus

To insure that the designed circuit works properly, it is simulated by using Proteus Virtual System Modeling (VSM) [3]. Proteus combines mixed mode SPICE circuit simulation, animated components, and microprocessor models to facilitate co-simulation of complete microcontroller-based designs. For the first time ever, it is possible to develop and test such designs before a physical prototype is constructed. This is possible because one can interact with the design using on-screen indicators such as LED and LCD displays, and actuators such as switches and buttons. The simulation takes place in real-time (or near enough to it). 1GMHz
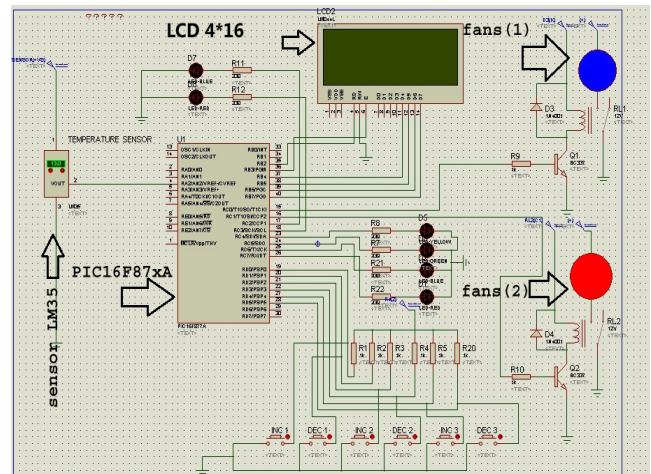

Fig. 8. The built system using Proteus

Pentium III can simulate a basic 8051 system clocking at over 12MHz. Proteus VSM also provides extensive debugging facilities including breakpoints, single stepping, and variable display for both assembly code and high-level language source. The library of the program contains all required components to be built together. After the stage of completing building the circuit, the program is executed. It reflects the performance of the designed system. Fig. 8 shows the built system.

4.2 Testing the prototype monitoring system

In the laboratory, a prototype is made to perform the online tests. A tank filled with oil is constructed. The temperature sensor is connected to the microcontroller as shown in Fig. 9. Then, the other components of the on-site
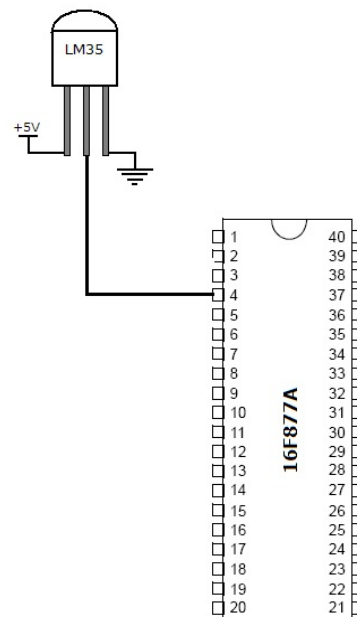

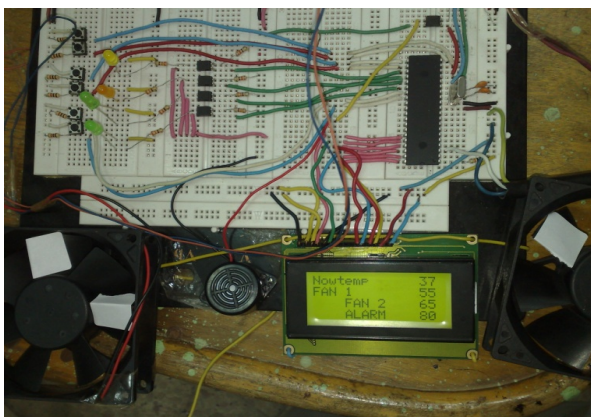**Fig. 9.** Temperature sensor connection with the micro-controller

Fig. 10. The implementation of the suggested system

unit are assembled as shown in Fig. 10. The oil tank is exposed to a source of heat to simulate a real case-study. During the test, all possible situations are considered. The performance of the suggested monitoring system proves very good appearance and successfully deals with the temperature problem as planned; according to the state diagram presented in Fig. 7.

5. Economic Feature

To make this work inclusive, it is required to carry out feasibility study to cover the economical issue. Zagazig city have 657 distributed transformers in service. Almost their rates range from 1000 kVA to 200 kVA. Table 2 contains some details about these transformers such as their prices and numbers.

The average life-time of these transformers is nearly 20 years. Nearly 55% of these transformers were indoor transformers that are placed in unsuitable rooms with bad ventilation. The cost of the suggested cooling system, after making the required modification, will never exceed 600 Egyptian Pounds (≈100$) for all the mentioned ratings of distributed transformers. For example, from Table 2, it is obvious that the transformers of rating 500 kVA represent 70% of the number of transformers in service. The price of each of them is 57420 Egyptian Pounds (≈9570$). So, the total cost after modification will be 58020 Egyptian Pounds (≈9670$), with very little increase of nearly 1.04%. Thus, applying this simple modification will save a big amount of money by avoiding repairing or replacing the faulty transformer. Also, the expected life-time of these

Table 2. Transformers features

Rates/Features	Number in service	Price/one In Egyptian Pounds
1000 kVA	131	107800
500 kVA	459	57420
300 kVA	30	41580
200 kVA	37	29920
Total	657	

transformers may be extended to 25 years.

6. Future Recommendation

In the future, the suggested monitoring system can be modified to be suitable to SCADA system. The general packet radio service (GPRS) communication technology can be applied so that remote signal transmission is accomplished by wireless network [9, 12, 15]. As mentioned before, until now the distribution utility of Zagazig city doesn't have SCADA system to communicate with the dispatch center. So, it is suggested to utilize temperature sensors (indicators). If the utility decides to use SCADA system, the suggested monitoring system can easily be modified to deal with SCADA system. Possibly, the modifications may include the hardware of on-site unit to be suitable for online managements and communications with the dispatch center. The heart of this unit is LPC2214, which is based on 32-bit ARM7 processor [5]. It has lots of integrated peripherals which bring great convenience to system design. After preparing the voltage signal that is obtained from temperature sensor indicator by using Analog to Digital (A/D) card, the processor transfers it to remote expert diagnosis system by GPRS. GPRS mobile network is based on the data packet commutation through the usable mobile network where the data quantity is charged not the duration of the connection. Having this in mind, a necessity is to choose the appropriate communication protocols and standards that would utilize that kind of data transfer in the most efficient way. Data is then sent to the SCADA application servers via IEC 60870-5-104 communication protocol. One of the points is to lower the cost of data transfer; other is to ensure that data is up-to-date (real-time data). The real-time data acquisition is the key to efficient distribution network management.

7. Conclusions

From the above contributions discussed in the present paper, it can be concluded that:

- The suggested monitoring system finds simple and inexpensive solution for cool problem of indoor transformers that are placed in unsuitable rooms with bad ventilation.
- Utilizing temperature sensors (indicators) are the best choice in the present case as the distribution utility of Zagazig city doesn't have SCADA system till now.
- Experiments that were carried out in laboratory either examining the designed circuit by using Proteus or testing the prototype monitoring system granted a good design and operation.
- In case of using SCADA system, the suggested monitoring system is still valid with minor modifications.

References

[1] http://www.ti.com/lit/ds/symlink/lm35.pdf

[2] http://www.wvshare.com/datasheet/Microchip_PDF/ PIC16F877A.PDF

[3] http://www.labcenter.com/products/vsm/vsm_educati onal.cfm

[4] http://www.linkedin.com/company/okuyan-metal-co-ltd-/products

[5] NXP LPC2212/LPC2214 16/32-bit ARM microcontrollers [Online]. Available: http://www.zlgmcu.com.

[6] Raphael Mukaro and Xavier Francis Carelse, "A Microcontroller-Based Data Acquisition System for Solar Radiation and Environmental Monitoring," IEEE Transactions on Instrumentation and Measurement, Vol. 48, No. 6, December 1999.

[7] Sarat C. Tripathy and Erkki Lakervi, "Evaluation of Transformer Overloading Capability," European Transactions on Electrical Power, Volume 15, Issue 5, September/October 2005, Pages: 455-464.

[8] Electric Power Systems: A Conceptual Introduction, Alexandra von Meier, John Wiley & Sons, Jun 30, 2006 - Technology & Engineering.

[9] Hai-Bao Mu, Yi-Xin Guo, Ming Dong, Guan-Jun Zhang, Wei Song, "On-line Monitoring Technology for MOA on HV Transmission Line," 2008 International Conference on Condition Monitoring and Diagnosis, Beijing, China, April 21-24, 2008.

[10] Zoran RADAKOVIC, Slobodan MAKSIMOVIC, "Dynamical Thermal Model of Oil Transformer Placed Indoor", 20th International Conference on Electricity Distribution, CIRED, Prague, 8-11 June 2009, Paper0304.

[11] Bo Su and Li Wang, "Application of Proteus virtual system modelling (VSM) in teaching of microcontroller," E-Health Networking, Digital Ecosystems and Technologies (EDT), Shenzhen, 17-18 April 2010.

[12] H. J. Zhou, C. X. Guo, J. Qin, "Efficient Application of GPRS and CDMA networks in SCADA System," Power and Energy Society General Meeting, 2010 IEEE, 25-29 July 2010.

[13] Roland Szabo', Aurel Gontean, Ioan Lie, "Embedded Temperature Monitoring System with a Microcontroller Used in the Automotive Industry", 20th Telecommunications forum TELFOR 2012 Serbia, Belgrade, November 20-22, 2012.

[14] Juan Carlos Olivares-Galvan, Rafael Escarela-Perez, Pavlos S. Georgilakis and Issouf Fofana, "Evaluation of Distribution Transformer Banks in Electric Power Systems," International Transactions on Electrical Energy Systems, Volume 23, Issue 3, April 2013, Pages: 364-379.

[15] Boris BRESTOVEC, Simon BATISTIČ and Marko BIZJAK, "Automation of Distribution Network Based on GPRS Communication", 22nd International Conference on Electricity Distribution, CIRED, Stockholm, 10-13 June 2013, Paper 0453.

[16] Anjali Chatterjee, Rajat Sarkar, Nirmal K. Roy and P. Kumbhakar, "Online Monitoring of Transformers Using Gas Sensor Fabricated By Nanotechnology," International Transactions on Electrical Energy Systems, Volume 23, Issue 6, September 2013, Pages: 867-875.

[17] Zoran Radakovic, Dusan Jacic, Jelena Lukic and Srdjan Milosavljevic, "Loading of Transformers in Conditions of Controlled Cooling System," International Transactions on Electrical Energy Systems, Volume 24, Issue 2, February 2014, pages 203-214.

Amal F. Abd El-Gawad She was born in Aswan, Egypt in 1971. She received the B.Sc, M.Sc, and PhD from the faculty of engineering, Zagazig University, Egypt, in 1993, 1996, and 2002, respectively. She is now associate professor in the faculty of engineering, Zagazig University, Egypt. Her research interest covers different aeries of renewable energy, protection and distribution systems.