Performing Temperature Regulation and Monitoring in an Oil Aging Test System

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Abstract: - We developed a system that continuously monitors, logs, and regulates transformer oil temperature during the aging process and maintains temperature consistency within strict limits. A microcontroller system was developed using two PWM regulation algorithms for controlling oil temperature set value in the range of 40°C to 200°C. An oil temperature monitoring and measured data logging system based on National Instruments cRIO technology was also developed to observe 12 transformer oil samples simultaneously within the fixed time period. The measured temperature values are stored in a database for further analysis.

Key-Words: - Temperature, monitoring, microcontroller, transformer oil, aging process, PWM regulation.

1 Introduction

New, as well as regenerated transformer oils must undergo oil aging tests according to appropriate IEC standard, in order to evaluate its behaviour during its exploitation time period [1], [2]. The oil aging is usually done at preset temperature value and preset time period, while in other tests the time interval is measured until certain chemical reactions occur.

The transformer oil is put into 12 glass cuvettes corresponding to 12 simultaneous test samples. The cuvettes are placed in an aluminum block whose temperature gradient is tested to be not in excess of 0.1°C throughout the whole block. The block also holds three 320W heaters equally spaced in a horizontal plane under the bored holes for inserting the cuvettes. Also, the block contains a Pt100 temperature sensor that measures the temperature in the block which is then used in the algorithm for regulating oil temperature. The first developed algorithm for oil temperature regulation is based on chopping parts out of the mains AC voltage supply of the three internal heaters [3]. Although the first algorithm achieved adequate performance required by the corresponding IEC standard, that is ±0.5°C for the set temperature value of 120°C, it was realized that even better performance is possible by using AC sine wave cycle skipping PWM technique [3]. This algorithm reduces the fluctuations of the oil temperature within ±0.15°C of the set value. The on-line monitoring of the all twelve oil temperatures was performed using National Instruments CompactRIO technology and LabVIEW application software [4], [5].

2 Problem Formulation

The challenge was to develop a system that continuously monitors, logs, and regulates transformer oil temperature during the aging process and maintains temperature consistency within strict limits. Before used, transformer oil characteristics and behaviour during exploitation measured in tens of years, have to be accurately predicted by subjecting it to accelerated aging process at the standard temperatures of 80°C , 120°C and 150°C that lasts for several hundred hours (usualy 500h [1]). The oil temperature must be held strictly within ±0.5°C for temperature range to 140ºC and ±1ºC above 140ºC for the entire duration of the experiment otherwise experiement results are discarded. There is no strict requirement for the time duration to attain the temperature set value. The monitoring and logging of measured data was required.

3 Problem Solution

The problem was solved by dividing it into two parts: 1) a microcontroller-based unit was developed to carry out the first task of strict temperature regulation for the set time period and 2) a separate monitoring and data logging system was developed to perform the second task.

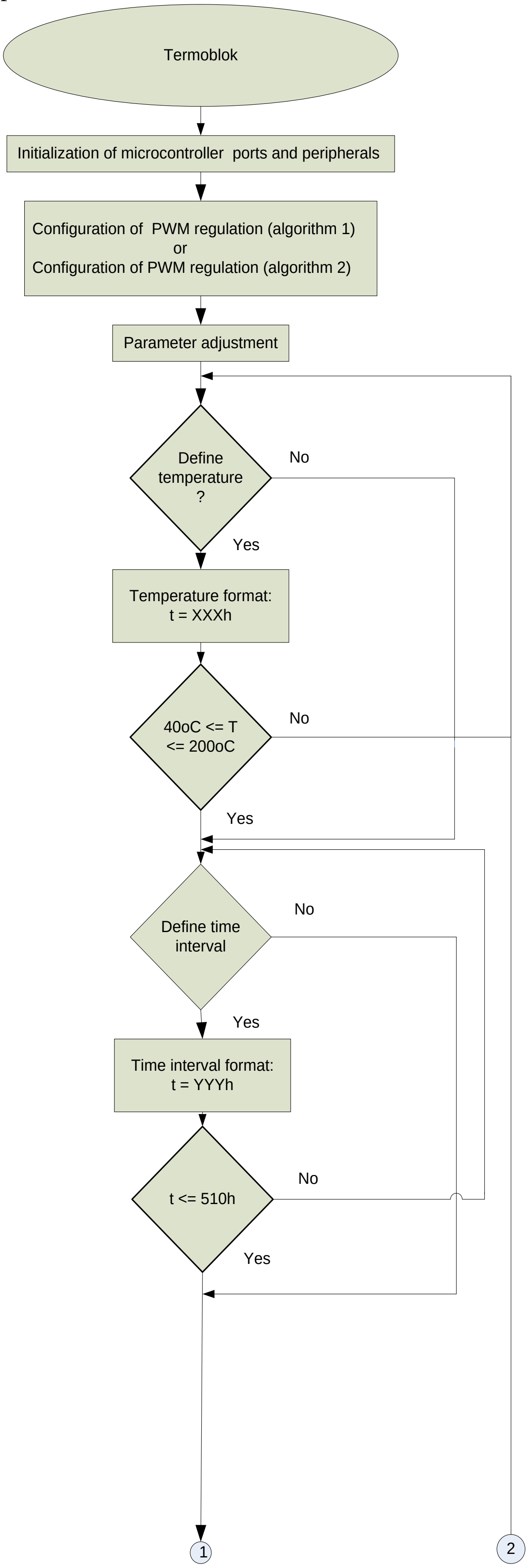
3.1 Temperature Regulation Unit

The temperature regulation unit was based on a NXP LPC2148 32-bit microcontroller with ARM7 architecture[6]. It regulates transformer oil sample temperatures in the range from 40°C to 200°C with a tolerance of 0.5°C for temperatures of 40°C to 140°C, and 1°C for temperatures between 140°C and 200°C. The aluminum block with test samples is thermally insulated from all sides but the top side in which the cuvettes holes are bored. That side serves for cooling of the block since no forced cooling is provided. The temperature regulation unit with oil samples is shown in Fig.1, and the block diagram of its software is shown in Fig. 2.

Fig. 1 Temperature regulation unit with oil samples

The temperature regulation unit performs several functions. Firstly, it measures temperature using two Pt100 temperature sensors, one of them placed in the aluminum block and the other in one of the twelve cuvettes as temperature probes. Temperature of the aluminum block is used in the algorithms for temperature regulation.

The first PWM algorithm is based on chopping parts out of the mains AC



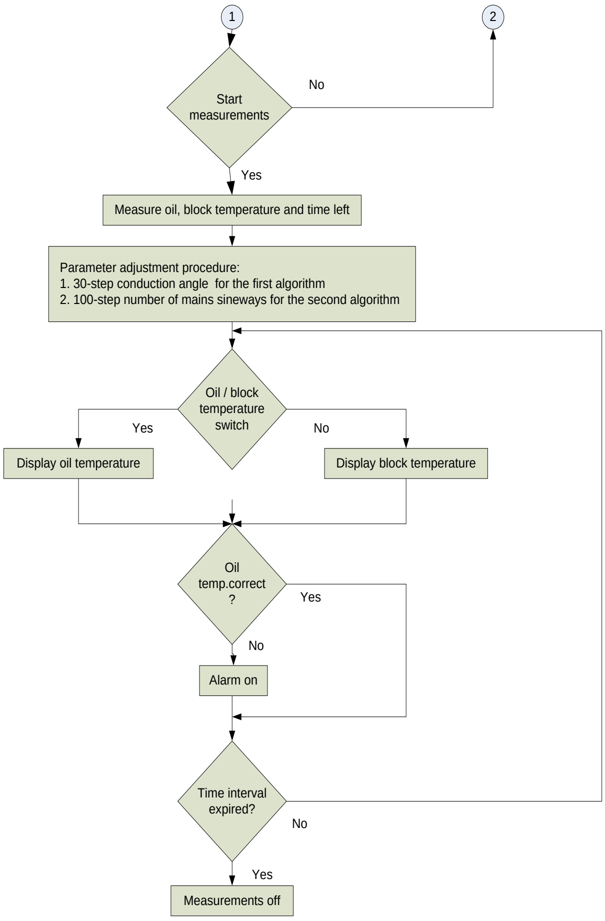


Fig. 2 Software block diagram of the Temperature Regulation Unit

voltage supply of the three internal heaters. It compares the temperature of the aluminum block to the temperature set value (as a reference).The difference of the two controls the conduction angles of the three triacs that regulate currents of the heaters and hence their heat output. The parameters of the used PWM algorithm were optimized experimentally. They were not optimized for speed, i.e. how fast the achieved temperature approaches the set value but to preserve very tight control on the temperature fluctuations when the set value is reached. The optimized parameters vary from one set value to the other. The experimental evaluation of the used algorithm was conducted using the optimized PWM algorithm parameters for the maximum time period required by the IEC standard of 500 hours. The algorithm performance was within required limits. However, in the course of device exploitation in the Chemical Laboratory of the Nikola Tesla Institute of Electrical Engineering the oil temperature experienced rare fluctuations in excess of the required upper limit by 0.3°C maximum. Since that could not be tolerated a new algorithm was developed that uses AC sine wave cycle skipping PWM technique. In order to achieve temperature fluctuations of no more than ±0.15°C around the set value, at least a hundred sine wave cycles had to be used for this particular PWM control algorithm. Although both algorithms are based on modulating the amount of current that flows through the heaters coils that is never zero (no on-off control) the second algorithm allows much finer possibility for tuning the heaters current and attain smaller oil temperature fluctuations. The graphical representation of experimental results for the representative temperature set value of 120°C of a characteristic sequence of 200 measurement points for both algorithms is shown in Fig. 3, while some numerical data for a shorter characteristic sequence of 10 measurement points is given in Fig. 4. The time interval between measurement points was 5 minutes,

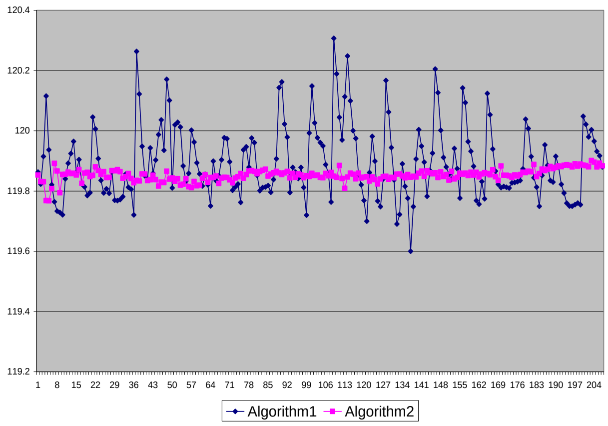


Fig. 3 Graphical representation of experimental results

Algorithm 1	Algorithm 2
119.8853	119.8724
119.8347	119.8813
119.8297	119.8742
119.9152	119.8783
119.8833	119.8832
119.8223	119.8811
119.7932	119.8852
119.7598	119.8873
119.7498	119.8851

119.7495	119.8797
119.7547	119.8903
Average value	Average value
119.8685	119.8844
Standard deviation	Standard deviation
0.098208	0.006806

Fig. 4 Numerical data showing experimental results

The Temperature regulation unit front panel is depicted in Fig. 5.

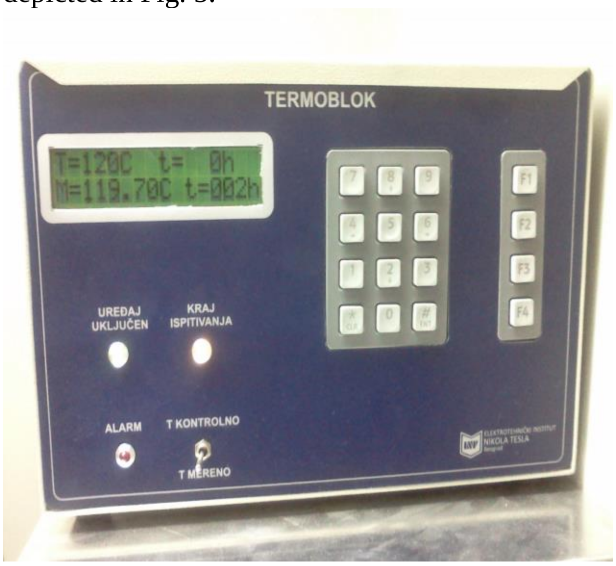


Fig. 5 Temperature regulation unit front panel

As shown in Fig. 5, the Temperature regulation unit has a 2x16 character LCD display that shows the temperature set value and the time period set value in the first row and measured temepraturе and elapsed time in the second row, a standard 12-way keyboard and a 4-way keyboard with 4 Function keys that are connected to the microcontroller using RS232 serial interface, a green LED that indicates power on/off status, a red alarm LED that indicates that the oil sample temperature is beyond the acceptable limits around the set value, a yellow LED that indicates that the set time period of the aging test is over and a switch that selects between showing the aluminum block temperature (K) or oil sample temperature (M).

3.2 Monitoring and Data Logging System

Monitoring of all twelve transformer oil samples is performed by a separate Monitoring and Data Logging System that is based on National Instruments cRIO-9073 platform and is shown in Fig. 6.


Fig. 6 Temperature monitoring and data logging system

That particular technology was chosen because it was already used for temperature monitoring system of two power transformers at the coal-fired power plant TENT-B in Obrenovac, Serbia [7]. The cRIO-9073 is an integrated 266 MHz real-time controller with 2M gate FPGA. The cRIO-9073 is connected to twelve Pt100 temperature sensors using three National Instruments NI 9217 4-Channel, 100 Ω RTD, 24-Bit analog input modules [8]. The NI 9217 module supports both 3 and 4-wire RTDs and it has built-in excitation to support passive Pt100 temperature probes. The temperature probe consists of a 4-wire resistive Pt100 thermometer encapsulated in a 250mm long and 2mm wide stainless-steel pipe. It has to be thin so that when immersed in oil. It must not touch either the glass walls of the cuvette or the copper spring also immersed in the oil sample playing the role of transfomer copper coil.

Temperature monitoring and data logging application was realized using LabVIEW 2010 SP1 Professional Development System. The application monitors each of the twelve oil samples by sampling its temperature every 5 minutes. The sampling rate does not need to be faster since the phenomenon being monitored is relatively slow. The measured temperatures for each oil sample are shown on a separate graph. The upper and lower temperature limits about the set reference value are clearly so that the operator can easily notice temperature values out of range. The measured temperature statistics data are also clearly shown in appropriate numeric boxes: the minimum temperature value that was measured from the start of the measurement up to that moment, the maximum temperature value that was measured from the start of the measurement up to that moment, the amount of time that the oil sample spent on temperatures above the upper allowable limit the amount of time that the oil sample spent on temperatures below the lower allowable limit. These data are required for further analysis. The measured data together with their statistics are stored in a database and can be retrieved any time either during the measurements or after the preset time period for measurements has elapsed on any PC connected to the Institute's LAN. The possibility of observing the screen of the local monitor on-line for anyone with appropriate data access rights connected to local LAN is also provided. Hence, any authorized person on a local LAN can see at any moment everything what the operator can see. This is the remote front panel feature enabled by the built-in LabVIEW Web Server. Two more information are also available: channel active indicator showing if the measurements are being performed or not and the alarm indicator for each channel, going red if the measured oil temperature is out of allowable range.

4 Conclusion

A system that continuously regulates, monitors and logs transformer oil samples temperature during the aging process is described in this paper. These experiments are very important since transformer oil aging characteristics must be investigated properly before being poured into the transformer. In order to carry out the experiments according to IEC standards the oil sample temperature must be kept tightly within predefined limits about the set temperature value for the duration of the predefined time period, otherwise the experiment result in either too optimistic results (regulated temperature was below lower allowable limit) or too pessimistic results (regulated temperature was above upper allowable limit). Using a separate temperature regulation unit based on NXP ARM7 LPC 2148 microcontroller and a temperature monitoring and data logging unit based on NI cRIO-9073 with NI 9217 modules and LabVIEW software development environment the strict temperature regulation was made possible Two PWM regulation techniques were implemented keeping the temperature fluctuations about the set value within ±0.5°C with the first and even ±0.15°C with the second algorithm. Graphical monitoring, data logging and statistics as well as alarm indications were made possible and observable both on the local monitor and on the Institute LAN to authorized personnel.

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