Proceedings of the 4th International Congress APMAS2014, April 24-27, 2014, Fethiye, Turkey

A New Approach for Transformer Cooling Systems: Application of Phase Change Materials (PCM)

E. Buyukbicakci[a], I. Temiz[b], H. Edral[b,*], Z. Buyukbicakci[a]

[a]Sakarya University, Karasu Vocational School, Computer Programming Department, 54500 Sakarya, Turkey

[b]Marmara University, Technology Faculty, Electrical and Electronics Engineering Department, 34722 Istanbul, Turkey

Cooling transformer materials are used for heat storage. In this study, phase change materials (PCM) were investigated in order to use them as alternative materials in cooling systems. PCM materials were tested and the results are presented. A transformer heating model was designed, heating spots were cooled down by application of PCM material to the model transformer. At the end of the study it was observed that heated phase change materials (PCM) kept cool during the same time period, compared to the control experiment.

DOI: 10.12693/APhysPolA.127.1013

PACS: 84.71.Fk, 82.30.Hk, 07.20.Mc

1. Introduction

As it is the case for all electric machinery, during the operation of the the transformers, heat losses take place and windings get heated. Heat losses include the losses in iron core, due to the magnetic induction, and the copper losses that occur in consequence of the electrical current passing through the windings. It is necessary to transfer this heat to the external circuit and to reduce the transformer windings' temperature [1]. The biggest problem experienced in the operating transformers is the heating that occurs as a consequence of the losses taking place in the core and windings. Since the effect of heating of the isolating material determines the useful life of the transformer, the selection of the isolation materials is very important [2].

While the standard average temperatures for the standard-class dry transformer are 80, 115 and 150 °C, the temperatures of the hottest point reaches 150, 185 and 220 °C respectively [3]. The expected life of transformers at various operating temperatures is not exactly known. When calculating the effects of operating temperature on the life of electrical isolation, it is generally agreed that higher operation temperatures than normal, reduce the useful life of a transformer, because of the damage induced in the isolation by the increased ambient temperature [4–5].

For this reason, knowledge of the temperature in the hottest spot may help to increase the overload duration and lessen the limitations of a transformer, because heating of windings is not the same throughout the windings' height, under the normal working conditions of a transformer [6–7].

Transformers may be subjected to overloads during operation. These overloads cause such high temperatures, above the average windings' temperature, to increase even further for short time durations. In turn, the heat causes premature aging of the insulating material of the windings. This aging causes breakdowns that may include short-circuit of the winding. There are significant risks in cases of operation at temperatures above the heating limits of the isolation materials, used in the isolation of transformer windings.

Cooling systems of transformers have different types and forms [8]. Different cooling methods are generally based on different cooling materials, such as air, oil and water, and are conventionally used in the cooling of different types of transformers.

In order to achieve cooling in small power transformers and those used in energy transmission lines, usually additional equipment, oil maintenance, and fans for ventilating areas with inadequate circulation, are required. Thus the additional energy costs emerge. Phase changing materials (PCM) which are proposed here as an alternative for the conventional cooling methods, will reduce the windings' and core's temperature of the transformer without bringing in the additional energy consumption and will ensure cooling. In addition, by having various types of PCMs with different melting temperatures, the PCM can also be implemented in transformers with different cooling temperatures. These characteristics constitute an important advantage of the PCM material, regarding applications in transformer cooling [9].

PCMs have started to be used nowadays in the cooling systems. PCMs have many variations with different types and characteristics. Conductivity, specific heat, melting point, density and cost are among the primary parameters that are taken into consideration during the selection of PCMs. The literature includes many studies that explain in details the advantages and disadvantages of phase changing materials and the suitability of their properties for various applications [10–11].

*corresponding author; e-mail: erdal@sakarya.edu.tr

Materials that undergo through a phase-change within a suitable range of temperatures may be used to store thermal energy. Phase change may go from solid to liquid, from solid to gas and from gas to liquid. The basic principle here is the introduction of heat into a material under certain temperature and pressure conditions, or drawing heat from the material under such conditions. The thermal energy, which is either introduced into or is drawn from the material during phase change, is referred to, as the latent heat or phase change heat [12].

The experimental results obtained from the tests, conducted with the PCM, proposed as an alternative to the current cooling methods of transformers, are presented in this study. In addition to proposing an alternative cooling method for transformers, the study also suggests a proposition for application of PCMs in electrical machinery, as well as their other known application areas, such as energy storage, solar energy, thermal storage, bioclimatic building architectures, food technology, medical applications, space thermal systems, construction technology and textile technology. Examination of the related literature shows that until today PCM was not used at all in the studies conducted on the cooling systems of dry and oil transformers. In this respect, it is considered that the study will provide scientific contribution in terms of being a model study.

2. Materials and Methods

In the present study, an alternative method of transformer cooling is proposed which takes advantage of PCMs. The spots of the transformer winding which are most heated at ambient temperature of 17 °C, without the addition of PCM, were determined by mathematical modeling. The temperature values obtained for these numbered spots were between 75 °C and 85 °C. However, with the application to the transformer of the PCM, it was observed that the temperature in the considered sections has decreased.

3. Experimental results and discussion

In the conducted experimental study the transformer, which was used as a test model, was cooled with the use of phase changing material. The selected model transformer was single phase, mantel type transformer with 8 kVA power and 220 V/36 V input/output voltages. The PCM used in thus study was $Na_2SO_4 \cdot 10H_2O$ sodium sulfate decahydrate, which changes phase between 25 °C and 40 °C.

3.1. Results obtained from model transformer

By connecting 10 Ohm rheostats, shown in Fig. 1a, to the output of the model transformer, the overload condition was created, 22 A current was transmitted and, under operation at 8 kVA load, the transformer was heated. In Fig. 1b the specific spots (most heated spots 1 to 4), determined by the results of the mathematical model, are shown, before the addition of PCM, in which the instantaneous temperature values were recorded. After the application of PCM to the the model transformer (Fig. 1c), the transformer was once again loaded above the nominal load, temperature values were measured in the hottest spots on the front and back windings and on the magnetic core of the transformer. The results are presented in Fig. 2, where temperature values taken from the specific spots of the model transformer, before and after the application of PCM, are shown.

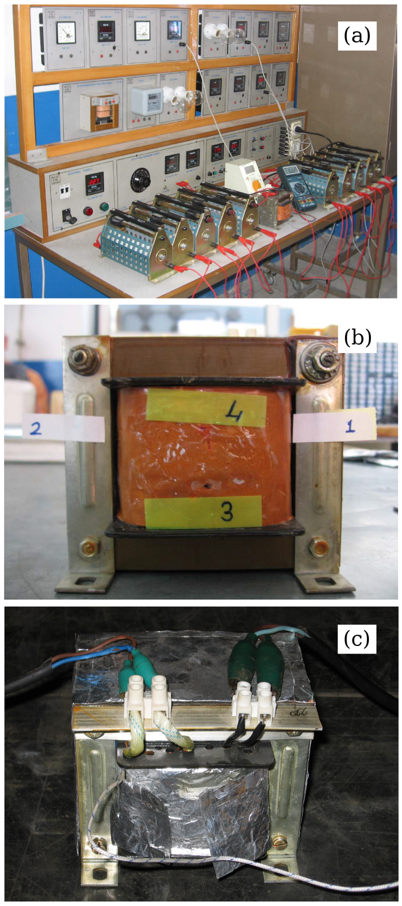

Fig. 1. (a) Model transformer test setup, (b) areas numbered from 1 to 4 of the model transformer, (c) model transformer after application of PCM.

4. Conclusions

In the present study, an alternative method of transformer cooling is proposed, which takes the advantage of phase changing materials. It was discovered that in the literature PCMs have never been used for transformer cooling.

In consequence, the experiments were carried out to test this idea. The values obtained from several heated points of the model transformer, before and after the application of PCM, were compared, and the following results were obtained for the model transformer:

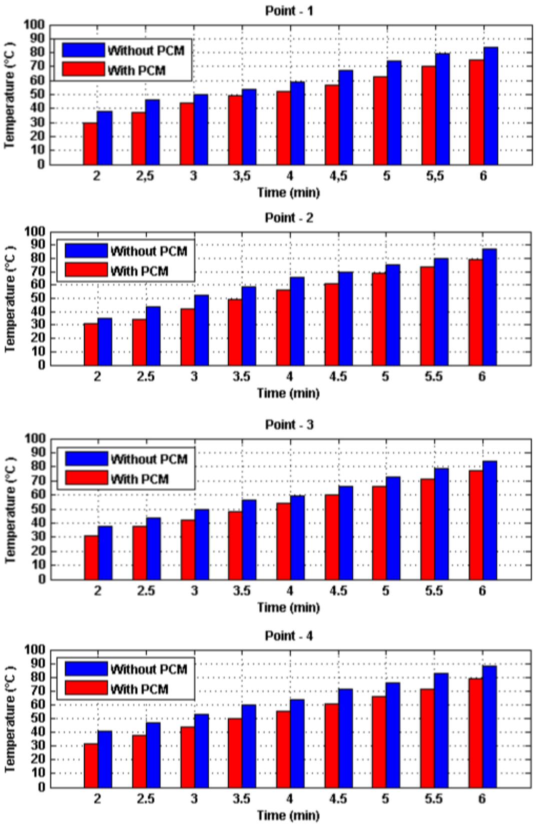

Fig. 2. Temperature measure on the specific spots of the model transformer, before and after the application of PCM.

1. The temperature values measured on the transformer without PCM were obtained by determining several areas of the transformer exhibiting increased heating. According to the temperature values read from these points, within the time frame from 5 to 5.30 minutes the temperatures at points 3 and 4 were between 79 and 83 °C, while the temperatures at points 1 and 2 of the winding and external body were 79–80 °C in the same time frame. It was observed that with the use of PCM the values read during the similar period decreased to 71 °C for points 3 and 4, and to 70–74 °C for points 1 and 2. According to these results it is determined, that application of PCM reduces temperature of the model transformer.

2. Although very good results were obtained during the experimental use of the chemicals, that store heat through phase change for the transformer cooling, the system may lose its efficiency, since their use in combination would cause the chemicals to lose their functionality in short time.

3. By means of the technology of the 21st century, which is the era of economy, combined transformer cooling systems may be rendered more efficient and attractive. This can be achieved by the discovery of new chemicals that are adequately economic and that do not lose their characteristics in consequence of long cycles, or by improvement of the existing chemicals in the way that will meet the required criteria for use of phase changing materials as an alternative to the custom transformer cooling systems.

References

[1] M. Lee, H.A. Abdullah, J.C. Jofriet, D. Patel, *Electric Power Systems Research* **80(9)**, 1065 (2010).

[2] D. Aşkın, İ.İskender, A. Mamızadeh, *J. Fac. Eng. Arch. Gazi Univ.* **26(4)**, 905 (2011).

[3] *IEEE Recommended Practice for Installation, Application, Operation, and Maintenance of Dry-Type General Purpose Distribution and Power Transformers*, IEEE Standard ANSI/IEEE **C57.94**, 1982.

[4] Q. He, J. Si, D. Tylavsky, *IEEE Transactions on Power Delivery* **15**, 1205 (2000).

[5] *IEEE Guide for Loading Dry-Type Distribution and Power Transformers*, IEEE Standard ANSI/IEEE **C57.96**, 1999.

[6] M. Lee, H.A. Abdullah, J.C. Jofriet, D. Patel, *Electric Power Systems Research* **80(1)**, 121 (2010).

[7] G. Kömürgöz, İ. Özkol, Predicting hottest spot temperature in self-cooled drytype transformer, in: *International Conference on Electrical and Electronics Engineering, ELECO* **A2**, 06 (2003).

[8] G. Kömürgöz, N. Güzelbeyoğlu, *ITU Journal/d Engineering* **1**, 1 (2002).

[9] E. Büyükbıçakcı, İ. Temiz, H. Erdal, A.K. Binark, *Transformer Cooling Heat Storage Material Chemical Applications*, METET1, International Vocational and Technical Education Technologies Congress, Istanbul-Turkey, 2006, p. 937.

[10] A. Sharma, V.V. Tyagi, C.R. Chen, D. Buddhi, *Renewable and Sustainable Energy Reviews* **13**, 318 (2009).

[11] B. Zalba, M.M. Jose, F.C. Luisa, M. Harald, *Applied Thermal Engineering* **23**, 251 (2003).

[12] G. Baran, A. Sari, *Energy Conversion and Management* **44**, 3227 (2003).