International Journal of Electrical and Computer Engineering (IJECE)
Vol. 12, No. 3, June 2022, pp. 2323~2334
ISSN: 2088-8708, DOI: 10.11591/ijece.v12i3.pp2323-2334

Monitoring of power transformers using thermal model and permission time of overload

Huthaifa Ahmad Al_Issa[1], Mohamed Qawaqzeh[1], Serhii Kurashkin[2], Serhii Halko[2], Serhii Kvitka[2], Oleksandr Vovk[2], Oleksandr Miroshnyk[3]

[1]Department of Electrical and Electronics Engineering, Faculty of Engineering, Al Balqa Applied University, Al-Salt, Jordan
[2]Department of Electrical Engineering and Elmecromechanics named after Professor V.V. Ovcharov, Faculty of Energy and Computer Technology, Dmytro Motornyi Tavria State Agrotechnological University, Melitopol, Ukraine
[3]Department of Power Supply and Energy Management, Faculty of Energy, Digital and Computer Technologies, State Biotechnological University, Kharkiv, Ukraine

Article Info

Article history:

Received Apr 20, 2021
Revised Dec 19, 2021
Accepted Jan 10, 2022

Keywords:

Condition monitoring
GSM
Power transformer
Remote monitoring
Substation protection

ABSTRACT

This paper presents the problem of increasing the reliability of electricity supply to consumers. Uninterrupted power supply to electricity consumers depends on the reliability of power supply system in general and power transformers in particular, the accident rate of which is quite high. The causes of the problem are the location of transformer substations at a considerable distance from the service centers, their spreading out over a large area, missing information about the current modes of their operation and so on. One of the ways to solve this problem is development and implementation a system for continuous diagnostics of power transformers. Failure analysis of power transformer based on fault tree is considered, the diagnostic parameters are determined. The insulation wear rate and permission operating time under overload have been defined with help of equivalent heat circuit. It is proposed to use a permission time as a parameter to diagnose the operation mode and increase the efficiency of maintenance of substations through remote monitoring based on the global service mobile (GSM) network. Remote diagnostics allows to receive an information about emergency situation timely. It helps to reduce operating costs, to ensure the reliability and quality of electricity supply for consumers.

Corresponding Author:

Huthaifa Ahmad Al_Issa
Department of Electrical and Electronics Engineering, Faculty of Engineering, Al Balqa Applied University
Al-Salt, Jordan
Email: h.alissa@bau.edu.jo

1. INTRODUCTION

Power transformers are required components in the transmission and distribution network of electricity delivery on the reliability of which depends the quality of electricity supply to consumers. The failure of even a single transformer can lead to significant economic losses and poor maintenance of dozens of energy facilities. The reliability of power transformer is largely determined by the reliability of its winding [1], [2], which depends on the insulation condition. The aging of insulation is influenced by various operational factors, but current overload played the main role when thermal wear is accelerated. Overload leads to local insulation defects of winding and then complete short circuit and power transformer failure. In addition to current overload, the power transformer is affected by other factors as shown in Figure 1. One of them is the ambient temperature, which has significant fluctuations both during a day and season. Rising an ambient temperature directly causes overheating of insulation resulting in intense wear [3].

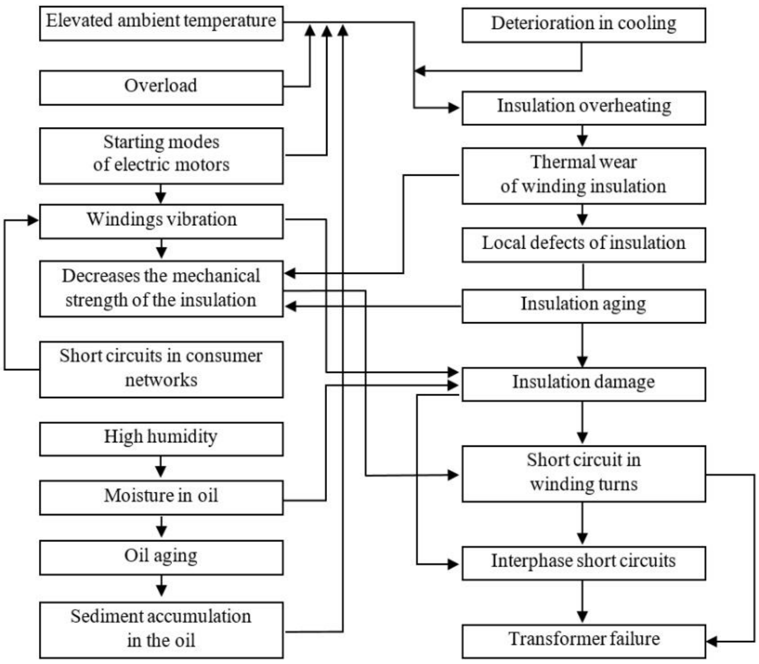

Figure 1. Transformer failure tree

Ambient humidity affects the insulating properties of transformer oil, accumulation of oxygen and sediment in the oil and on the active parts of the transformer, reducing the mechanical strength of insulation and raises its wear. The load of the power transformer depends on many factors–seasonality of work, number and type of consumers. Incomplete design of electrical networks, lack of automation and control over the load of powerful electricity consumers also affect overloads. Starting currents of powerful electric motors, short circuits and switching overvoltages in distribution networks have dangerous operational influence on isolation of the transformer. Systematic overloads are the cause of untimely insulation aging and transformers failure. Cooling conditions deterioration of the insulating structure occurs due to leakage of transformer oil, insufficient natural ventilation [4].

Factors mentioned above affects both individually and collectively on insulating structure reliability of the transformer winding–the most vulnerable element of its structure. Although transformers are considered to be very reliable equipment, the current fleet of them is quite old. The average age of transformers operated in distribution networks is 30 years, in utilities–20 years, in industry–15 years [5] that is, the service life of a significant part of the operating transformers has a limit value or close to it. Most of these transformers are installed at 10/0.4 kV consumer transformer substations and are under specific operating conditions asymmetrical load, seasonal load schedule, ambient temperature fluctuations, long transmission power lines. This, in combination with the significant ageing of transformers, leads to the fact that over the years the number of transformers failures increases as shown in Figure 2.

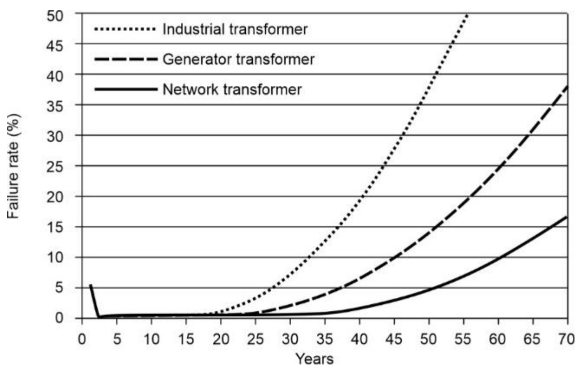

Figure 2. Development of the transformer failure rate in three different applications

A similar problem of increasing the continuity and quality of power supply exists in the European Union (EU) countries, where up to 8-10% of transformer substations fail annually [6]. Unexpected fails of power transformers cause serious limits in the operation of distribution networks. It leads to unscheduled power outages and problems for electricity delivery to consumers–this affects the economic performance and reputation of both energy supply companies and their customers. The significant cost of power transformers and their repair should also be taken into account [7]. The above shows that at present there is a problem of improving the operational reliability of power transformers installed in consumer substations.

The main reasons of power transformers failure are short circuits in electrical grid, overload, atmospheric overvoltages, reduced quality of transformer oil during operation, deterioration of cooling conditions, asymmetry with load currents [6]. In addition, the untimely and insufficient maintenance of power transformers and shortage of reliable information about the current modes of their operation contribute to the unsolved problem. This is especially true for that part of the power supply system where transformer substations are spreaded out over a large area and a considerable distance from service centers [8].

One of the ways to increase the reliability of power transformers is the development and implementation of remote diagnostics of their modes (remote monitoring). It allows to inform the emergency situation timely, which reduces operating costs, ensures the reliability and quality of electricity supply to consumers. First of all, remote diagnostics is actual for transformers without permanent maintenance. It leads to a significant reduction of transformer failures–according to According to international council on large electric systems (CIGRE) the probability of failures is reduced by 2.5 times. Early detection of problems can reduce repair costs by 75% and loss of revenue by 60% [9].

Remote monitoring can be done in different ways. ABB uses the transformer electronic control (TEC) monitoring system that receives all the relevant information from just a few multipurpose sensors [10]. Data exchange is carried out through the ethernet or internet. A feature of TEC is its focus on industrial electricity consumers, powerful transformers. But this way is not an optimal solution for consumer power substation. Power transformer monitoring system, which is presented in [11], provides access to a wireless fidelity (Wi-Fi) network that has a short range (up to 50 m from the access point) and in remote locations, the installation of power equipment is not an appropriate solution.

Some of diagnostics systems are using supervisory control and data acquisition (SCADA) technology with power line communication (PLC) protocol to remote monitoring of power transformers [12], [13]. It is characterized by low operation costs, but it is sensitive to the quality of the electrical network and the interference generated by low-quality consumer equipment. The maximum range of PLC communication is only 400 meters, which also prevents it from being used for transformers of consumer substations dispersed over a large area.

It is noteworthy the technology for collecting and processing data from distributed wireless sensors low-power, wide area networking (LoRaWAN) [14], [15], which has a long range. A LoRaWAN network in rural and semi-rural areas that are partially covered by vegetation, has a range of more than 20 km [16]. Communication between sensors and a base station (gateway) that transmits data to the server or internet occurs over the air at the frequency 433 MHz or frequency band 864-865 and 868,7-869,2 MHz. However, this technology is still not widespread due to the insufficient number of base stations–the end user needs to provide a full set of expensive equipment.

According to discussed above, it follows that many power transformer remote diagnostics systems use data transmission channels that are limited by distance. The most rational is the use of remote control based on advanced wireless global service mobile (GSM) technology [17]. Base stations of various mobile operators cover most of the territory near settlements, which allows using relatively inexpensive available equipment for remote diagnostics and monitoring of power transformers.

The usage of GSM network for remote monitoring of power transformers is not new, several studies [18]–[22] have previously paid attention to this issue. GSM network technology is used in the online environmental monitoring systems [23], [24] as well. The use of a GSM modem to remote monitoring the operation of a power transformer does not require saving its power consumption [25]. The industry produces GSM-controllers and loggers for remote control of power equipment [26], [27] but such devices are only a way of data transmission and does not take into account the thermal processes occurring in the power transformer.

The analysis of the above developments shows that most of them apply current and temperature sensors, but do not take into account the thermal properties of the power transformer. For example, the heating times of a temperature sensor and a complex object such as a power transformer are different, and the oil temperature varies depending on where the temperature sensor is installed. Thus, it is impractical not to take into account the thermal model of the power transformer during its monitoring. In contrast to the existing remote monitoring, we propose to construct the operation of the diagnostic device on the basis of such a diagnostic parameter as the permission operating time under overload. This will allow the overload characteristics of the transformer under variable load conditions to be fully taken into account. The use of such a device will increase the operational reliability of the power transformer and ensure uninterrupted power supply to consumers in case of permissible overloads and enable the transformer to be disconnected in case of emergency. The following is required for the design of this device: i) to analyze the equivalent heat circuit and system of thermal balance equations, ii) to obtain a mathematical model of the functional state of a power transformer based on its thermal model, iii) to verify the adequacy of the obtained mathematical model experimentally, and iv) to make an algorithm of the remote diagnostic device, in which the GSM-module transmits information about the current state of the transformer.

2. RESEARCH METHOD

To develop a system for power transformer remote diagnostics it is necessary to consider a model of its functional state, which means the transformer ability to transmit electrical energy. Power transformer has a rated (nominal) functional state when transmitting electricity, a wear rate of the transformer resource is nominal or less. When transmitting electricity, a wear rate of insulation resource is greater than nominal value the transformer has a non-nominal functional state. The wear rate of transformer resource ε is determined mainly by the consumption rate of isolation resource. It depends mainly on thermal wear of the insulation, and is determined by the (1) [28]:

$$\varepsilon = \varepsilon_n \exp\left(B\left(\frac{1}{\theta_n} - \frac{1}{\theta}\right)\right) \quad (1)$$

where ε_n is nominal wear rate of isolation resource; B is a temperature coefficient characterizing the insulation class (K); θ_n is a nominal absolute insulation temperature (K); θ is a current absolute insulation temperature (K),

$$\theta = \tau 1 + \vartheta env + 273 \quad (2)$$

where τ_1 is an exceeding the insulation temperature of winding above the ambient temperature (ºC) and ϑ_{env} is an ambient temperature (ºC). Exceeding the insulation temperature τ_1 depends on many factors, but the main one is the current load. To establish the relationship between exceeding insulation temperature and current of the transformer, there should be considered how the heating process of power transformer runs during symmetrical overload. According to equivalent heat circuit [29], [30] the power transformer thermal model is presented as a system of three bodies – winding, magnetic circuit (core) and oil as shown in Figure 3.

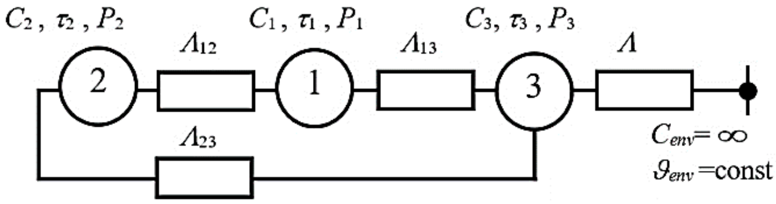

Figure 3. The equivalent heat circuit-based thermal model of power transformer

Bodies 1, 2, 3 (winding, core and oil) have their own heat capacity C_1, C_2, C_3 and interconnected by thermal conductivity Λ_{12}, Λ_{13}, Λ_{23}. Body 3 is linked to the environment by thermal conductivityΛ. Environment heat capacity C_{env} is equal to infinity. Bodies release heat through active power losses P_1, P_2, P3. It is assumed that no dependence between heat capacity and thermal conductivity from temperature. The ambient temperature ϑ_{env} is constant. The system of differential equations of heat balance for the above circuit is as (3):

$$\left.\begin{aligned} &C_1 d\tau_1 + \Lambda_{12}(\tau_1 - \tau_2)dt + \Lambda_{13}(\tau_1 - \tau_3)dt = P_1(1 + \alpha\tau_1)dt \\ &C_2\tau_2 + \Lambda_{23}(\tau_2 - \tau_3)dt - \Lambda_{12}(\tau_1 - \tau_2)dt = P_2 dt \\ &C_3\tau_3 + \Lambda\tau_3 dt - \Lambda_{13}(\tau_1 - \tau_3)dt - \Lambda_{23}(\tau_2 - \tau_3)dt = P_3 dt \end{aligned}\right\} \quad (3)$$

where τ_1, τ_2, τ_3 is temperatures rise above the ambient temperature of corresponding body (ºC); $C_1 d\tau_1$, $C_2 d\tau_2$, $C_3 d\tau_3$ is energy used to heat up the corresponding body (J); $P_1 dt$, $P_2 dt$, $P_3 dt$ is energy released as heat in corresponding body (J); $\Lambda_{12}(\tau_1 - \tau_2)dt$ is energy transfer from winding to magnetic core (J); $\Lambda_{13}(\tau_1 - \tau_3)dt$ is energy transfer from winding to oil (J); $\Lambda_{23}(\tau_2 - \tau_3)dt$ is energy transfer from magnetic core to oil (J); $\Lambda\tau_3 dt$ is thermal energy transfer from oil to ambient environment (J) and α is temperature coefficient of resistance for conductor material (1/°C). The system of (3) solution using classical method [9], [10] does not take into account the magnetic circuit and oil influence on transformer winding heating, so this system has been solved by differential operator method. Taking into account the overcurrent ratio k, the system of (3) according to this method is (4):

$$\left.\begin{array}{l}(pC_1 + \Lambda_{12} + \Lambda_{13} - \alpha k^2 P_{1н})\tau_1 - \Lambda_{12}\tau_2 - \Lambda_{13}\tau_3 = k^2 P_{1н}/p \\ -\Lambda_{12}\tau_1 + (pC_2 + \Lambda_{12} + \Lambda_{23})\tau_2 - \Lambda_{23}\tau_3 = k^2 P_{2н}/p \\ -\Lambda_{13}\tau_1 - \Lambda_{23}\tau_2 + (pC_3 + \Lambda + \Lambda_{13} + \Lambda_{23})\tau_3 = P_3/p\end{array}\right\} \quad (4)$$

where p is a differential operator; P_{1n}, P_{2n} is power of corresponding body under nominal rate (W). The solution to system of (4) after simplification is winding temperature excess:

$$\tau_1(p) = \frac{\Delta_1(p)}{\Delta(p)} = \frac{p^2 b_1 + pc_1 + d_1}{p(p^3 a + p^2 b + pc + d)} \quad (5)$$

Coefficients of the equation are:

$a = C_1C_2C_3$;
$b = C_1C_2(\Lambda+\Lambda_{13}+\Lambda_{23})+C_1C_3(\Lambda_{12}+\Lambda_{23})+C_2C_3(\Lambda_{12}+\Lambda_{13}-\alpha k^2P_{1n})$;
$c = \Lambda_{12}(C_1+C_2)(\Lambda+\Lambda_{13}+\Lambda_{23})+C_1\Lambda_{23}(\Lambda+\Lambda_{13})+C_2\Lambda_{13}(\Lambda++\Lambda_{23})+C_3(\Lambda_{13}\Lambda_{12}+\Lambda_{13}\Lambda_{23}+\Lambda_{12}\Lambda_{23})-$
$\alpha k^2P_{1n}(C_2\Lambda_{13}+C_2\Lambda_{23}+C_3\Lambda_{12}+C_3\Lambda_{23}+C_2\Lambda)$;
$d = \Lambda_{12}\Lambda_{23}\Lambda+\Lambda_{12}\Lambda_{13}\Lambda+\Lambda_{13}\Lambda_{23}\Lambda-\alpha k^2P_{1n}(\Lambda_{12}\Lambda+\Lambda_{12}\Lambda_{13}+\Lambda_{12}\Lambda_{23}+\Lambda_{23}\Lambda+\Lambda_{13}\Lambda_{23})$;
$b_1 = C_2C_3k^2P_{1n}$;
$c_1 = C_2k^2P_{1n}(\Lambda+\Lambda_{13}+\Lambda_{23})+C_3k^2P_{1n}(\Lambda_{12}+\Lambda_{23})+C_3k^2P_{2n}\Lambda_{12}+C_2P_3\Lambda_{13}$;
$d_1 = \Lambda_{12}k^2(P_{1n}+P_{2n})(\Lambda+\Lambda_{13}+\Lambda_{23})+k^2P_{1n}\Lambda_{23}(\Lambda+\Lambda_{13})+k^2P_{2n}\Lambda_{13}\Lambda_{23}+P_3(\Lambda_{13}\Lambda_{12}+\Lambda_{13}\Lambda_{23}+\Lambda_{12}\Lambda_{23})$

According to Laplace transform

$$F_1(p) = p^2 b_1 + pc_1 + d_1 \quad (6)$$

$$F_2(p) = p^3 a + p^2 b + pc + d \quad (7)$$

The (5) will take the form

$$\tau_1(p) = \frac{F_1(p)}{(pF_2(p))} \quad (8)$$

The equation $\tau_1(t)$ is original function of image (7):

$$\tau_1(p) = \frac{F_1(0)}{F_2(0)} + \frac{F_1(p_1)}{p_1 F_2'(p_1)} e^{p_1 t} + \frac{F_1(p_2)}{p_2 F_2'(p_2)} e^{p_2 t} + \frac{F_1(p_3)}{p_3 F_2'(p_3)} e^{p_3 t} \quad (9)$$

$$\begin{aligned}\tau_1 = \frac{d_1}{d} &+ \frac{b_1 p_1^2 + c_1 p_1 + d_1}{p_1\left(3ap_1^2 + 2bp_1 + c\right)} e^{p_1 t} + \frac{b_1 p_2^2 + c_1 p_2 + d_1}{p_2\left(3ap_2^2 + 2bp_2 + c\right)} e^{p_2 t} + \\ &+ \frac{b_1 p_3^2 + c_1 p_3 + d_1}{p_3\left(3ap_3^2 + 2bp_3 + c\right)} e^{p_3 t}\end{aligned} \quad (10)$$

where p_1, p_2, p_3 are roots of the (7). Relation (10) is the heating equation of power transformer winding as a time function of thermal model that consist of three bodies (winding, magnetic circuit and oil). In contrast to the classical transformer thermal model, in mathematical heating model obtained, each body affects the heating of another body, including the winding, and part of this influence varies exponentially. A heating curve of the transformer winding is the sum of three exponents. Each body effects on that heating. Non-variable component $F_1(0)/F_2(0)$ shows from which state (cold or heated) the transformer is loaded.

The temperature exceeding of transformer winding $\tau_1(t)$ depends on the constant design parameters (heat capacity of the active parts and thermal conductivity between them), as well as on the variable parameters (active energy losses in the bodies). The last depends on the overcurrent ratio k. Thus, it follows from (9), (10) that heating equation of transformer winding as a heterogeneous system has the form:

$$\tau_1 = \tau_{1stab}^{'}\left(1 - e^{-t/T'}\right) + \tau_{1stab}^{''}\left(1 - e^{-t/T''}\right) + \tau_{1stab}^{'''}\left(1 - e^{-t/T'''}\right) \quad (11)$$

where τ'_{1stab}, τ''_{1stab}, τ'''_{1stab} are established partial exceedances of the winding temperature (ºC) and T', T'', T''' are partial time constants of heating winding (s).

$$T^{'} = -1/p_1; \quad T^{''} = -1/p_2; \quad T^{'''} = -1/p_3 \quad (12)$$

According to research of TM-25/10 power transformer, the thermal model partial components that have a larger time constant (T') determine the duration of the thermal process, while the components with smaller ones (T'', T''') affect only the initial stage of heating as shown in Figure 4. The heating curve of power transformer represented by a homogeneous body is differs from curve of heterogeneous system. As seen in Figure 5 there is a divergence up to 30% at the beginning of heating, which over time almost disappears. If replace the real heating curve of transformer winding with an equivalent one, it could be obtained the heating equation:

$$\tau_1 = \tau_{1stab}\left(1 - e^{-t/T}\right) + \tau_{1s}e^{-t/T} \quad (13)$$

where τ_{1stab} is established and τ_{1s} is initial temperatures excess winding temperature (ºC); t is a current time (s) and T is equivalent heating constant (s):

$$T = \frac{C_1 m_1 \tau_{1n} + C_2 m_2 \tau_{2n} + C_3 m_3 \tau_{3n}}{\Delta P_n} \quad (14)$$

where m_1, m_2, m_3 are the winding, core and oil masses accordingly (kg); τ_{1n}, τ_{2n}, τ_{3n} are the winding, core and oil excess temperatures in nominal mode accordingly (ºC), ΔP_n is power loss in the transformer in nominal (W).

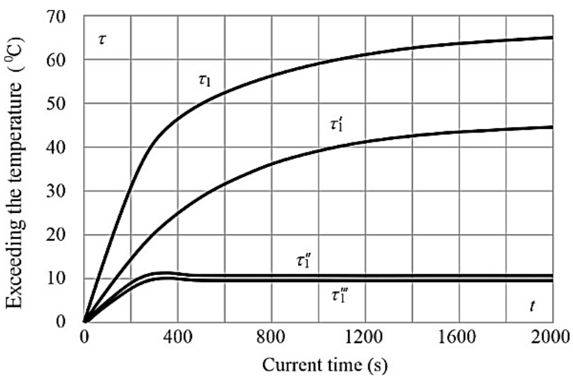

Figure 4. Partial components τ'_1, τ''_1, τ'''_1 of heating curve

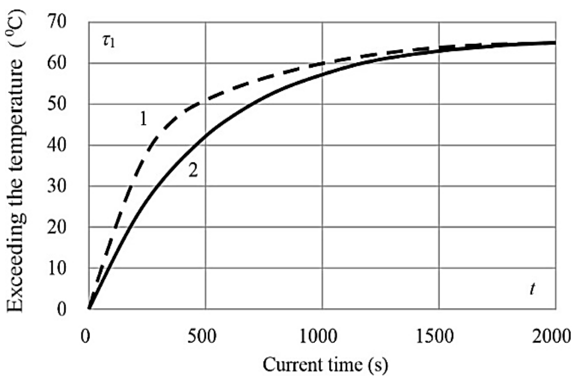

Figure 5. Heating curves $\tau_1(t)$ of heterogeneous (1) and homogeneous (2) power transformer model

The established temperature of winding is calculated as (15):

$$\tau_{1stab} = \tau_{1n}\frac{a+k^2}{a+1-\alpha\tau_{1n}(k^2-1)} \quad (15)$$

where a is a relation of power loss in the core $\Delta P_{const.n}$ to power loss in the winding $\Delta P_{var.n}$ under rated load and k is an overcurrent ratio

$$k = I/I_n \quad (16)$$

where I is an effective value of the overload current (A) and I_n is a rated (nominal) value of the current (A).

When overload current increases, the permission operating time t_p decreases. During this time the winding temperature reaches the limit value. If to set a certain exceeding temperature limit for winding τ_p, it could be found the permission operating time under overload. On condition $\tau_1=\tau_p$, $t=t_p$, $\tau_{1s}=0$ the (13) will change to:

$$\tau_p = \tau_{1stab}\left(1 - e^{-t_p/T}\right) \tag{17}$$

The permission operating time during transformer overload is calculated as (18):

$$t_p = T\ln\frac{\tau_{1stab}}{\tau_{1stab}-\tau_p} \tag{18}$$

Finally, (1), (2), (14), (15), (16), and (18) obtained above represent a mathematical model of the functional state of the power transformer, based on its thermal model.

3. RESULTS AND DISCUSSION

By using the functional state model, graphs of transformer winding TM-25/10 excess temperature $\tau_1 = f(t)$ under symmetrical overload from 20 to 60 percent relative to the rated mode of operation were received as shown in Figure 6. The obtained dependences allowed to build the overload characteristic in Figure 6 and to estimate the overload effect on power transformer permission operation time during the winding temperature reaches τ_p. It could be concluded from Figure 7 that time depends on overcurrent ratio k and decreases if it increases.

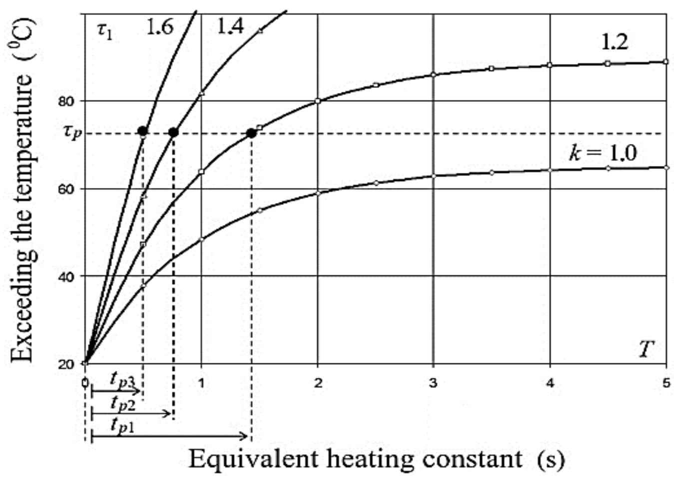

Figure 6. Graphics of excess temperature $\tau_1 = f(t)$

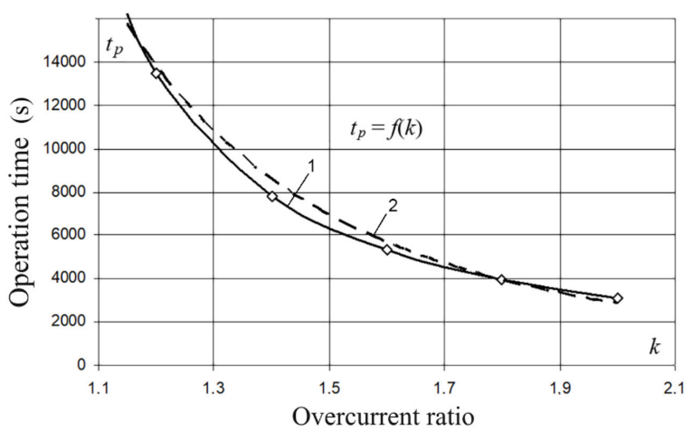

Figure 7. Permission operation time t_p dependence on overcurrent ratio k experiment (1) and computation (2) results

To validate received model the experimental verification was provided with loading of power transformer TM-25/10. The research was conducted in the conditions of the repair service. To obtain reliable information, the measurements were repeated three times. As a result, the overload curve was obtained. By using the functional state model in Figure 6, the overload curve was calculated as well. Experimental (1) and calculated (2) overload curves comparison of power transformer in Figure 7 shows that maximum discrepancy between analytical and experimental data does not exceed 8%. It indicates the adequacy of obtained functional state model of power transformer.

According to research, the thermal wear rate dependences of insulation on overcurrent ratio $\varepsilon = f(k)$ and ambient temperature ϑ_{env} are obtained as shown in Figure 8. Based on the obtained results, it can be concluded that thermal wear rate of the transformer insulation depends on its design parameters and significantly depends on the ambient temperature, the overcurrent ratio and initial preceding conditions. According to received model of the functional state of the power transformer, the data flow diagram for the remote diagnostics device was developed. It is presented in Figure 9.

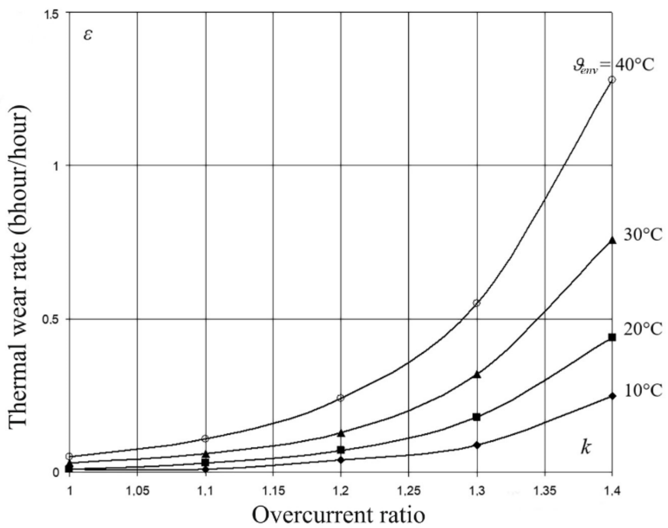

Figure 8. Thermal wear rate ε dependences of insulation on overcurrent ratio k and ambient temperature ϑ_{env}

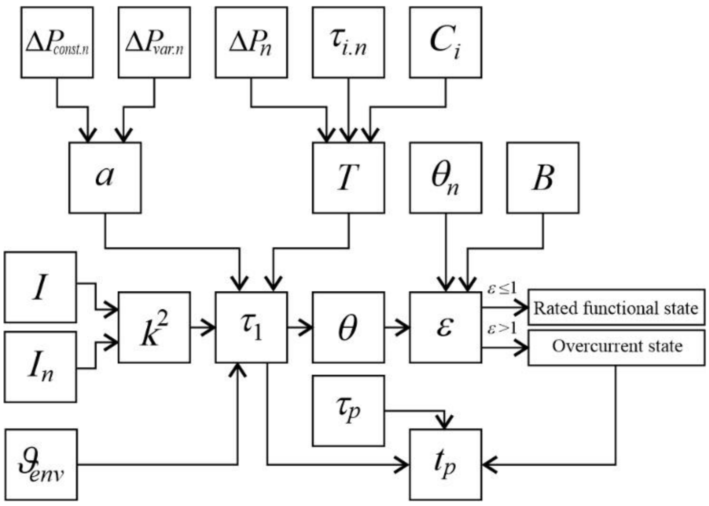

Figure 9. Data flow diagram of power transformer diagnostics

According to diagram, the values have to be set: nominal power losses $\Delta P_{const.n}$ (in the core), $\Delta P_{var.n}$ (in the winding) and ΔP_n (in the transformer); nominal temperatures τ_{1n} (winding), τ_{2n} (core) and τ_{3n} (oil); heat capacity C_1 (winding), C_2 (core) and C_3 (oil); nominal absolute insulation temperature θ_n; temperature coefficient B, value of rated current I_n, exceeding temperature limit for winding τ_p. The values of effective current I and ambient temperature υ_{env} are measuring by sensors. Then the device calculates by a given program an overcurrent ratio k, equivalent heating constant T, temperature rise of winding τ_1, absolute insulation temperature θ, permission operating time t_p, wear rate of transformer resource ε. The remote monitoring device periodically informs the operator about the current status of the transformer–whether it is overloaded (ε>1) or not (ε≤1). In case of exceeding the permission overload time, the transformer is switched off. The above algorithm is realized in the remote diagnostic device, a block diagram of which is shown in Figure 10. The device consists of blocks: current sensor (CS), environment temperature sensor (TS), oil level sensor (OLS), oil temperature sensor (OTS), programming microcontroller unit (MCU) with build in ADC convertor, GSM-module, SIM card slot, relay module (REL1-REL3), power supply (AC/DC), antenna (ANT).

The device works as follows. The current sensor measures the root mean square current value of the power transformer, at the same time ambient temperature and oil level in the transformer tank are measured. The microcontroller MCU calculates the overcurrent ratio k according to data received from sensors CS and TS. In case the transformer overload exceeds the rated value, the permission operating time during overload is calculated t_p. If value t_p is less than time that has elapsed since the overload occurred, a signal to disconnect the transformer from network is generated using relay module REL.

The oil level control in the tank is performed according to a separate subprogram-the signal for shutdown is formed only if the level falls below the critical value. The flowchart for remote diagnostic device is shown in Figure 11 and construction is shown in Figure 12. At software intervals, the device transmits the measured and calculated data by installed SIM card by means of the GSM-module. It is reasonable to place a large amount of received data on a third-party WEB-server. Thus, the available database can be further used in SCADA-system design, providing full operator control over the process.

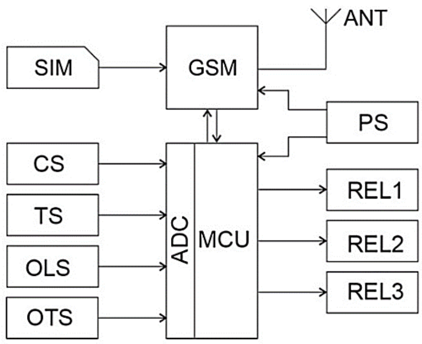

Figure 10. Block diagram of the remote diagnostic device

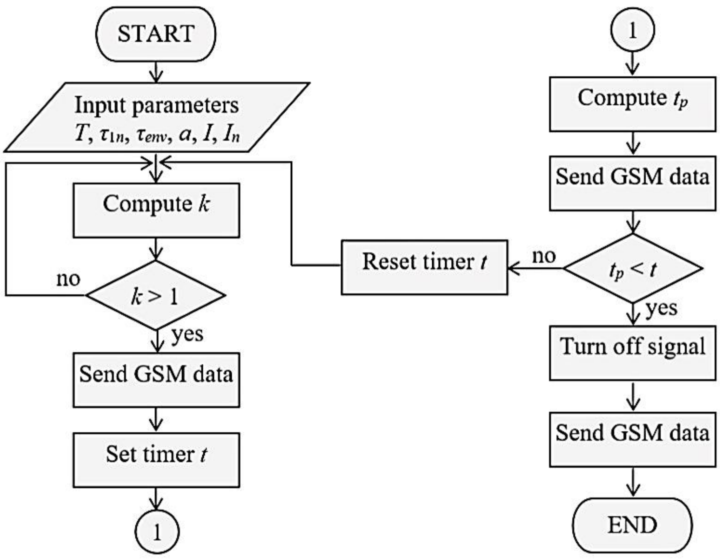

Figure 11. Monitoring flowchart

Data is transmitted to the operator with a delay typical for the GSM network-no worse than 300-1000 ms (legacy 2G networks), but usually 100-500 ms (3G networks) and even less than 100 ms (4G networks) [31], [32]. This is normal, considering that the power transformer shutdown instantly when the permissible overload time is reached. In contrast to similar works, the proposed method calculates the permission operating time based on received data (oil temperature, load current) in addition to transmitting the current data of transformer state. The outage is not immediate in the event of an abnormal situation, but after a time sufficient to ensure that the resource flow rate does not exceed the permissible value.

Figure 12. Remote diagnostic device construction

4. CONCLUSION

The power transformer reliability depends on timely and high-quality diagnostics of thermal processes that occur during overload. To do this, it is proposed to use a model to diagnostics the thermal mode of the transformer. It represented by a system of three bodies-winding, magnetic circuit and oil. The result of calculations is allowable operating time determination when power transformer under overload. Since the transformers of distribution networks 10/0.4 kV are located on a large area away from the service organizations, the remote monitoring usage of functional state reduces operating costs, ensures the reliability and quality of electricity supply to consumers. It is rational to perform this control on GSM network basis, which have a significant coverage area and range. The data obtained from remote diagnostic devices on power transformers 16-160 kVA functional state can be used to organize SCADA systems for centralized territorial maintenance of the distribution network.

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BIOGRAPHY OF AUTHORS

Huthaifa Ahmad Al_Issa received his Bachelor's and Master's degrees in Electrical and Computer Engineering at the Near East University, Cyprus, in 2003 and 2005, respectively with high honors GPA. He received his Ph.D. degree in Electrical Engineering at the University of Dayton, Dayton, Ohio, USA, in 2012. Currently, he is an Assistant Professor in the Department of Electrical and Electronics Engineering at Al Balqa Applied University. He has been a member of the Jordan Engineers Association (JEA) since 2003. He can be contacted at email: h.alissa@bau.edu.jo.

Mohamed Zaidan Qawaqzeh graduated from The Eastern Ukrainian State University in 2001 and was qualified as an Electrical Engineer. He received his PhD in Electric Engineering from Donetsk National Technical University in 2006. Currently, he is an Asssistant Professor at Al Balqa Applied University, Jordan. His research interests are in the area of power engineering, automation system, electric drive, Smart Grid, Renewable energy. He can be contacted at email: qawaqzeh@bau.edu.jo.

Serhii Kurashkin received the PhD degree in electrical complexes and systems from the Tavria State Agrotechnological University, Melitopol, Ukraine, in 2011. He is the author of two books, more than 50 articles, and 9 inventions. Currently, he is an Assistant Professor in the Electrical Engineering and Electromechanics Department at Dmytro Motornyi Tavria State Agrotechnological University, Melitopol, Ukraine. His research interests include renewable energy, quality of electrical energy, losses of electrical energy, remote monitoring and control of electrified objects. He can be contacted at email: serhii.kurashkin@tsatu.edu.ua.

Serhii Halko graduated from Melitopol Institute of Mechanical Engineers of Agriculture, Ukraine, in 1994, and was qualified as an Electrical Engineer. He received his PhD in Electric Engineering (power stations, systems and networks) from the Donetsk National Technical University, Ukraine, in 2003. Presently, he is an Assistant Professor of Dmytro Motornyi Tavria State Agrotechnological University and Educational Scientific Institute of General University Training, Melitopol, Ukraine. He is the author of more than 100 scientific publications, 10 inventions, and two monographs. His research interests are related to research in the field of renewable and alternative energy. He can be contacted at email: serhii.halko@tsatu.edu.ua.

Serhii Kvitka received the PhD degree in application of electrical technologies in agricultural production from the Tavria State Agrotechnical Academy, Melitopol, Ukraine, in 2003. Presently, he is a Head of Electrical Engineering and Electromechanics Department at Dmytro Motornyi Tavria State Agrotechnological University, member of two scientific publications editorial board. He is the author of 7 books and monographs, more than 100 articles and more than 10 inventions. His research interests include the control and protection of power electrical equipment, microcontrollers, automation system, and control systems for induction motors drives. He can be contacted at email: sergii.kvitka@tsatu.edu.ua.

Oleksandr Vovk graduated from Tavria State Agrotechnical Academy, Ukraine, in 1996, and was qualified as an Electrical Engineer. The PhD degree have been received in in Electric Engineering (power stations, systems and networks) from Tavria State Agrotechnical Academy, Melitopol, Ukraine, in 2003. Currently, he is an Assistant Professor of Dmytro Motornyi Tavria State Agrotechnological University. He is the author of three books, more than 50 articles and 7 inventions. His research interests are in the area of power engineering, energy saving in electromechanical systems. He can be contacted at email: oleksandr.vovk@tsatu.edu.ua.

Oleksandr Miroshnyk received the M.Sc. degree from the Kharkiv State Technical University of Agriculture, Kharkiv, Ukraine, in 2004, and the Doctor of Technical Sciences degree from the National Technical University "Kharkiv Politechnic Institute", Kharkiv, Ukraine, in 2016, all in electrical power engineering. He is the author of three books, more than 200 articles, and more than 30 inventions. His research interests include the Smart Grid, renewable energy, quality of electrical energy, losses of electrical energy, overhead power lines monitoring, power system automation. He can be contacted at email: omiroshnyk@ukr.net.