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# Routine Test Analysis in Power Transformers by Using Firefly Algorithm and Computer Program

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**ABSTRACT** Faults that occur during the transmission and distribution of energy usually occur in power transformers. The interruptions in the transformers, the voltage drops, the sudden interventions in the over currents cause important problems. For this reason, power transmission and distribution companies should perform routine tests and transformers more effectively. In this study, transformer routine tests have been analyzed by using the generated firefly algorithm. Data from sensor and measuring instruments in the transformer units obtained. A data collection system consisting of hardware and software has been created to collect the data and transfer it to the computer center. Electronic hardware has been utilized for transferring data from sensors connected to different units of transformer to computer. The data received from the transformer has been synchronized with the PIC microcontrollers in the designed circuit and transferred quickly and safely to the computer by means of the USB port. An interface written in Visual Studio programming language has been created in order to present the analog signals in digital format to the user in a visual way. The voltage values obtained from the sensors have been displayed on the Transformer Routine Test Analysis Program screen created on the computer. The measurement accuracy and success of the designed software and hardware have been tested on real system. The data obtained showed that the system is successful. Thus, remote monitoring, control and routine testing of transformers with the software and hardware created have been realized.

**INDEX TERMS** Transformers, power transformers, animal behavior, test.

## I. INTRODUCTION

The demand for electricity in the world is increasing day by day. Electrical energy should be delivered to the consumer with the least loss, uninterrupted, in the highest efficiency and in the most economical way. The systems used in the generation, transmission and consumption of electrical energy must be routinely tested to ensure that they are of good quality and continue to work in a quality manner.

The field test and routine power factor tests of the power transformers should be done regularly and the test results should be evaluated. Thus, possible malfunctions will be predicted. Unwanted power outages will be prevented and the energy quality will be maintained. The equivalent circuits of power transformers in different connection types are in the form of multi-model functions. The most appropriate population-based heuristic algorithm for optimizing multi-model functions is firefly algorithm. The main purpose of using this algorithm is to capture all local maximum values in power transformers in different connection forms. In multi-model function optimization problems, the most important difference between firefly herd optimization and previous approaches is the dynamic decision area used by the individuals in the herd who efficiently place multiple peaks. Each individual in the herd uses the decision-making area to select his neighbors and determines his movement through the signal strength he receives from his neighbors.

In this study, software has been developed in C # program language by using firefly algorithm developed. On the basis of this algorithm to optimize parameters in power transformers, Routine Test Analysis Program has been created in Visual Basic Programming language [1]. Using this program, it has become possible to perform routine analysis in power transformers.

## II. THE CREATED FIREFLY ALGORITHM

The developed firefly method is one of the stochastic numerical optimization search methods. It has been developed to

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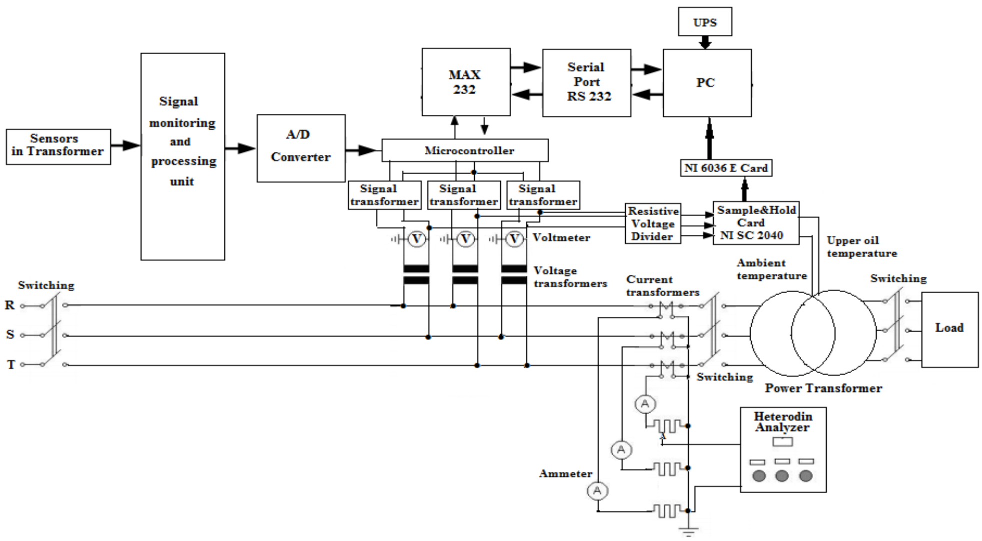


**FIGURE 1. Created experiment test diagram in power transformers.**

optimize multi-model functions [1]–[3]. The firefly lot optimization method was developed by observing and imitating the social behaviours of fireflies. The main purpose of using this method is to capture all local maxima. In multi-model function optimization problems, the most important difference between firefly herd optimization and previous approaches is the dynamic decision space used by individuals in the herd who efficiently place multiple peaks [4]–[6]. Each individual in the herd uses the decision area to select their neighbours. It determines the movements with the signal strength it receives from its neighbours. The attractiveness of fireflies is directly proportional to their brightness [7]–[9]. The distance between the fireflies decreases the attractiveness because they reduce the brightness. If the firefly has a brighter firefly than in the environment, this firefly will move towards the bright one. If there are no more bright fireflies in the environment, they move in random directions. In the developed firefly optimization algorithm, at the beginning a certain number of fireflies are randomly generated to spread in the appropriate search space. Each firefly has its own position. Each firefly is first placed in random positions. This initial position equation is given in Equation (1).

$$x_i = X_{min} + R.(X_{max} - X_{min}) \quad (1)$$

Random number selection has been used from 0 to 1 for the R value. $X_{min}$ is equal to 1. $X_{max}$ is the total number of values in the variable set. $f(x_i)$ function values have been determined for each $x_i$ position value in the design space. $p_i^t$ best position of the firefly with number i until the iteration step t and $p_g^t$ global optimum position of the firefly has been updated. Also, the location of each firefly has been updated. The best position value of a firefly so far has been determined as the best position value for that particle. For each firefly has been stored in a separate vector. This position has been saved in the vector, called the best position value if the best position obtained in the cluster since the beginning of the optimization process. The position of fireflies at (t+1) is calculated by Equation (2).

$$x_i^{t+1} = x_i^t + \alpha_0.e_{ij}^{-\gamma.r^2}(x_j^t - x_i^t) + \beta_t.\varepsilon_i^t \quad (2)$$

The $x_i^{t+1}$ expression determine the position of the i. firefly in step t+1. $\alpha_0$ refers to the initial attractiveness of firefly. $\gamma$ refers light absorption coefficient. r is distance of fireflies. The distance between the fireflies decreases the attractiveness. The new position of each firefly in iterations is determined by following Equation (2). ß is the random order parameter and a number ranging from 0 to 1. $\varepsilon$ is a parameter of the weight of the firefly in determining the new position. The Cartesian distance between the two fireflies at points i and j is calculated by Equation (3).

$$r_{ij} = \left\| x_i - x_j \right\| \quad (3)$$

Functions where the variables take actual values are optimized. Each of the functions corresponds to a point in the design space. The decision variable can take all the values in a region limited by constraint functions [10]–[12]. Functions in which the variables take actual values are optimized. Since the equivalent circuits of the power transformers in different connection forms are in the form of multi-model functions, the most suitable population for optimizing these functions is the firefly algorithm. The main purpose of using this algorithm is to capture all local maximum values in power transformers in different connection forms.

## III. TEST ANALYSIS IN POWER TRANSFORMERS

The control panel, which performs routine test analyzes on power transformers, has been developed in Mersin University Laboratories. This routine test analysis control panel diagram is given in Figure 1. The measurement panel is shown in Figure 2.

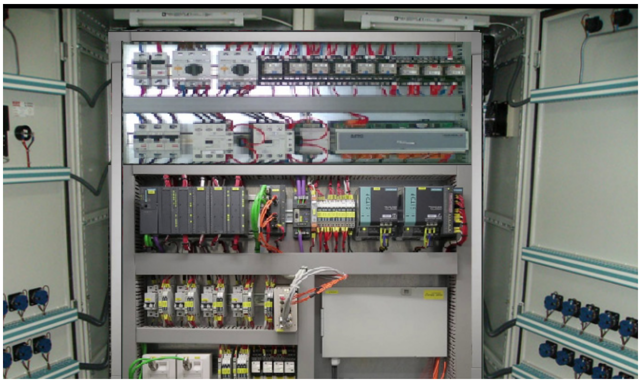

**FIGURE 2.** The power transformers measurement panel.

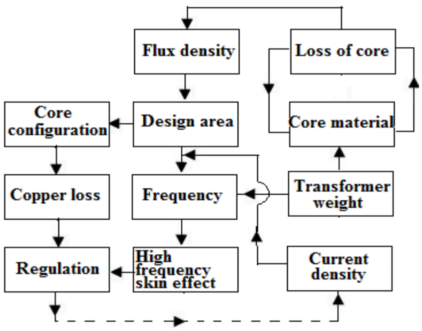


**FIGURE 3.** Test analysis Diagram in power transformers.

The power transformers measurement panel hardware consists of three current and voltage transformer, one resistive voltage divider card, three resistive voltage divider, one data acquisition card, one sampling & holding card, one uninterruptible power supply, one personal computer. Sensors are installed in each unit of the transformer. Analog/digital signal converters and many serial ports have been used for the sensors. This power transformers measurement panel has been installed within the control building of Silifke Transformer Center. The current, voltage and temperature information of the measuring point of the power transformer has been brought to the measurement system with cables. Oil temperature sensors and ambient temperature sensors are installed in each unit of the transformer. The information received from the sensors has been brought to the measuring system using a signal converter. All the parameters of the transformer have been estimated by processing the obtained data with the algorithm and computer program [1]. The analysis diagram in power transformers is shown in Figure 3.

Deformation of the transformer windings, short circuit of the winding, winding breaks and core malfunctions have been determined by the excitation current test. Insulation tests have been carried out to determine the insulation condition of the insulating materials forming the transformer. The insulation tests on the transformer have been made between the windings and the windings and between the windings and the tank ground. Isolation data of the transformer have been recorded in a database and kept in the direction of isolation. The values obtained in the insulation measurements between the winding tanks have been compared with the previous values and the changes are checked. If there is a change, it has been investigated to what extent this change is and why it is caused. The% PF test has been also applied on the insulating oil. About 25% of the weight of the transformer is oil [13]–[18]. Oil is used for isolation and cooling of transformers [19]–[23]. The isolation of the oil varies according to the rate of moisture, water and foreign substances in its content [24]–[27]. This is due to the fact that the tap changer has a movable structure and because of the arcs formed during the on-load tap-change operation, the insulating oil of the stage is contaminated more quickly. For this reason, tank oil and tier oil are contained in separate compartments in the tank. Usually the value of the conductivity of the insulation surface area varies. The insulation resistance rises rapidly as soon as the first voltage is applied and its value decreases logarithmically. According to the structure of the insulation material used in transformers, this increase can sometimes take a few hours, while in some materials it takes between ten and fifteen minutes. The polarization index is obtained by dividing the tenth-minute resistance value by the first minute resistance value. This value helps to decide the insulation condition of the transformer considering the characteristic resistance curve. In the dielectric absorption ratio, an evaluation has been made according to the absorption current.

The insulation resistance in the transformers has been measured between the primary, secondary windings and the tank and between the primary secondary windings. In insulation resistance measurements, the most important factors affecting the measurement are humidity, pollution and temperature [28]–[31]. Leakage flows vary according to the dry and clean surface. If the insulation surface is damp or oily, the insulation resistance will be low as leakage currents will increase. Therefore, this situation is also seen in the polarization index. In the same way, the current will increase according to the amount of moisture absorbed by some insulating materials [32]. This will change the insulation resistance badly. To eliminate the differences between the two measurements, the temperatures of the windings are taken into account. The obtained values have been multiplied by the temperature correction coefficient given with reference to 20 °C. The measurements are fixed to a specific temperature.

As a result of all these measurements, the measured values are expected to be above a certain limit. The winding ratio test has been used to determine whether the winding are suitable for the project or not. It is understood whether there is a conductor break or short circuit fault in the transformer windings. The measurement has been made between the winding pairs in single phase. During the measurement, the conversion ratio between the pairs of windings in which the same magnetic flux flows has been measured. The conversion ratio has been measured between the pair of windings which are parallel to each other in the vector diagram.

In order to test the bridge method, it is necessary to know the connection group of the transformer and to examine the phase diagrams. The connection structure of the transformer must be examined to determine the connection group. The purpose of the transformer winding resistance tests is to determine the short circuit of the transformer winding, bad contact in the joints, the status of the contacts, the winding and the breakage of the faults. The DC resistance values measured at the same stage has been compared with the factory test values or the previous test values by taking into consideration the temperature values. The phases have been evaluated in each stage. Values between the stages should increase or decrease steadily. According to the order of priority, detailed tests and controls have been performed to determine the source of the fault. Winding resistance measurements have been generally measured using a bridge technique, voltmeter-ammeter method or micro-ohmmeter. The measured results have been compared with the previous values. If there is any looseness in the windings or a break in internal connections, the values will be high. The difference between phases or temperature-corrected values of the previous measurement should not exceed 5%.

The other transformer tests are the dielectric strength test, and the puncture voltage test. Mineral oils are generally used in transformers and there are two types of paraffin and naphtha based. Naphtha based oils oxidize more quickly than those based on paraffin [33]. Products resulting from this oxidation dissolve more quickly and do not sink to the bottom of the transformer. In this case, the circulating oil circulates inside the transformer, which creates an undesirable situation. The oil in the transformer loses its insulation properties over time. The dielectric strength test is a very simple and highly demanding test. Current is applied to the ends of the electrodes and the tension is increased until a jump occurs. When the jump occurs, the current is immediately interrupted. The value of this voltage at the time of the jump is the result of the test. It has been compared with the value given by the standard. The measured values have been recorded. The aging of the oil has been monitored. If the puncture voltage is below the specified limit value, it is replaced with new oil according to the cleaning process or operating conditions [23].

## IV. ROUTINE TEST ANALYSIS BY USING FIREFLY ALGORITHM

In defining the parameters of the transformer, some limitations have been made for the optimum solution. First, some pre-definitions have been made to narrow the search field and save time. The basic steps of the firefly algorithm for routine test in power transformers are as follows.

Step 1: Create random transformer parameter solution sets. Each solution set contains as many elements as the number of parameters. Compatibility values of the generated solution sets are found.

Step 2: All transformer parameter solution sets are applied in order to improve the formula.

Step 3: Return to Step 2 until you reach the maximum iteration.

**TABLE 1. Firefly parameters.**

| Algorithm Parameters | Explanation |
|---|---|
| n | Number of solutions |
| f | Number of wrong zones selected from problematic n number of errors |
| b | Selected "f" is the best number of zones in the wrong region |
| nbp | Number of solutions applied to the best solution b zone faulty region |
| nrp | Remaining number of solutions (f-b) |
| nss | Neighbor solution search size |
| itn | Stop criterion (number of iterations) |

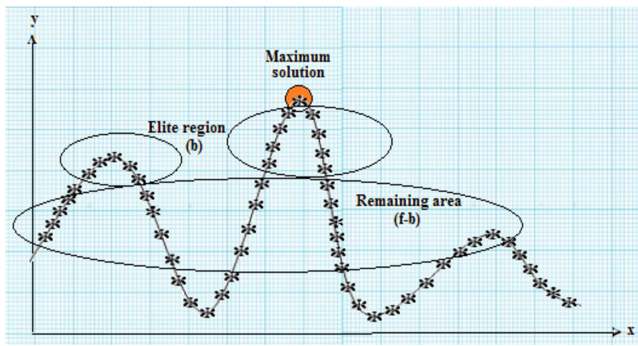


**FIGURE 4. 'n' resolution search space.**

The formula for the development of each parameter of each of the generated solution sets is applied in order. Each firefly controls all other fireflies and moves randomly for fires that are self-glossing, if not bright, while moving towards them, depending on the formula. Firefly parameter is shown in Table 1. 'n' resolution search space is given in Figure 4. Algorithm begins with the random placement of n solution research space. n resolutions are compared to each other and more suitable regions (f) are selected according to the suitability of the points examined. The elite regions (b) and the regions with the best fit value (f-b) are selected. The neighborhood search size (nss) of these elite regions is determined. More appropriate points are searched in the selected regions. Regions that express the best solutions (nbp) are applied to the remaining solution regions (nrp) as compared to other selected regions (nbp). For the new population, the most appropriate valued solution is selected for each region and the other solutions are separated from the research area. To obtain new potential solutions, other solutions (f-b) are randomly placed in the research area [1].

The Firefly Algorithm for analyzing routine test of power transformers is given in Figure 5. The solutions obtained for each selected region and random search regions are retained until the optimization criterion is achieved. The flow chart of the transformer routine test analysis program is shown in Figure 6. Routine Test and Measurement diagram is given in Figure 7. This measuring system is installed in Silifke GIS Substation.

The signal transducer, the personal computer and the uninterruptible power supply of the sensors have been used in

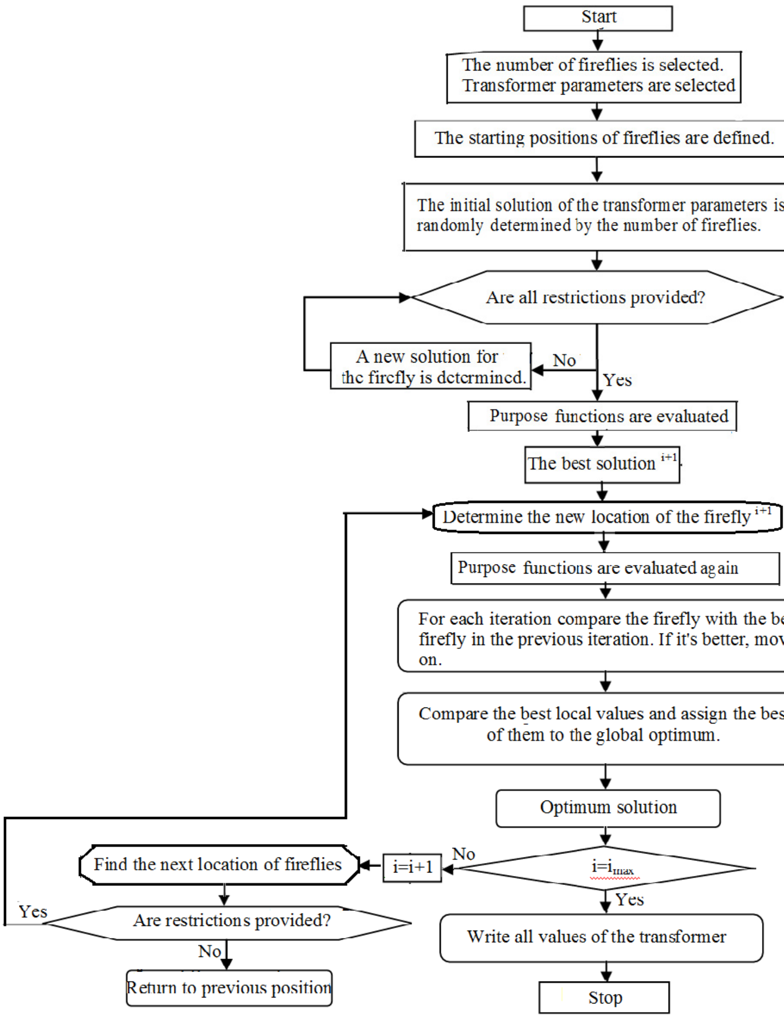


**FIGURE 5.** The firefly algorithm for analyzing routine test of power transformers.

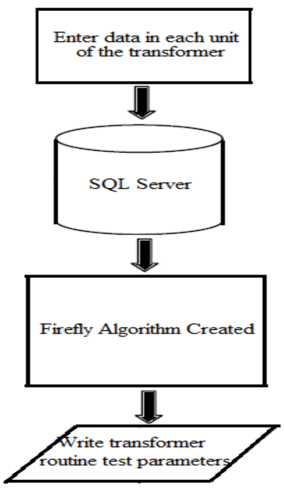


**FIGURE 6.** The flow chart of the transformer routine test analysis program.

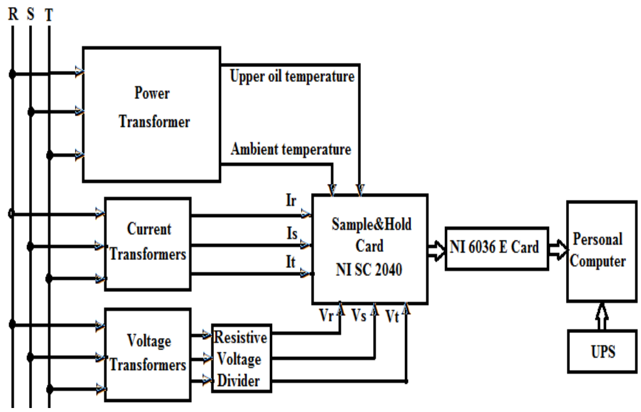


**FIGURE 7.** The diagram of routine test analysis measurement system.

the routine test analysis measurement system. Using the Lab-view program, the data received in seconds have been processed by the codes written in the Matlab Program. The data obtained from the sensors in each unit of the power transformer are written to the appropriate places in the M file. The data obtained from the sensors in each unit of the power transformer are written to the appropriate places in the M file. All parameters, ambient and upper oil temperature

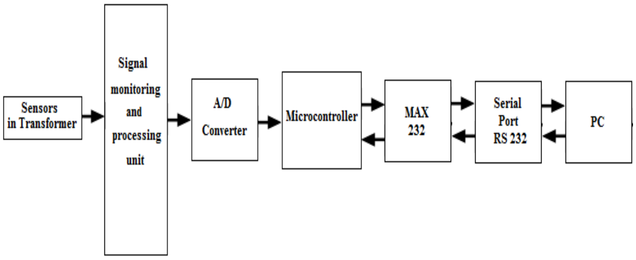


**FIGURE 8.** Hardware of the transformer routine test analysis.

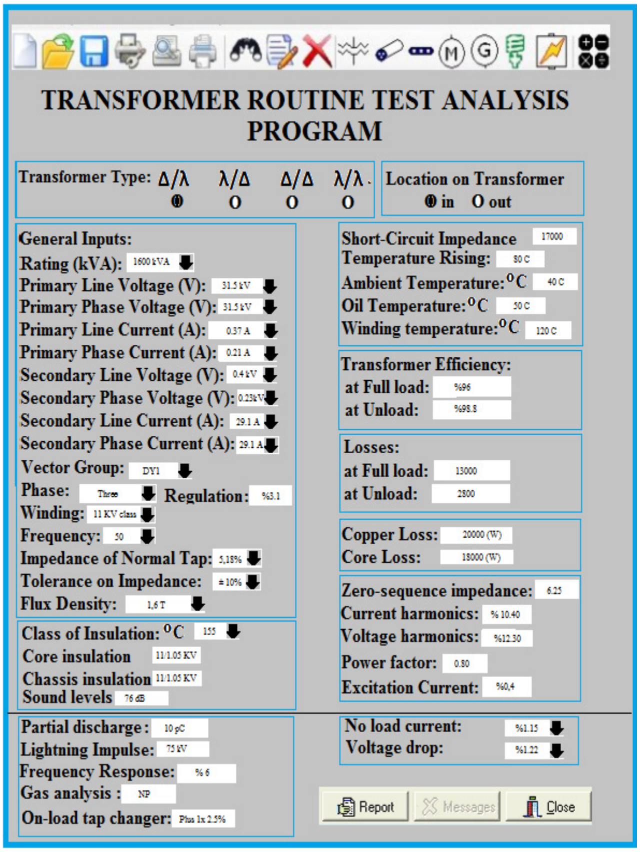


**FIGURE 9.** The interface of transformer routine test analysis.

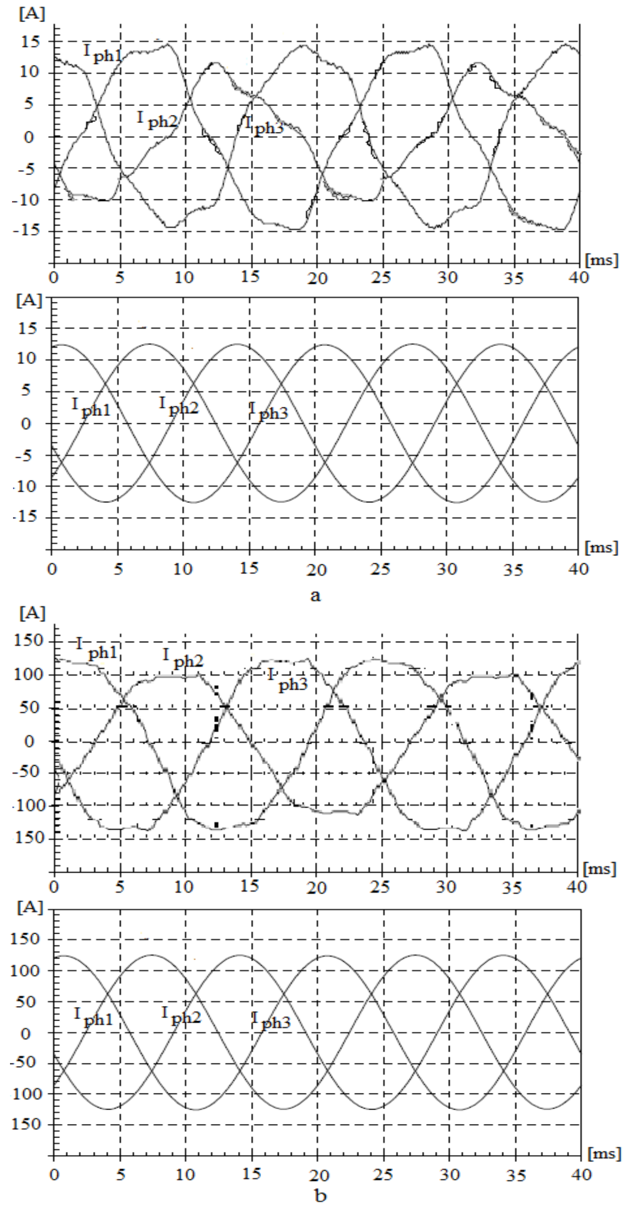


**FIGURE 10.** a) No-load test primary side experimental and simulated currents waveforms b) Steady-state load test primary side experimental and simulated currents waveforms.

values of the power transformer have been obtained by using eight channels on National Instruments SC2040 board. The 6036E Card has been used for analog/digital signal conversion between the SC2040 and the computer and to sample the analog signals from the SC2040 output plugged into the PCMCIA slot. Voltage divider board has been used to obtain voltage information. Cable type current clamps have been used to obtain current information. Resistance thermometers have been used for temperature measurements. SC2040 channels have been used to convert output currents [1]. The hardware of the transformer routine test analysis is given in Figure 8.

Power Transformer Routine Test and Analysis Software was developed in Microsoft Visual Studio 2017. It is coded using C # programming language. The obtained power transformer data was stored in Microsoft SQL Server 2017 database. In the generated firefly algorithm, power transformer information is entered in the fault table. When the iteration of the algorithm ends, the transformer fault information generated is automatically displayed on the transformer routine test and analysis program interface. The sensor has been located in each unit of the power transformer. Electronic equipment has been created to transfer data from these sensors to the computer. An interface board is designed using the microcontroller. The program of this card has been encoded in the PICC. By this interface board, the data obtained from the sensors has been transmitted to the control computers via serial ports. Transformer information obtained from these sensors using BRS-232 serial port has been displayed on

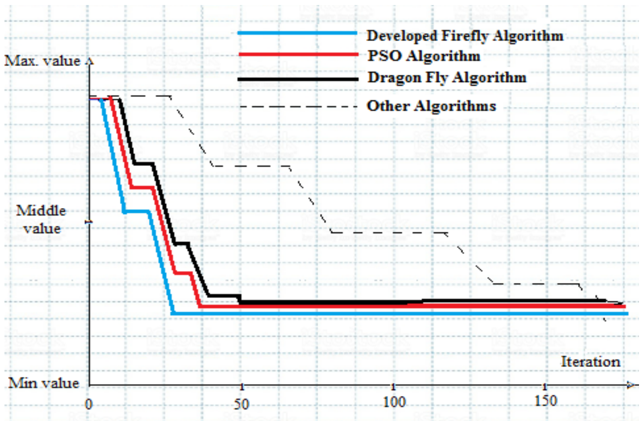


**FIGURE 11.** Iteration change of the firefly algorithm and other algorithms.

computer screen with routine test and analysis program [1]. The Interface of transformer routine test analysis is given in Figure 9.

Information such as demand records obtained with the remote control unit, recording information of interruptions and voltage drops, temperature and power threshold alarms of the transformer have been used in the control of transformer centers and routine tests. Knowing the transformer load may be prevented from being changed prematurely. Due to the overload, the premature wear of the transformers may be prevented. Transformer maintenance operations are simplified. The response time can be set. The cause and location of the problem may be known. The protection relay breakdown dates and times have been recorded. Thus, the number and duration of interruptions can be determined. In addition to the traditional distribution transformer control methods, the operator can also use the grid related transformer equipment, load curves, etc. The information has been provided in a simple and economical way. In this way, service quality improvements have been provided such benefits. In this way, it is ensured that the electrical networks which are spread over a wide area from a central point are monitored instantaneously, routine tests are performed, and enterprises can operate safely and economically. No-load test primary side experimental and simulated currents waveforms are shown in Figure 10a. Steady-state load test primary side experimental and simulated currents waveforms are shown in Figure 10b.

When the data obtained from the developed firefly algorithm and the data obtained from power transformer experiments are compared, it is understood that the error is between -2% and 2%. The results were obtained more accurately and faster with the firefly algorithm. Recursive variation of the generated firefly algorithm and other algorithms is given in Figure 11. The result was reached in the 36th iteration of the Particle Swarm Optimization Algorithm. The 49th iteration in the Dragon Fly Algorithm has been reached. In the other algorithms, the result was obtained in the 170th iteration. Therefore, when compared to the firefly algorithm and other algorithms, the improved algorithm is capable of a better search. Also, Fly Algorithm is the most trustworthy and fastest.

## V. CONCLUSION

In traditional methods, there are many routine tests in power transformers. These tests are expensive and time-consuming tests. At the same time, the tests are dangerous because they are made with high voltage.

In the study, it has provided routine testing and evaluation with hardware and software without performing many tests in power transformers. There is no such study in the literature. Using the heuristic algorithm, performing routine test evaluations in power transformers without performing many tests gives a new phenomenon to the literature.

The complexity of the parameters in the power transformers necessitated the use of the optimum resolution algorithm. For this reason, it has been preferred to develop a firefly algorithm to solve complex optimization problems quickly and accurately in routine testing and analysis of power transformers. Based on this algorithm, the software has been coded in C# programming language. C# programming language has been preferred because of its flexible working structure, minimization of code memorization, rich graphical infrastructure, ease of communication with hardware and rich in visual theme and tracking elements.

Electronic hardware and software have been created to transmit data from 30 sensors connected to power transformer units to the computer. In the power transformer routine test and analysis system, a microcontroller interface board has been designed to transmit signals received from the sensors placed in transformer units to the computer via serial ports. The software of this microcontroller card has been coded in PICC. The obtained power transformer information has been displayed on the computer screen with the generated Power Transformer Routine Test and Analysis Program. Data transfer via microcontroller and serial port has been performed. The data received from the sensors on the transformer have been sent to the computer. The inputs and outputs have been monitored by means of the hardware controller. Entering the information to be read and determining the rates have been carried out via the interface. The values entered were sent to the PIC and values have been determined. The parameters produced from the sensors in the transformer units have been monitored by the microcontroller. When the data obtained from the developed firefly algorithm and the data obtained from power transformer experiments are compared, it is understood that the error is between -2% and 2%. The results were obtained more accurately and faster with the firefly algorithm. Accuracy, learning speed and stability of this algorithm has been approved by the outcomes obtained from transformer tests.

By this study, the overload is prevented by automatically canceling the overload when the transformer is overloaded. Thus, the most expensive and important element of the electricity transmission and distribution chain transformers will be operated in a healthy way and will not exceed their useful lives. Possible failures of the power transformers, which are the basic elements of the electrical energy system, have been evaluated regularly by evaluating the test results of the field commissioning and routine power factor tests. Energy quality has been maintained by preventing undesired power cuts.

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