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DESIGN OF POWER TRANSFORMER CORE USING CREATED ANT/FIREFLY HYBRID OPTIMIZATION ALGORITHM

M. Zile

UTIYO Information Systems and Information Technology Department, University of Mersin, Mersin, Turkey
mehmetzile@mersin.edu.tr

Abstract- One of the important issues in developing and developed countries is the efficient use of energy resources. They are the transformers used in the production, transmission and distribution stages of the electricity machine which consumes the most electricity. It is becoming more important and functional in terms of energy efficiency due to the transfer of very large powers through the transmission and distribution stage of electrical energy. In this study, it has been tried to reduce the magnetic losses and the cost of the core material by using created ant/firefly hybrid algorithm optimizing the core shape. The core geometry has been designed with the help of ant/firefly hybrid algorithm and the results have been evaluated. Thus, the most optimal form of cores has been tried to be obtained. For the designed core, all parameters of the transformer are taken into account. By optimizing the magnetic core geometry with the developed ant/firefly hybrid algorithm, the magnetic losses and the cost of the magnetic material used are reduced. Thus, the reduction of magnetic losses has made it possible to increase the magnetic performance. At the same time, the cost of the transformer has decreased and the transformer weight has decreased with the decrease in the use of magnetic material.

Keywords: Core Design, Power Transformers, Hybrid Optimization, Ant/FireflyAlgorithms.

I. INTRODUCTION

Electricity generation is done in three phases at voltages of 13.2 kV or higher. The energy transmission takes place at high voltages of 110, 132, 275, 400 and 750 kV. Therefore, there is a need for transformers which increase the voltage to give the generated voltage to the transmission line. These transmission voltages are reduced to 6600, 4600 and 2300 Volts distribution voltages and then to 440, 220 or 120 Volts operating voltages. Transformer systems are used in the transportation of the electricity produced in the power plants to the cities and in the efficient distribution of them to the houses. Efficiency is important in transformer systems without moving parts and working stably. Improving the properties of the ferromagnetic materials in the structure of transformer, reducing the dimensions of the material, removing the foreign matter in the structure, changing the core geometry are the main processes to increase the efficiency [1, 2].

Some of the losses in the transformer systems are due to the magnetic induction behavior of the ferromagnetic material used. When the behavior of the material against the magnetic field is determined, it can be understood whether the material is suitable for the manufacture of the transformer [3, 4]. In this study, the core shape has been optimized using developed ant/firefly hybrid algorithm. Thus, magnetic losses and core material cost have been reduced and new core shape has been tried to be obtained.

II. TRANSFORMER CORE

The core of the transformer is made of cold drawn and oriented crystals. Due to losses, labor and economic reasons, the core is made of 0.35 mm thick hair. These hairs are sliced with zero burrs and sized according to the desired size with modern size cutting machines [4, 5]. It is possible to form the cores in any form including step-lap, over-lap, 90 ° cut, perforated, without hole. One side of these hairs are covered with an insulating layer (lac, paper, carlit, etc.). The core section is made according to the power of the transformer.

The core coil and cover assembly are designed to resist the prescribed short circuit mechanical forces [5, 6]. In the case of standard transformers, the active part including the lid is attached to the boiler by means of bolts. All fasteners and HV bushing arc horns on the cover are made of special coated material which may be stainless or corrosion resistant. The core structures of the transformers are made in the form of square in Figure 1.a, rectangular in Figure 1.b and in Figure 1.c according to their size. EI shell type lamination in Figure 1.d, EI shell type lamination in Figure 1.e, EI core type lamination in Figure 1.f and UI core type lamination in Figure 1.g core types are shown.

In this way, the air gap is provided between the windings and the feet for cooling. The cooling channels are opened for large power transformers. The hair bundle forming the core is divided into small packages with thin paper sheets made from pure cellulose to reduce losses. After the core is compacted with compression plates, the epoxide is wrapped with glass fiber strips impregnated with artificial resin.

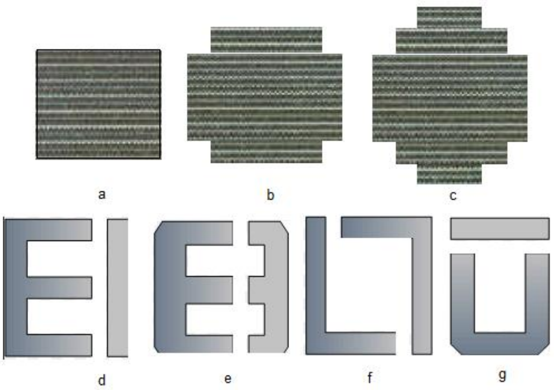

Figure 1. Various core types

These bands are then tensioned with bolted locks. 30% of the total loss in energy networks occurs on distribution transformers. 70% of this loss is consumed as core loss. Since the network constitutes the majority of its losses, the works which increase the efficiency in the transformers are generally made on core losses (idle losses) [7-9]. Electro motor force is given in Equation (1). The maximum flux in the core is given in Equation (2).

$$E_{rms} = (\frac{N.\varpi}{\sqrt{2}}).\Phi_{\max} \tag{1}$$

$$\Phi_{\max} = \sqrt{2}\frac{E_{rms}}{N.\varpi} \tag{2}$$

where, E_{rms} is electromotive force, N is the number of coil windings, ω is angular frequency and Φ is the amount of flux in webers. The cross-sectional area of the core (A) is given in Equation (3), where, A is cross-sectional area of the core, B is magnetic flux density and f is frequency.

$$A = \Phi_{\max} / B \tag{3}$$

Window space factor for three phase core type transformer is given in Equation (4), where, a_1 is sectional area of low voltage conductors, a_2 is sectional area of high voltage conductors, N_1 is primary number of turns, N_2 is secondary number of turns, A_w is window area, I_1 is primary current, I_2 is secondary current, δ is permissible current density and Q is rating in KVA.

$$K_w = \frac{2(a_1.N_1 + a_2.N_2)}{A_w} \tag{4}$$

Put equation value of a_1 and a_2 to Equation (4) and then the Equalities (5) and (6) is obtained.

$$K = \frac{2(\frac{I_1}{\delta}.N_1 + \frac{I_2}{\delta}.N_2)}{A_w} \tag{5}$$

$$K = \frac{4.I_1.N_1}{\delta.A_w} \tag{6}$$

$$Q = 4.44 f.A_i.B_m.N_1.I_1 \times 10^{-3} \tag{7}$$

Put equation value of $N_1.I_1$ form Equation (6) to Equation (7) then the Equalities (8) and (9) are obtained.

$$Q = 4.44 f.A_i.B_m.\frac{\delta.K.A_w}{2} \times 10^{-3} \tag{8}$$

$$Q = 2.22 f.A_i.B_m.\delta.K.A_w \times 10^{-3} \tag{9}$$

Window space factor for three phase shell type transformer is given in Equation 2.

$$Q = 6.66 f.A_i.B_m.\delta.K.A_w \times 10^{-3} \tag{10}$$

For square core, gross area and actual iron area is obtained in Equation (11), where, d is diameter of circumscribe circle.

$$\begin{cases} \text{Gross Area} = 0.5d^2 \\ \text{Actualiron Area} = 0.45d^2 \end{cases} \tag{11}$$

Width of the window, W, is obtained from Equation (12).

$$W = D - d \tag{12}$$

Height of the window, L, is obtained from Equation (13).

$$L = \frac{A_w}{W} \tag{13}$$

In this study, core geometry is designed in the core optimization process by using developed hybrid intuitive algorithm. Volume of iron in core, V [m^3] is obtained from Equation (14).

$$V = 3L.A_i \tag{14}$$

Weight of iron in core, W, is obtained in Equation (15), where, ρ is density of iron [kg/m^3].

$$W = 3\rho.L.A_i \tag{15}$$

Total iron loss, TL, is obtained in Equation (16), where, p_i [watt/kg] is corresponding to flux density B_m in core and p_y is specific iron loss corresponding to flux density in yoke.

$$TL = 3p_i.\rho.L.A_i + 2p_y.\rho.W.A_y \tag{16}$$

III. ANT/FIREFLY HYBRID OPTIMIZATION ALGORITHMS

The pheromones, which the ants actually use to find the shortest path, are a kind of chemical secretion that some animals use to influence other animals of their own species [10]. As the ants move, they leave their pheromones that they have stored in the paths they have crossed. They prefer the path where pheromone is more likely to be the least. Its instinctive behavior explains how they find the shortest path to food, even if a pre-existing path is unavailable [11]. Considering that each ant leaves the same amount of pheromone at the same speed. It may take a little longer than the normal process if the ant recognizes the barrier and chooses the shortest path. Each ant takes a step-by-step decision-making policy starting from the source node and creates a solution to the problem. On each node, the local information is stored in the node itself or the arcs that exit from this node are read by the ant [12]. The next step is to decide which node to use when going randomly. Natural behavior of ants is given in Figure 2.

An ant hits the node from the node until it reaches the destination node, completes its forward movement and goes back to the motion mode [13, 14]. The optimization potentials through the behavior of ants colony and during the analysis has been realized that the ants are able to find the shortest path to reach the food from the nest that can be used in solving complex problems [15]. Fireflies usually emit a flashing light at short intervals.

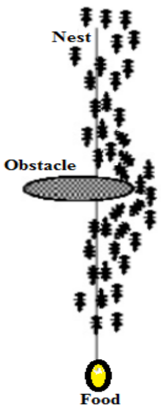

Figure 2. Natural behavior of ants

The flashing rhythm of this light is part of the signaling system that enables fireflies to meet and distinguish fireflies from other light-scattering insects. The speed, frequency and the time before fireflies respond to each other have special meanings [16, 17]. The optimization method developed based on this logic that determines the survival patterns of fireflies is called the firefly algorithm [18-20]. The recommended population-based intuitive algorithm for optimizing multi-model functions. Firefly herd optimization method has been developed by observing and imitating the social behaviors of fireflies [21-23]. Natural behavior of fireflies is given in Figure 3.

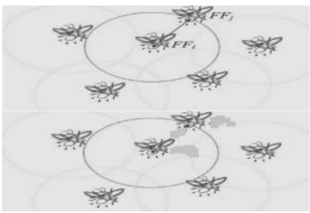

Figure 3. Natural behavior of fireflies

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 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.

Meta heuristics studies have made possible improving of optimization techniques that have the aim of providing top quality solutions to complex systems [24]. In the generated hybrid algorithm, mathematical modeling of ant and firefly colony behavior was performed. This method was used to solve the continuous and discontinuous problems in the design of power transformer core, mimicking the natural behavior of ants and fireflies. Hybrid optimization of generated ants and fireflies; It is a hybrid optimization technique which is used as a result of monitoring the paths used by ants between food sources and nests and evaluating the light intensity of fireflies.

IV. DESIGN OF POWER TRANSFORMER CORE USING IMPROVED ANT/FIREFLY HYBRID ALGORITHM

Power transformer core design algorithm improved is shown in Figure 4. The basic steps of the algorithm are as follows:

- Step 1. Enter number of experiments, maximum number of generations and the number of the population (*N*).
- Step 2. Enter the substation information.
- Step 3. Determine the core model.
- Step 4. Enter primary voltage, secondary voltage, number of primary winding, number of secondary winding, nominal current at full load, output power, specific gravity of core metal material, specific resistance of core metal material, saturation induction, typical core loss, material thickness, filling factor, annealing temperature, annealing atmosphere, annealing feature, electric field force, magnetic field force, electrical flux density, magnetic flux density, magnetic field potential, electrical load density, current density, electrical conductivity, magnetic permeability, electrical conductivity, permanent magnetic field density.
- Step 5. Generate *N* chromosomes for the initial population.
- Step 6. Set total number of bars, number of rows, number of columns, depth of network embedding.
- Step 7. Calculate suitability for each solution.
- Step 8. If the maximum number of generations is reached, identify and store the chromosome that is the best fit in the experiment.
- Step 9. Increase the number of experiments if maximum number of generations is reached, but maximum number of experiments is not reached.
- Step 10. Start the experiment again.
- Step 11. If the maximum number of generations is not reached, go to Step 5.
- Step 12. Go to Step 18 if both the maximum generation number and maximum number of experiments are reached.
Step 13. Divide the *N* number of chromosomes into binary groups and cross.
- Step 14. Apply mutation to *N* chromosomes.
- Step 15. Select the best *N* number of chromosomes for the next generation from the chromosomes obtained by *N* number of chromosomes, *N* number of chromosomes and *N* number of mutations.
- Step 16. Increase the number of generation by 1 and go to Step 5.
- Step 17. Calculate core parameters of the 3*N* number of chromosomes when the eddying condition is not met.
- Step 18. Identify the best chromosome in all experiments
- Step 19. Calculate the average of the best chromosome of each experiment.
- Step 20. View results; core diameter, inside diameter of core, body mass, strip width, cross section area of primary winding, cross section area of secondary winding, cross section area of gap spacing between windings, equivalent leakage area of winding in radial direction, equivalent leakage area of winding in axial direction, height of primary and secondary windings.

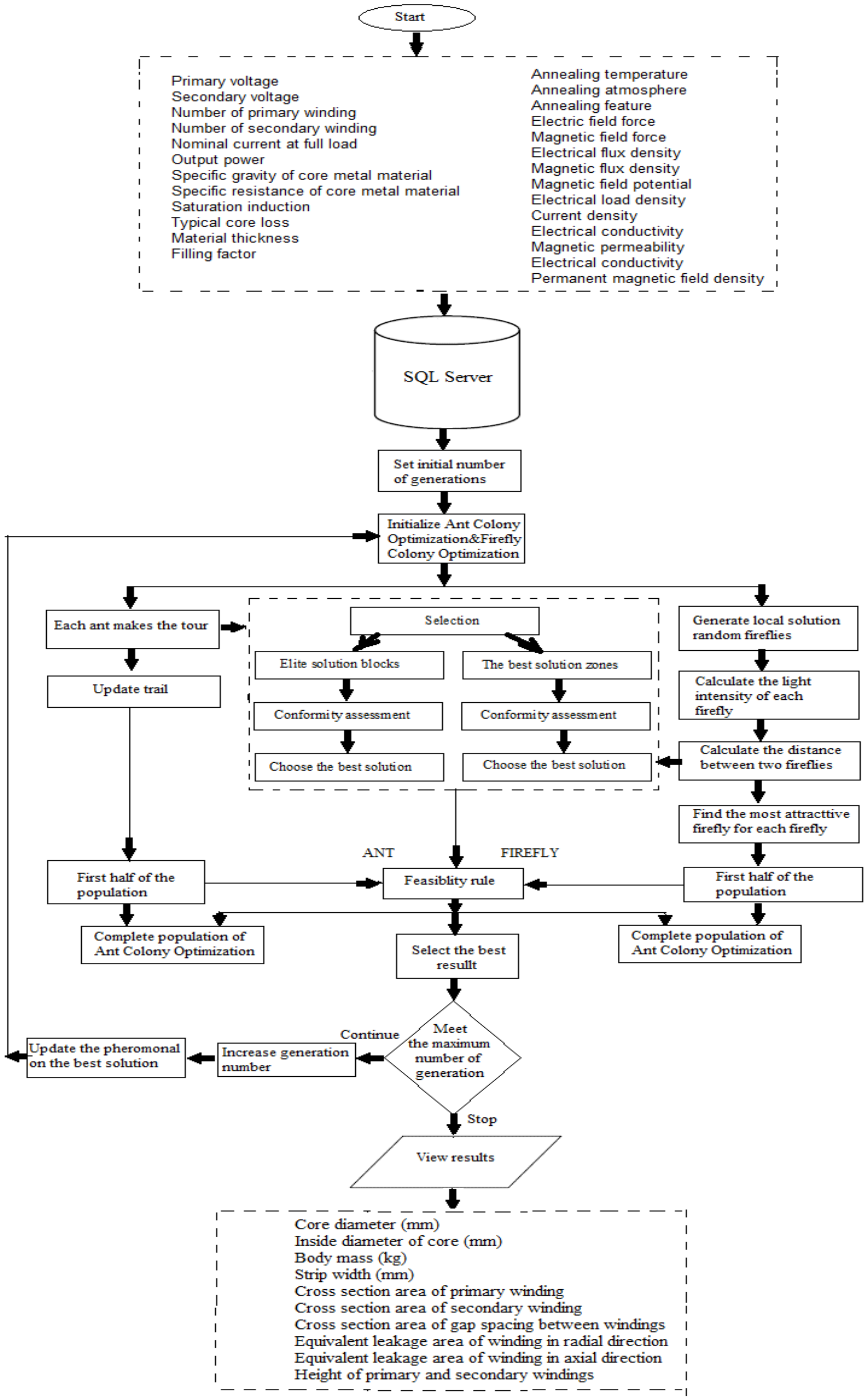

Figure 4. Power transformer core design algorithm improved

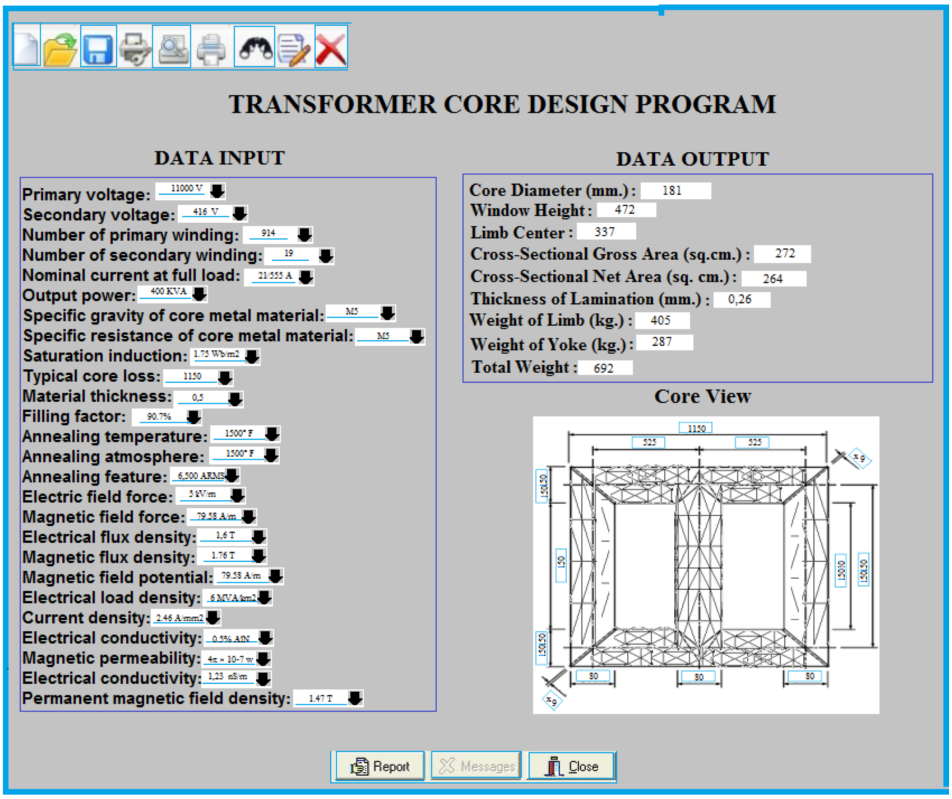

Figure 5. Power transformer core design program interface improved

Table 1. The variables of power transformer core design optimization

Detail of Core/Rate of Transformer	No-optimization design (100 KVA transformer)	Optimization design (100 KVA transformer)	No-optimization design (630 KVA transformer)	Optimization design (630 KVA transformer)
Core Diameter (mm)	115	103	203	181
Window Height (mm)	489	441	524	472
Limb Center (mm)	266	238	376	337
Cross-Sectional Gross Area (sq. cm)	96	85	302	272
Cross-Sectional Net Area (sq. cm)	94	83	295	264
Thickness of Lamination (mm)	0.27	0.26	0.27	0.26
Weight of Limb (kg)	120	108	449	405
Weight of Yoke (kg)	72	64	321	287
Total Weight (kg)	192	173	770	692
No-Load loss (W)	259	208	998	800
Load loss (W)	1761	1408	6498	5200

Power transformer core design program interface improved is shown in Figure 5. The variables of power transformer core design optimization is given in Table 1.

V. CONCLUSIONS

Power transformers are an indispensable element of today's energy systems. Power transformers are the most widely studied electrical machines in electrical machinery. Since the logic of transformer design is essentially an established issue, it has continued for decades. New studies on this subject, rather than producing new theories to increase the efficiency of transformers, to reduce the cost of high-density composite magnetic material, to improve working conditions, to increase the design speed, and so on concentrated on topics. In this study, an interface program for the design of power transformers has been developed by using artificial bee algorithm, cuckoo algorithm and flower pollination algorithm. The interface program has a very easy to use format that includes windows components. Power transformer design is a preferred interface for a designer with knowledge of design. With the interface created, a flexible design was possible by taking all the necessary inputs for the design. All necessary calculations have been made and numerical results have been presented to the designer.

Using of the developed algorithm and the computer interface created, 100 kVA and 630 kVA transformers have been optimized. It is understood that there is a decrease of 10% in core diameter, window height, limb center, cross-sectional gross area, weight of limb and weight of yoke. Also, there is a decrease of 20% in no-load loss and load loss. By this study, it has become possible to reduce leakage currents and losses in power transformers. Also, the dimensions and weight of the transformer were reduced. So, the costs of power transformer were reduced.

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BIOGRAPHY

Mehmet Zile was born in Ankara, Turkey, 1970. He received the B.Sc. degree from Yildiz Technical University, Istanbul, Turkey, the M.Sc. degree from Gazi University, Ankara, Turkey and the Ph.D. degree from Yildiz Technical University, all in Electrical and Electronic Engineering, in 1992, 1999, and 2004, respectively. Currently, he is an Assistant Professor of UTIYO at University of Mersin, Mersin, Turkey. He is also an academic member of UTIYO Information Systems and Information Technology Department at University of Mersin and teaches information systems and control systems. His research interests are in the area of control systems and electrical machines. He is a member of the International Electrical and Electronic Engineers (IEEE).