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Research Article

Optimization of Dry-Type Transformer Parameters with Different Methods and FEA Analysis

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Abstract

Due to the importance of correct optimization of transformer design parameters and efficiency, six design variables are used in this study for the optimization of a dry type three-phase transformer based on FEA analysis. Optimization was carried out using the variables of an iron cross-section acceptability (C), the current density of primary and secondary windings (s), magnetic flux density (B), and primary and secondary windings cross-section area (q_1, q_2). For efficiency optimization, particle swarm optimization (PSO) and Artificial Bee Colony (ABC) algorithms are used and magnetic flux distribution and loss values are obtained with ANSYS/MAXWELL. As a result of the optimization, 98.67% and 98.69% efficiency, 1096.56 and 1108.45 W power gains were obtained with PSO and ABC. In addition, the change in magnetic flux distribution according to the cross-sectional area determined according to the C value obtained as a result of the optimization is shown.

Keywords: Power transformer, optimization, PSO, Artificial bee colony, FEA

Kuru Tip Trafo Parametrelerinin Farklı Yöntemlerle Optimizasyonu ve SEY Analizi

Öz

Trafo tasarım parametrelerinin ve verimliliğin doğru optimizasyonunun öneminden dolayı, bu çalışmada, FEA analizine dayalı olarak kuru tip üç fazlı bir transformatörün optimizasyonu için altı tasarım değişkeni kullanılmıştır. Optimizasyon işlemi, bir demir kesit kabul edilebilirliği (C), birincil ve ikincil sargıların (s) akım yoğunluğu, manyetik akı yoğunluğu (B) ve birincil ve ikincil sargı kesit alanı (q_1, q_2) değişkenleri kullanılarak gerçekleştirilmiştir. Verimlilik optimizasyonu için partikül sürü optimizasyonu (PSO) ve Yapay Arı Kolonisi (ABC) algoritmaları kullanılıp, ANSYS/MAXWELL ile manyetik akı dağılımı ve kayıp değerleri elde edilir. Optimizasyon sonucunda PSO ve ABC ile %98.67 ve %98.69 verim, 1096,56 ve 1108,45 W güç kazancı elde edilmiştir. Ayrıca optimizasyon sonucunda elde edilen C değerine göre belirlenen kesit alanına göre manyetik akı dağılımındaki değişim gösterilmektedir.

Anahtar Kelimeler: Güç Transformatörü, Optimizasyon, PSO, Yapay Arı Kolonisi, SEY

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1. Introduction

With increasing energy efficiency and environmental awareness, the importance of more environmentally friendly and efficient transformers is increasing. Dry-type transformers have started to be preferred more because they are more environmentally friendly in cooling and design. However, the parameters to be considered in the design come to the fore. Two crucial issues come to the fore for more efficient transformer design: The first one is the ability to see the electrical and electromagnetic properties of the transformer with the help of ANSYS/Maxwell software, which allows us to make realistic analyzes without the need for any prototypes. This makes it possible to obtain the losses and magnetic flux density distributions easily. The other issue is the optimization of the design variables determined by various optimization methods and the determination of other parameters to obtain the minimum loss. This way, weight, volume, and transformer losses are determined at optimum values.

Each method will calculate the selected variable values differently. The obtained values comment on which parameter affects efficiency and how much it affects other design parameters.

More than 20 optimization methods for transformer design have been used for efficiency, cost, sizing, and temperature optimizations in the literature so far. They are compared in terms of performance, speed, and improvement with each other. A review study was conducted in [1], which gives information about these algorithms. In [2], material and cost analysis was performed using two different algorithms besides bee algorithms. In [3], on the other hand, performed both efficiency and weight optimization using Particle Swarm Optimization (PSO), Firefly (FF), and Invasive Weed Optimization (IWO) and evaluated the algorithms according to each other. In another study [4], weight and cost optimizations were made using Genetic Algorithms (GA), PSO, and Artificial Bee Colony (ABC). In [5], besides optimization with the Nondominated Sorting GA (NSGA-II) algorithm, magnetic characteristic analyzes were obtained with FEM analysis.

Our motivation for this study is to identify two methods used for dry type transformer, which is gaining importance day by day, and make variable optimizations with them, modeling the design with Finite Element Analysis (FEA) and seeing the magnetic changes that occur. Therefore, in this study, six design variables have been used to optimize the efficiency of a dry-type three-phase transformer based on FEA analysis. The optimization process has been performed using an iron cross-section acceptability (C), the current density of primary and secondary windings (s), magnetic flux density (B), and primary and secondary windings cross-section area (q1, q2) variables. This situation is of great importance in giving an idea about the model before the design. It is possible to summarize the main purpose of this study as follows:

- application of PSO and ABC algorithms to a dry-type transformer design variable to optimize the efficiency
- Comparing results in terms of optimal performance in terms of efficiency increase
- FEA analysis of the transformer for the electromagnetic characteristics.

2. Material and Method

2.1. Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) is one of the heuristic methods developed by Kennedy and Eberhart [6]. PSO is based on the social behavior of living species such as birds and fish. Kennedy and Eberhart have been inspired by monitoring their behavior while foraging for survival and have developed PSO. Each bird in the swarm is called a particle. Swarm behavior is a collective behavior exhibited by animals of the same species and grouped, walking in the same place, moving in groups, or migrating in the same direction [7]. Most of the time, individuals who could not obtain anything by themselves during the search and discovery of the food source were more successful in reaching the food source by moving in flocks. Observations have shown that the random movement of each individual in the herd affects other individuals in the herd, and with this effect, the herd reaches its common goal more quickly.

Particle swarm optimization has succeeded [8] – [10]. (1) and (2) shows mathematical expression related to position and velocity:

$$v_i(t+1) = \omega v_i(t) + c_1\big(p_{best}(t) - x_i(t)\big) - c_2(g_{best}(t) - x_i(t)) \quad (1)$$

$$x_i(t+1) = x_i(t) + v_i(t+1) \quad (2)$$

Where pbest, g_{best}, and $v_i(t+1)$ are the local best particle, the global best particle, the position of a particle i in iteration t, the velocity of a particle i in iteration $(t+1)$, respectively. In Eq. (1-2), t, $v_i(t)$ and $x_i(t)$represent the number of iterations, the speed value of the particle i, and the position values of the particle i, respectively.

The acceleration coefficients, which call c_1 and c_2, vary to interval $0 < c_1, c_2 \leq 2$. The inertia weight is indicated by $\omega \in [0.8; 1.2]$. The inertia weight equals 1 in the (1) in this work. We use the inertia weight to balance local and global searches. The aim is that the optimal outputs are achieved with less iteration. Therefore, determining the appropriate value of inertia weight is essential.

2.2. Artificial Bee Colony (ABC) Optimization

The ABC algorithm is one of the swarm-based optimization algorithms, and it has been preferred in various optimization problems such as absorber design [11], [12] UAV path planning [13] and image segmentation [14], and determination of geometric parameters of power transformer [2]. The modeling of the algorithm is inspired by the foraging behavior of bees [15], [16]. Basically, the algorithm includes three-phase of employed, onlooker, and scout. The algorithm is summarized as follows.

1. In the initial phase, random food sources corresponding to the solution of the problem are generated within the solution space of the problem.

2. In the employed phase, to generate new solutions, the employed bees search in the neighbor of the food source. According to the greedy selection procedure, the current solution is updated by comparing the objective function value of the new resource and the current resource. if the current solution is not updated, its abandonment counter (trial) is incremented by 1.

3. In the onlooker phase of the algorithm, onlooker bees search for new solutions in the source neighbor depending on the probability value of the current source. The location of the current solution is updated by applying the greedy selection. If the current solution is not updated, its abandonment counter (trial) is incremented by 1. The obtained best solution (food source) is memorized so far.

4. In the scout bee phase of the algorithm, if the solutions (food sources) in the population reach the abandonment counter limit value, random new solutions are generated instead of these solutions, as in step 1.

5. If the algorithm reaches the termination criterion, it is stopped; otherwise, it continues by going to step 2.

2.3. Design of Dry-Type Three Phase Transformer

The mathematical formulas used in modelling the dry-type transformer and calculating the losses are given in [8]. However, the formula of this study used for core loss has been updated with (3).

$$P_{fe} = K_h B_{pk}^{1,6} f + K_c B_{pk}^2 f^2 + K_e B_{pk}^{1.5} f^{1.5} \quad (3)$$

The variables K_c, K_h, and K_e, are defined as eddy current loss constant, hysteresis loss constant, and abnormal loss constant, respectively. Since these variables are constants that change depending on the material, it allows the optimization application to be carried out regardless of the material change.

The specifications of the transformer used for this study are given in Table 1. Table 2 shows the maximum and minimum values of the variables selected for design parameters optimization.

As a result of the optimization, higher efficiency and power saving have been achieved. The basic calculation of this can be made according to the following formula [17]:

Power gain=Sload factor $(1/\eta_{st}-1/\eta_{new})$ (4)

An example of the table is given below.

Table 1. Specification of transformer

Quantity	Values
Power Level	50 kVA
Voltages	380/220 V
Connection Type	Δ/Y
Turns	128/75
A_c	0.0128 m^2

Table 2. Max and min limits of optimization variables

Design Variables	Lower Limit	Upper Limit
C	5.9	10.6
s	2.2	3.5
k_{cu}	0.8	0.9
B	0.9	1.2
q_1	28	35
q_2	48	55

3. Results and Discussion

As a result of the optimizations, the efficiency value with the label value of 96.58% was obtained using PSO and ABC algorithms as 98.6756% and 98.6931%, respectively, shown in Figure 1. In addition, the Ac value changed depending on the C value from the optimized values of the variables given in Table 3.

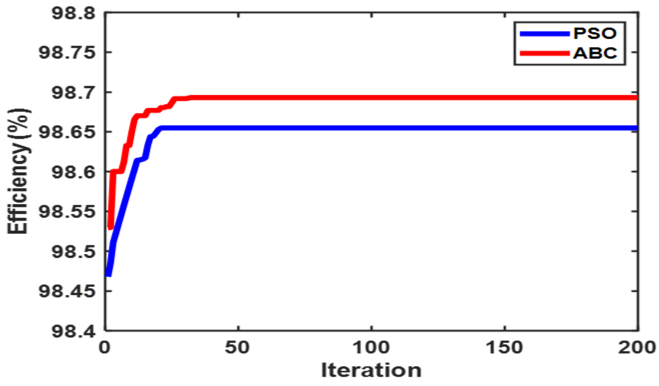

Figure 1. The efficiency of transformer based on PSO and ABC algorithms

Table 3. Optimized values of variables

Design Variables	PSO	ABC
C	5.9	5.9
s	3.5	3.2693
k_{cu}	0.9	0.8646
B	0.9	0.9
q_1	35	35
q_2	55	55

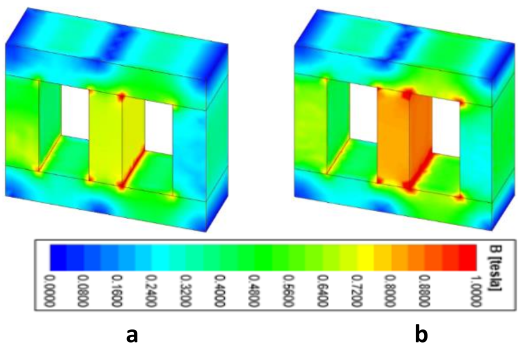

Figure 2. Magnetic flux density a) Ac= 128 cm² b) Ac= 107 cm²

When the core size is reduced, the core loss automatically decreases. As seen in Figure 2b, although the instantaneous magnetic flux density seems higher than in the first case, Bmax is approximately equal in both cases. However, it seems more intense due to the narrowing of the cross-section area.

The increase in efficiency and power gain according to (4) There is a 2.17% efficiency increase and 1096.56 W power gain in the PSO at full load condition. ABC also has an efficiency increase of 2.18% and a power gain of 1108.45W.

4. Conclusions and Recommendations

This study optimized a three-phase 50 kVA 380/220 V dry type transformer to achieve maximum efficiency using optimization methods such as PSO and ABC. Then electromagnetic analyzes were made using ANSYS/Maxwell program. For this, kernel coefficients (C and s) and some design parameters (B, k_{cu}, q_1, q_2) are used. Between these two algorithms, ABC $\eta = 0.9869$ gave good results. The maximum efficiency of the transformer was obtained, as seen in Table 2. The relative differences of these two yield results are approximately 2.17% and 2.18% for PSO and ABC, respectively. In addition to these, according to the power gain calculations, the gains for PSO and ABC are 1096.56 and 1108.45 W.

As a result, a study was conducted on optimizing the design parameters for maximum efficiency in dry-type transformers and comparing efficiency and power gain. As a future study, different design parameters and optimization methods can be used to contribute to design improvement with objective functions such as temperature, cost, material minimization.

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