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# A Review on Transformer Design Optimization Using Artificial Intelligence Technique

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***Abstract – The purpose of transformer design is to achieve the dimensions with all sections of the transformer in such a way that it is commercially viable, has good efficiency &, at same time, can gratify all the restrictions placed by international requirements & user specifications. With the advent of Artificial Intelligence (AI) techniques, it is now probable to reduce active part cost, manufacturing cost, and total owning cost, while simultaneously satisfying international standards and constraints. In Indian industries, AI techniques are yet to be employed for TDO problems. The objectives of the paper to develop software based on AI techniques that could be utilized for the optimal design of distribution transformer.***

***Key Words – Transformer Design Optimization, Artificial Intelligence, Genetic Algorithms***

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## INTRODUCTION

Distribution transformers are most important components in a power system network, where in any distribution network a huge number of distribution transformers are used. A transformer is a device with one or two magnetically coupled electric circuits by a common magnetic field that is used to transform voltage from one level to another. Distribution transformers are also the most varied types of transformers where in the Kingdom of Saudi Arabia a huge number of transformers are installed in the public electricity supply system ranging in size from 50 kVA to 1000 kVA.

Manufacturing companies have introduced computer aided transformer design that help reduce the man hour needed, but mainly to reduce and optimize the amount of material needed and to reduce the delivery cycle time to the customer. Computer design techniques will ensure that the user’s requirements in addition to the standard design constraints such as efficiency, loaded and non-loaded losses, temperature rise and other constraints are all achieved. In the end this will give us a number of different designs which all guarantee the desired characteristics of the transformer. Even though all the designs meet the requirements, the transformers will have different parameters such as core radius, number of lamination layers, winding type and number of turns, and so on. This in turn indicates that the total cost for every transformer design will differ as the two main factors affecting the costs are; the amount of material used, and the total losses of the transformer.

Transformers are considered to be one of the most important components in any distribution power system. design process is not unique for every transformer, in fact the design concepts are very similar for all the different possible capacities. Variation in the design technique and formulas exist only when a different type of construction or material is used, such as different type of core, or a change in the winding construction is needed. Transformers provide a crucial function in interconnecting power grids at varying voltage rates. Without a converter, it will actually not be practical to utilize electrical electricity in most of the forms it is done recently. As a consequence, the transformers hold crucial roles in the electrical power grid, which is a critical connection between the electricity plants and the gas stations. There are more than 400 written papers, 50 books & 65 guidelines in the field of transformers that have contributed significantly to the development of the quality and efficiency of the transformers.

## TRANSFORMER DESIGN OPTIMIZATION

With the latest implementation of new legislation demanding the usage of high-efficiency delivery transformers, the evolving manufacturing sector is confronted with the task of designing the right (optimum) technologies because, in today's intensely dynamic retail climate, it would be too challenging to ask consumers to adequately pay for the resulting rise in material prices.

TDO is a mixed-integer non-linear programming problem with a dynamic & discontinuous objective feature & constraints, with the goal of comprehensive computation of the characteristics of the transformer centered on national & foreign specifications & specifications of the transformer customer, utilizing available materials & manufacturing techniques, to reduce manufacturing.

There are some various types of accurate functions distinct in the TDO literature, however the most frequently used ones are the minimization of the cost of manufacturing the transformer & minimization of the TOC that characterized as the cost of the life-associated with the purchase & operation of the transformer. Minimization of key material costs, manufacturing costs, & TOC are the three goal feature options available in the program prepared for this report. Although the governing bodies are implementing regulations requiring the utilize of high-efficiency transformers, transforming consumers are encouraged to continue utilizing TOC since the regulations are intended solely to raise the minimum standard of transforming efficiency (Global Industry Analysts 2014.). Transformers & transformer architecture optimization are two topics which has widely studied in the literature.

## ARTIFICIAL INTELLIGENCE TECHNIQUES FOR TDO

Artificial Intelligence approaches have been widely utilized to tackle the dynamic task of improving the architecture of the transformer. This segment discusses the usage of different AI approaches used by TDO researchers.

### Genetic Algorithms

GAs are built on Darwin's principle of fittest survival. J.H.Holland (1975) introduced the fundamental principles of GAs, while De-Jong (1975) and David Goldberg (1989) showed the practicality of utilizing GAs for complicated problems. A genetic algorithm has been commonly utilized for optimization in a number of areas, including research, industry & engineering. The key explanations for their popularity are broad applicability, ease of usage & global perspective.

GAs has been used to reduce the expense of installation of transformers, as well as to decrease maintenance and operational costs (S. Zhang 2011). GAs have often been used to refine the configuration of the cooling mechanism for delivery transformers (J. Smolker 2011). Function detection of the power transformer was proposed in V. Galdi 2001, where GA was used to establish an evolutionary computational model. Genetic algorithms have also been used to improve the output of cast-resin style delivery transformers or toroidal core transformers. Georgilakis (2009) addressed the problem of converting cost minimization by integrating GA with a finite element analysis using an alternative elitism technique. The Hybrid Optimal Model of the Distribution Transformer was introduced in M. Arjona (2010), a mixture of 2-D finite element, GA & probabilistic algorithm for final solution. Optimal transformation architecture centered on total ownership costs that used a simple GA was illustrated in S. Zhang (2011) which followed a penalty function approach to the treatment of objective parameters with weighted correlations.

### Artificial Neural networks

The analysis of ANN is associated with the study of theoretical structures influenced by hypotheses and the examination of the form and operation of biological neural cell networks in the brain. These are usually designed as templates for solving statistical, technological & technical problems. ANNs for predicting the key characteristics of magnetic transformers and core losses were used (Geromel 2002), that also focused primarily on the the iron losses of installed transformers, while the NN production stage cost estimate was suggested in S.S. Karami Madahi, P. Salah (2012). Evolutionary design coupled with neural networks has been investigated in[20] to boost the accuracy of wound core delivery transformers. The estimation of damages in the delivery transformer utilizing NN was conducted by Adriano et using the knowledge available from the routine load curve. (N.D. Doulamis 2002) in which the service does not need to carry out calculations to determine the load profile for all forms of users. Analysis of iron losses under imbalanced supply conditions utilize NN has been investigated (Tai-Ken Lu 2010), as optimization of the manufacturing process of individual cores that use the Taguchi techniques & minimization of iron losses has been illustrated (P. Georgilakis 2001).

### Swarm Intelligence

Swarm Intelligence is a collaborative knowledge analysis in cognitive systems (H. Ahadpour 2011). Collective knowledge arises from the collaboration of a vast number of homogenous actors in the system. Examples involve a flock of ducks, a fish farm, or ant colonies. The prototype consists of two dominant sub-fields: ACO & PSO that scrutinizes probabilistic algorithms influenced by education, flocking or herding. Swarm intelligence algorithms are known to be proactive methods is usually used to solve search & optimization problems.

Lately, there was growing interest between many investigator to solve TDO problems utilizing swarm intelligence algorithms. ingOptimal option of number of turns in primary winding utilizing ACO minimizes the expense of the transformer, while optimizes the size of the transformer tap shift environment in the power transmission network to increase voltage stability. ACO was often utilized to adjust the size of the transformer to suit the expected load. Optimal tolerance consistency problems for the output of power transformers, and maximized the optimal exploitation rate of sheet material for the construction of core power transformer segments. Transformer own cost estimation using traditional, GA & PSO methods shows that the PSO approach is slightly superior to two approaches. Swarm intelligence technology to train multi- NN for discriminating among magnetizing inrush currents & fault currents was used in (A. Gallas 2001) that also demonstrates the PSO technique for neural network creation is more effective than the traditional back propagation process. Improved PSO algorithm was used in (J. Du 2010) to improve the rectifier transformer design to overcome the locally configured trapping flaw in the conventional PSO algorithm. The swarm-based AI mechanism recognized as the BFOA was widely recognized as a regional optimization & control algorithm (R. Thomas 2013). Optimal configuration of a single phase transformer utilizing BFOA to accurately measure the variables of a single phase core style transformer.

### Multi-objective Optimal transformer Design utilizing Evolutionary Algorithms

Whenever the optimization issue requires just one goal, the process of seeking an optimal solution is referred to as single purpose optimization. Moreover, where the optimization problem requires more than one goal, the process of seeking one or more optimal solutions is considered to as multi-objective optimization. Multi-objective optimization utilizing EA has gained traction as a community of solutions is distributed per day. This characteristic offers EA a tremendous benefit for their utilize in multi-optimization problems[S. Subramanian 2011] The correlation algorithm growth approach predicated on the truncated gamma distribution function was established in [S. Padma and S. Subramanian (2010), whereas the unlimited population size genetic multi-optimization algorithm method associated with chaotic sequences was used.

Transformer modeling utilizing multi-objective evolutionary optimization has also been used in C. Versele (2009) for approximate estimate of the specifications of the transformer. The Multi-Objective Optimized Transformer Architecture that used a Bacterial Foraging Algorithm (S. Padma 2010) proposed an effort to simultaneously optimize performance and reduce the expense of a 500 kVA transformer. The researchers claim that multi-objective optimized transformation architecture is an emerging field & multi-objective optimization algorithms including Vector Evaluated GA (VEGA), Weight Based GA (WBGA), Multiple Objective GA (MOGA), Nondominated Genetic Sorting Algorithms (NSGA) Niched Pareto Genetic Algorithm (NPGA) may be used for transforming optimization. Certain expert multi-objective optimization techniques including Non-Dominated Genetic Sorting Algorithm (NSGA-II), Power Pareto Evolutionary Algorithm (SPEA), Range Pareto GA (DPGA), Thermodynamic GA (TDGA), Pareto-Archived Evolution Strategy (PAES) are often recommended for the solution of TDO problems.

## ARTIFICIAL NEURAL NETWORKS ARCHITECTURE

Artificial Neural Networks (ANN) Architecture implies how neurons are arranged in the form of layers and the type of interactions between the neurons. Architectures of neural networks are closely related to the training/learning algorithm applied on these networks. There are three broad categories of neural network architectures.

(a) Single Layer Feed forward Artificial Neural Networks

(b) Multilayer Feed forward Artificial Neural Networks

(c) Recurrent Networks

## LITERATURE REVIEW

A.K. Sawhney et al. (2006) discusses the point-by-point approach for the design of the transformers, as well as the optimal designs, such as the least expense design or the most severe design. This book describes all the relevant pieces of the transformer as well as the design requirements.

Geromel, Luiz H et al. (2002) introduces a innovative approach to power transformer architecture utilizing intelligent frames. Right now, the technique portrays the usage of ANN networks in some phases of the architecture. Epic metedology is a significant instrument for the improvement of ventures, but in addition to significantly limiting the importance of their execution, since it streamlines the design process.

Pavlos S. Georgilakis et al. (2007) examines the fact that the design of the transformer is designed to fully acquire the components of a considerable number of transformer parts that are dependent on the supply. For now, the Transformer Project Streamlining Plan recommends optimizing the construction of the Transformer with a view to achieving the basic base cost.

J.G. Breslin et al (2003) believe that, despite the ongoing use of Computer programming to assist in the design of power supply parts, such as transformers and inductors, no work has been done to investigate the usefulness of the electronic situation for their operation. This paper introduces an online transformer concept platform that can be used to build new updated transformer designs.

Rabih A. Jabr et al, (2005) suggests that the performance problem involves reducing the overall mass of the center and wire content while ensuring that the measurements of the transformers and the various design specifications are carried out. This paper reveals that the design problem can be programmed in the GP category geometric programming as GP provides a constructive and reliable solution to the design enhancement question with a few variables and guarantees that the acquired structure is ideal worldwide.

Farrukh Shahzad, M.H. Shwehdi, et al. (2000) examined that proximity to PCs in laboratories provided additional incentives for power building instruction. Using this tool, the lab teachers will display and explain the concept of a transformator design on this screen and easily react to understudies with on-line clarification. Understudies can know more by using the software and exchanging thoughts and questions with specific understudies. The development skill of the understudy has grown tremendously by shifting the accentuation from numerical analysis and PC programming to the awareness of the core principles of the architecture of the transformer.

Cunkas et al. (2006) used the Finite Element Model to build the stator openings in the approval engine and to reduce the middle and spinning misfortunes by approximately 2.22%. The efficiency of IM has been increased by modifying the mechanical production cycle and is named no tooling cost (NTC). It does not include a full overhaul of overlays. Creators modified the accompanying in a totally enclosed cooled fan regular IM, I the copper bar rotor recalled for the gap before the aluminum bite the dust of the tube, (ii) the duration of the middle of the core, (iii) the middle of the stator. Creators also now concluded that the expense of producing higher performance engines has been significantly reduced by NTC.

Prasetiyono Hari Mukti et al. (2014) Power transformer is amongst the most significant & expensive elements of the power grid, with almost 60% of overall expenditure. Owing to the expense of expenditure in the power transformer, the inspection and maintenance of the state of the transformer is a big undertaking in the sector. There are various symptomatic methods for the transition of the state of well-being in published plays. Be it as it might, such methods fail to view the situation after a variety of deficiencies have arisen. In fact, the emergence of man-made logic calls attention to the various desires of specialists. In this article, the 2-level multilayer neural network as an AI category is suggested to be used to diagnose the state of the transformer. With this technique, the level 1 and level 2 perception precision of the study is reached by 92.4 per cent and 99.5 per cent respectively. The suggested technique is also accepted by means of a k-crease cross-approval.

Amit Kumar Yadav et al. (2011) The electricity converter is among the most critical tools in the electric grid. The optimum layout of the transformer involves the determination of the design limits of the power transformer when it is adjusted to satisfy a variety of specifications. This paper uses Simulated Annealing (SA) to optimize Power Transformer Configuration (OPTD). The maximum mass of center and copper is chosen as a goal that will be reduced. The findings obtained suggest that this strategy has generated a global ideal. Calculation time and mass of complex content becomes greatly decreased as opposite and natural construction effects are obtained. The efficiency of the transformer can be increased by using this algorithm.

## MATERIALS AND METHODS

This Invetigation describes the application of Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Teaching Learning Based Optimization (TLBO) for solving Transformer Design Optimization (TDO) problem. The No-Free Lunch Theorem states that there is no single metaheuristic, best suited for solving all optimization problems. In other words, it can be said that a particular meta-heuristic may show very promising results on a particular set of problems, except the similiar algorithm may show poor results on a dissimilar set of problems.

## RESULTS AND DISCUSSION

This section discusses the results obtained by Exhaustive Search Method (ESM) for Transformer Design Optimization (TDO) problem. According to Bureau of Energy Efficiency (78), the constraints on no-load losses, load losses, percentage impedance & total losses at half load for 1-star & 2-star rating transformer, & even other parameters entered in the software are illustrate in Table1.1.

**Table 1.1 Input Parameters for 1-Star & 2-Star Rated Transformers**

| Sr. No. | Parameter | 1-star | 2-star | Units |
|---|---|---|---|---|
| 1 | Rated power | 100 | 100 | kVA |
| 2 | Max. Total Losses permitted | 2020 | 1910 | W |
| 3 | Max. Losses permitted at half load | 700 | 610 | W |
| 4 | Max. No load losses permitted | 220 | 200 | W |
| 5 | Max. Percentage impedance permitted | 4.7 | 4.7 | % |
| 6 | Rated low voltage | 433 | 433 | V |
| 7 | Rated high voltage | 11000 | 11000 | V |
| 8 | Permitted Temperature rise | 50 | 50 | ⁰C |

Tables 1.2 and 1.3 demonstrate the results of software for 1-star & 2-star rating of 100 kVA 11/0.433 kV, distribution transformer.

**Table 1.2 Sample of Acceptable Solutions Pertaining to 1-Star Rating**

| Active Part Cost (INR) | No-load losses (W) | Loan losses (W) | %Z | Efficiency |
|---|---|---|---|---|
| 59608 | 187.19 | 1760.67 | 4.27 | 98.089 |
| 61632 | 189.61 | 1675.74 | 4.53 | 98.168 |
| 59564 | 187.19 | 1767.69 | 4.27 | 98.082 |
| 61351 | 188.70 | 1683.01 | 4.55 | 98.162 |
| 59284 | 186.29 | 1774.71 | 4.29 | 98.076 |
| 61307 | 188.70 | 1690.27 | 4.55 | 98.155 |
| 59242 | 186.29 | 1781.72 | 4.29 | 98.069 |
| 61263 | 188.70 | 1697.54 | 4.55 | 98.148 |
| 61263 | 188.70 | 1697.54 | 4.55 | 98.148 |
| 59199 | 186.29 | 1788.74 | 4.30 | 98.063 |
| 61208 | 190.88 | 1664.51 | 4.51 | 98.178 |
| 59146 | 188.45 | 1756.26 | 4.26 | 98.092 |
| 58825 | 187.53 | 1770.27 | 4.28 | 98.079 |
| 67707 | 216.64 | 1505.61 | 3.55 | 98.306 |
| 69698 | 219.65 | 1427.22 | 3.75 | 98.379 |
| 68741 | 212.63 | 1531.47 | 3.57 | 98.285 |

Total number of designs = 20400

Total designs rejected due to violation of constraints= 13403

Total designs accepted = 6997

Design no. selected from all total designs = 1178

Design no. selected from all shortlisted designs = 15

**Table 1.3 Sample of Acceptable Solutions Pertaining to 2-Star Rating**

| Active Part Cost (INR) | No-load losses (W) | Loan losses (W) | %Z | Efficiency |
|---|---|---|---|---|
| 59529 | 183.16 | 1706.80 | 4.61 | 98.145 |
| 63804 | 177.02 | 1707.04 | 4.59 | 98.150 |
| 63377 | 178.26 | 1702.74 | 4.58 | 98.153 |
| 62877 | 179.25 | 1698.50 | 4.57 | 98.156 |
| 61931 | 181.62 | 1697.50 | 4.55 | 98.155 |
| 61650 | 180.76 | 1704.86 | 4.57 | 98.149 |
| 61251 | 182.15 | 1700.73 | 4.56 | 98.151 |
| 61206 | 182.15 | 1708.07 | 4.56 | 98.144 |
| 71517 | 198.61 | 1628.94 | 3.86 | 98.205 |
| 70891 | 199.53 | 1624.28 | 3.85 | 98.208 |
| 64972 | 199.67 | 1624.02 | 3.87 | 98.208 |
| 58272 | 194.91 | 1654.76 | 4.45 | 98.183 |
| 57921 | 196.83 | 1651.04 | 4.44 | 98.185 |
| 65877 | 196.35 | 1615.72 | 3.86 | 98.220 |
| 67898 | 199.01 | 1533.85 | 4.08 | 98.296 |
| 66857 | 192.26 | 1630.86 | 3.88 | 98.209 |

## IMPLEMENTATION OF GA FOR UNCONSTRAINED OPTIMAL TRANSFORMER DESIGN

The strategies for optimum configuration of 100 kVA, 11/0.433 kV, transformer distribution utilizing GA. The key benefit of GA is that a minimal change in the software multiple target functions may be streamlined.

**Table 1.4 Performance of Various GA Selection Operators for TDO Problem**

| Sr. No. | Selection Operator | Objective Function | Best value | Worst value | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
| 1 | RWS | Active part cost (INR) | 45662 | 47554 | 46516 | 499.82 |
| | | Total losses (W) | 1608.79 | 1722.79 | 1649.40 | 29.50 |
| | | Percentage Impedance | 3.192 | 3.330 | 3.259 | 0.037 |
| | | Tank Volume (cm³) | 228358 | 244905 | 231970 | 3978 |
| 2 | SRWS | Active part cost (INR) | 45545 | 46841 | 45977 | 327.18 |
| | | Total losses (W) | 1605.25 | 1638.94 | 1618.98 | 10.08 |
| | | Percentage Impedance | 3.191 | 3.270 | 3.211 | 0.027 |
| | | Tank Volume (cm³) | 227354 | 230958 | 226139 | 917.45 |
| 3 | TS | Active part cost (INR) | 45165 | 45207 | 45174 | 12.08 |
| | | Total losses (W) | 1594.16 | 1620.02 | 1599.72 | 10.04 |
| | | Percentage Impedance | 3.176 | 3.181 | 3.178 | 0.002 |
| | | Tank Volume (cm³) | 226098 | 227210 | 226289 | 403.96 |

## CONSTRAINED OPTIMIZATION RESULTS

This section discusses transformer design optimization results obtained by GA, PSO and TLBO. The limits on decision variables are mentioned in Table. Optimal design dimensions and performance parameters are derived by considering a set of GA parameters and penalty factor with active part cost as the objective function. Three different techniques RWSBGA , SRWSBGA and TSBGA have been employed to find the global optimum

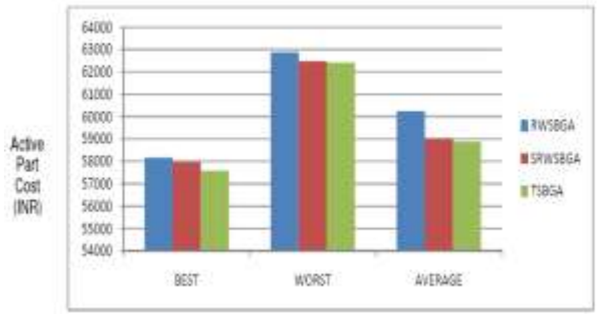


**Figure 1.5 Comparative Performance Analyses of RWSBGA, SRWSBGA and TSBGA for 2-Star Rated Transformer**

After analyzing the results obtained from three different selection operators, Tournament Selection based Genetic Algorithm (TSBGA) was able to find to find a better value as compared to RWSBGA and SRWSBGA.

**Table 1.3 Dynamic Performance Characteristics of Transformers designed by TLBO under short circuit conditions**

| Parameter | 1-star rating | 2-star rating | Units |
|---|---|---|---|
| Asymmetrical SC current on HV side | 125.68 | 126.26 | A |
| Asymmetrical SC current on LV side | 5530.11 | 5555.71 | A |
| Asymmetrical SC Ampere turns in LV | 431349 | 383344 | AT |
| Asymmetrical SC Ampere turns in HV | 452953 | 402525 | AT |
| Hoop stress in LV | 29.67 | 27.31 | kg/cm² |
| Hoop stress in HV | 47.56 | 52.34 | kg/cm² |
| Radial bursting force experienced by LV | 16429 | 15308 | kg |
| Radial bursting force experienced by HV | 17207 | 15978 | kg |
| Axial compressive force in both windings | 1883.19 | 2058.51 | kg |
| Temperature of LV for SC of 2 sec | 113.27 | 111.97 | °C |
| Temperature of HV for SC of 2 sec | 113.48 | 112.43 | 0c |
| Magnetizing current inrush in HV | 52.40 | 38.99 | A |

## CONCLUSION

Transformers carry on a crucial job of connecting power systems at dissimilar voltage levels. It would actually not be probable, without the transformer, to use electric power from different perspectives is used today. The Artificial Neural Networks field is concerned about examining computational models propelled by speculations & perception of the structure & function of neural cell biological networks within the cerebrum. The primary objective in this section was to think about the exhibition of swarm and developmental optimization procedures for optimization of the transformer design problem. The variety of variables in the framework was chosen according to the law of the transformer manufacturer. Ideal program measurements and transformer execution boundaries were obtained by adjusting the GA, PSO, and TLBO control boundaries.

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