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Optimal Design of Transformer Using Artificial Intelligent Techniques

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Abstract: **Optimal transformer design becomes an important feature to achieve lower cost, lower weight, reduced size and better operating performance. In this paper an attempt has been done for optimum design of power transformer. Genetic algorithm has been used as an optimization technique along with artificial neural network to select the different design variables in transformer design. Simulated results are compared with the conventional design method. It has been found that the optimization of design for a transformer becomes very simple with the application of artificial intelligent techniques. MATLAB is used for simulation purpose.**

Keywords: artificial neural network, genetic algorithm, intelligent systems, multi objective optimization, MATLAB, transformer design.

I. Introduction

Power transformers are large and complicated equipments and may contain as many as 2000 components. For every order received the supplier has to do the complete design, make all the arrangement/assembly as well as most of the component drawings for the manufacture of the transformer. Thus standardization is generally not possible and in most cases limited to a few components [1] and the release of engineering information takes as much as 40% of the total delivery cycle.

Design of transformer may be carried out using the normal procedure adopted by various researchers [1,6]. Selection of design variables are very important for a particular transformer before dealing with the logical procedure for the determination of main dimensions. High value of flux density results in the saving of the cost of iron and copper, but on the other hand a high value is objectionable due to increased iron losses, saturation in magnetic part and high magnetizing current. Further if a high value of current density is chosen, it causes in the copper saving, reduces sectional area for the windings. This result in to an increase in the resistance and increased copper losses.

A novel power transformer design methodology has been presented using artificial neural networks (ANN) by [3]. A database has been used which contains the results of several hundreds of actual power transformers to train the ANN. Web based environment has been used by [4] through shared information space for designing the power transformer.

The aim of the transformer design is to completely obtain the dimensions of the entire transformer based on the given specification, using available materials economically in order to achieve lower cost, lower weight, and reduced size and better operating performance[5].

Generally, the process of finding the optimum design variables of a transformer has been implemented with the help of a suitable computer program, which uses different input parameters in order to make the transformer program as parametric as possible [1].

It has been observed that during the normal design process, the value of variables defined, is selected at random, which does not leads to the best utilization of the transformer. Hybrid techniques are also used by [11] to find the optimum design parameters. In the present work an attempt has been made to use the artificial neural network and genetic algorithm [2,3],for the selection of various design variables simultaneously, to yield an optimum design. ANN is trained by actual data to find the accurate conductor dimensions which are required for realistic design not reported yet. GA has been used to find the optimum design variables with embedded ANN.

All the results are verified by a representative mathematical example of 5000 kVA, 35/2.3 kV power transformer [1]. It has been shown that the optimizing results are satisfactory. It proves the ability of ANN and GA for global searching, excellent solution precision and has a bright application prospect in the fields of power transformers design. Thus this paper presents the optimum design of power transformer using genetic algorithm along with embedded ANN by taking efficiency, weight and efficiency and weight simultaneously as an objective functions. Effect of this design on other parameters has also been shown.

II. Transformer Design Optimization

The aim of the transformer design is to completely obtain the dimensions of the entire transformer based on the given specification, using available materials economically in order to achieve lower cost, lower weight, reduced size and better operating performance. Conventionally, the transformer design has been worked out by using various methods based on accumulated experience realized in different formula, equations, tables and charts. The transformer design methods vary between the several transformer manufacturers. A transformer design optimization method has been proposed so as to meet the specifications with the various objectives e.g. maximum efficiency, minimum weight, mechanical forces, stresses, thermal loading etc. with optimized design variables. Therefore for designing the transformer, it is important to study the available information and work through a logical sequence of calculations to ensure that all the requirements are met.

In the proposed approach, five design variables (B_m, k_1, k_o, k_s, k_f) have been selected for the application of genetic algorithm for design purpose. To solve the given problem chromosomes are to be coded in string structures. After that design parameters are mapped to a specified interval [A_{max}, A_{min}], where A_{max} and A_{min} are the maximum and minimum values of various parameters as shown in Table 1[11].

Table I: Constraints on Control/design Variables

S. No.	Design Parameters	A_{min}	A_{max}
1.	B_m, wb/m^2	1.55	1.65
2.	k_1	0.70	0.90
3.	k_o	0.86	0.88
4.	k_s	0.875	0.960
5.	k_f	1.05	1.35

ANN is used to find the conductor width and thickness for calculated cross section area of different sections of transformer windings. The training and testing processes are embedded together in a single algorithm. The whole processes are represented in the form of a flowchart as shown in Fig. 1(APPENDIX-I).

After applying GA it is found that the design variables are automatically adjusted to keep the system at an optimum level of performance. Here following objective functions are used as performance index, which are function of the variable design parameters:

1. Efficiency
2. Weight
3. Efficiency and Weight

Objective function used here can be written as follows;

$$OF = K_1\eta + K_2 (W_I + W_C) \quad (1)$$

Where, K_1 and K_2 are the normalization factors used suitably. W_I and W_C are weight of iron and copper respectively. Efficiency and weights has been computed by normal design procedure [1].

Minimum value of this index then gives the optimum set of parameter values. This performance index of a GA is fitness function, which is used to resolve the viability of each chromosome. All the parameters are optimized according to their fitness value calculated by the performance index. If the requirement is not achieved, chromosome of the current generation will go through operations, crossover and mutation. After some number of generation, the program converges. Whole process is shown in Fig.2 (APPENDIX-II).

III. Results and Discussions

The design of a transformer has been carried out using artificial intelligent techniques. In the proposed approach, conductor thickness and width is determined using ANN and selection of different design variable/parameters (B_m, k_1, k_o, k_s, k_f) using GA.

Table II: Optimum design parameters for maximum efficiency

B_m	k_1	k_o	k_s	k_f	OF
1.57239	0.81588	0.87525	0.91990	1.25069	0.50240
1.55940	0.87792	0.86979	0.88601	1.09863	0.50239
1.55724	0.83932	0.86402	0.91969	1.15557	0.50239
1.55185	0.82076	0.86858	0.89963	1.12570	0.50240
1.55605	0.88565	0.86695	0.95279	1.28813	0.50239
1.55710	0.89652	0.87923	0.88715	1.12835	0.50288

Optimum results corresponding to the design variables in Table 2 are shown in Table 3.

Table III: Optimum results for maximum efficiency

Total losses	eff	q_oo	q_oa	q_olt	F_r	F_l	Sigma_ht	Sigma_lt	G_tr
49095	99.028	970.45	581.26	573.73	517880	19377	656.07	278.91	16380
48128	99.047	1196.4	673.34	665.74	608170	22844	931.04	334.72	15779
48380	99.042	1134.1	638.31	639.72	538840	20010	754.37	324.64	16105
48395	99.041	1095.9	637.49	659.33	506730	18742	677.21	325.13	16118
48609	99.037	965.75	606.28	611.92	60230	22418	791.66	389.74	16382
47939	99.050	1192.1	672.07	711.09	590460	21662	901.51	451.53	15854

Table IV: Optimum design parameters for minimum total weight

B_m	k_1	k_o	k_s	k_f	OF
1.60433	0.87716	0.86707	0.90442	1.08960	0.72435
1.64773	0.88373	0.86887	0.88141	1.06218	0.77955
1.63490	0.86559	0.86441	0.88832	1.05214	0.78095
1.61804	0.86385	0.86006	0.94172	1.05136	0.77569
1.63870	0.87525	0.86526	0.93557	1.05220	0.77635
1.62569	0.86669	0.86111	0.94671	1.10658	0.78760

Table V: Optimum results for minimum total weight

Total losses	eff	q_oo	q_oa	q_olt	F_r	F_l	Sigma_ht	Sigma_lt	G_tr
48766	99.034	1252.2	729.11	726.81	570910	21039	899.35	407.72	15646
49583	99.018	1279.8	709.22	749.43	571680	20966	916.07	423.25	15552
49313	99.023	1290.3	729.37	766.55	542690	19830	859.86	430.17	15565
48819	99.033	1348.6	729.06	786.35	534350	19491	889.64	439.85	15449
49369	99.022	1311.5	747.92	786.11	560820	20524	888.32	443.64	15536
49604	99.018	1183.6	697.35	733.16	547880	20066	771.96	415.46	15934

Table VI: Optimum design parameters for maximum efficiency and minimum total weight

B_m	k_1	k_o	k_s	k_f	OF
1.64294	0.87513	0.86251	0.92198	1.10776	1.29018
1.59253	0.87657	0.86583	0.91777	1.07125	1.28382
1.57279	0.86443	0.86871	0.90098	1.10322	1.29423
1.62343	0.88953	0.87109	0.93230	1.05992	1.27538
1.62004	0.89634	0.86446	0.89527	1.07551	1.27121
1.62770	0.89146	0.86405	0.91889	1.09830	1.28021

Table VII: Optimum results for maximum efficiency and minimum total weight

Total losses	eff	q_oo	q_oa	q_olt	F_r	F_l	Sigma_ht	Sigma_lt	G_tr
49687	99.016	1221.4	696.03	724.62	561460	20556	849.07	418.09	15751
48446	99.041	1308.2	718.23	762.98	559180	20486	900.13	443.66	15623
48150	99.046	1267.7	703.04	749.66	544020	19926	850.28	416.91	15640
48754	99.034	1363.9	737.32	1115.8	549620	19824	914.83	1147.2	15478
48855	99.032	1276.2	733.05	822.27	546880	19568	876.96	601.72	15551
49129	99.027	1264.6	743.94	755.04	575240	21000	916.93	469.21	15608

Table 2 to Table 7 shows the optimum parameters and results for various objective functions. The process results in to a maximum efficiency of 99.047% and minimum weight 15478 kg with a optimum set of design parameters (Bm, k1, ko, ks, kf). Tables also give the effect of optimized design on different performance parameters of power transformer. Above novel design procedure gives an idea about the various specific ranges of design parameters for different objective functions. Thus instead of giving the whole range of various parameters as shown in Table 1, specific narrow ranges may be given for fast results as selected by GA-ANN approach.

V Conclusions

In this paper, artificial neural network and genetic algorithms approach has been proposed to select the optimized design parameters of power transformer. ANN is used to find the accurate conductor dimensions. It makes the analysis more realistic. It has been found that the application of GA's to a transformer design problem, results in such values of (B_m, k_1, k_o, k_s, k_f), which are found to be in close agreement with the values suggested by [1]. This confirms the validity of the approach proposed.

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.Appendix-I

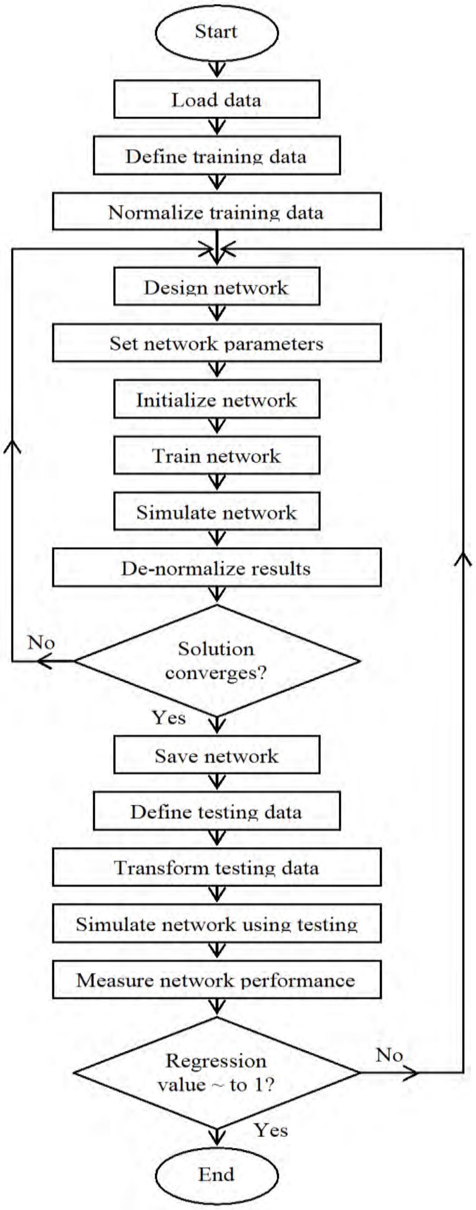
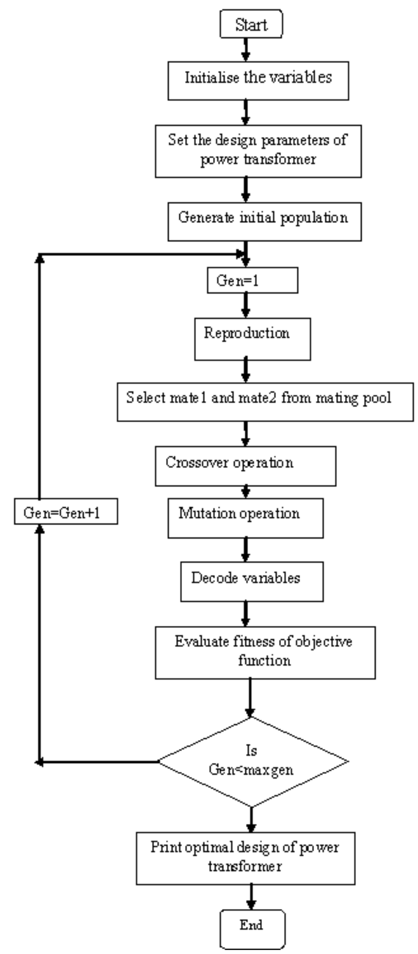


Fig. 1: Flowchart for finding the conductor dimensions using artificial neural network.

Appendix-II



Appendix - III

B_m	Core flux density, Wb per square meter
k_1	Proportionality factor for E.M.F. per turn
k_o	Space factor
k_s	Stacking factor
k_f	Stray loss factor
OF	Objective function
loss_total	Total losses, W
eff	Efficiency
q_oa	Specific thermal load for A type coils of the high voltage winding, W/cm^2
q_olt	Specific thermal load for ordinary coils of the low voltage winding, W/cm^2
F_r	Radial forces affecting the windings during a three phase short circuit, Kg

F_l	External forces due to the asymmetrical distribution of mmf, Kg
Sigma_ht	Stress in copper of the high voltage winding, Kg/cm^2
Sigma_lt	Stress in copper of the low voltage winding, Kg per square centimeter
G_tr	Total weight of transformer, Kg