Performance Comparison of Conventional, Genetic Algorithm and Particle Swarm Optimization for optimal design of Transformer with respect to its Total Owning Cost

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Abstract- Evaluation of Transformer Owning Cost (TOC) plays an important role during the selection of a transformer by an industrial customer. The dependency and the relationship between the transformer design and the TOC is used to obtain a cost optimal design for the test case. The TOC evaluation by conventional method is compared with those of results obtained after optimizing design variables using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO), out of which the latter has provided a much minimized solution than the other two methods. Thus a minimized total owning cost is obtained using design variables optimized by particle swarm optimization technique.

Index Terms- Optimisation,Genetic Algorithm(GA), Particle Swarm Optimisation(PSO), Total Owning Cost(TOC)

I. Introduction

The quality of transformers depends on good design. Generating plants, generating the bulk of AC power at high voltage are concentrated in few favorably situated stations. The power so generated is then transmitted at appreciably high voltage to reduce the amount of conducting material and to increase the transmission efficiency. However the distribution of power should be carried out at low voltage. Hence generated power is transformed twice, thrice or even four times before it is utilized. A transformer is a static device by means of which electric power in one circuit is transformed into electric power of the same frequency in another circuit. Building electrical equipment as economically as possible to meet the performance expectations of the intended application is of paramount importance for the manufacturers of electrical apparatus. The aim of design is to obtain completely the dimensions of all the parts of the machine to furnish data to manufacturers. While designing a transformer much emphasis should be placed on lowering its cost by saving the materials and reducing to a minimum labour consuming operation in its manufacture. The design should be satisfactory with respect to electrical strength, mechanical ruggedness, dynamic and thermal resistance of winding in the event of short circuit. Thus only the joint efforts of the designer and production engineer can develop new design of transformer satisfying closely the technical requirements with good reliability in service and with minimum cost.

This paper presents the design for rectifier transformer coil using Genetic algorithm[2]. The optimization data show that the improved genetic algorithm which can produce performance improvements in execution time and accuracy for a given coil optimization design is effective for practical use. [4] minimized the cost of power transformer using Chaos genetic algorithm.

[1] proposed optimal design of power transformer using particle swarm optimization and minimized ratio and phase displacement errors and construction cost. [3] proposed the idea of using Particle swarm optimization in design of Rectifier transformer.

II. CONVENTIONAL DESIGN OF TRANSFORMERS

TABLE I: TEST CASE

LV	440 V
HV	6600V
Maximum Flux Density	1.35Wb/mm^2
Frequency	50 Hz
Rated Output	300 kVA
Resistivity Of Copper	0.021Ω-m
Maximum Temperature rise	50
Type Of Cooling	Oil Natural Air Natural

A. IRON LOSS CALCULATION

When voltage is applied to the exciting or primary winding of the transformer, a magnetizing current flows in the primary winding. This current produces the flux in the core. The flow of flux in magnetic circuits is analogous to the flow of current in electrical circuits. When flux flows in the steel core, losses occur in the steel. This loss is constant throughout the operation of the transformer irrespective of its loading.

Volume of core = No. of limbsxCore areaxHeight of Core
Weight of core = Volume of core X Specific weight of iron
Volume of yoke = 2 X Area of yoke X Length of yoke
Weight of yoke = Volume of yoke X Specific weight of iron
Core loss = Weight of core X Specific loss in Core
Yoke loss = Weight of yoke X Specific loss in Yoke
Total iron loss = Core loss + Yoke loss

B. COPPER LOSS CALCULATION

Copper weight calculation involves calculation of both HV and LV windings together.

LV side:

Volume of copper in LV = No. of limbs X Area of LV X LV Turns X mean length of LV turns

Weight of copper=Volume of copper in LV X specific gravity of copper

HV side:

Volume of copper in HV= No. of limbs X area of HV X HV turns X mean length of HV turns

Weight of copper= Volume of copper in HV X specific gravity of copper

HV copper loss =(Phase current in HV) ^{2} X Resistance of HV Winding

TOTAL COPPER LOSS =LV COPPER LOSS+ HV COPPER LOSS

LV copper loss= (Phase current in LV) ^{2} X Resistance of LV Winding

Weight of copper = Volume of copper in LV X Specific gravity of Copper

Total Owning Cost TOC = Cost of materials + Cost of No load loss + Cost of Load loss

Cost of Core loss = A X No load loss in Watts
Cost of Load loss = B X Load loss in Watts
Where,

A = Avg. power cost X Avg. no-load running time during life period

B = Avg. load rate during life period X Load running time during life period X Avg. power cost

C. LOAD PROFILE

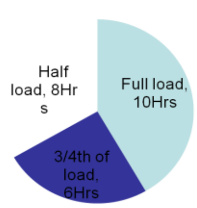

Fig I: Load profile

TABLE II. LOAD PROFILE

No. Of Hours(kW)	Load in KVA	Power factor	Load
10	300	0.95	285
6	225	0.95	213.75
8	150	0.95	142.5

Total Cu loss for a day ie, 24 hrs = (10* 3.6032) + (6* 2.0268) + (8* 0.9008) = 55.3986 kWhr
Cu loss at full load ie, 285 kW = 3.6032 kW
Cu loss at 3/4th of load ie, 213.75 kW = 2.0268 kW
Cu loss at 1/2th load ie, 142.5 kW = 0.9008 kW

CONVENTIONAL COST OF MATERIALS

TABLE III. COST OF MATERIALS

PART	MATERIAL	COST
CORE	Hot rolled steel	31 Rs/kg
COIL	Copper	445 Rs/kg
TANK	Mild Steel	50 Rs/kg
OIL	Refined mineral oil	15 Rs/litre
TUBE	Mild steel	50 Rs/kg

weight of core = 719.3606 kg
weight of copper = 228.1570 kg
weight of tank = 177.5301 kg
total volume of oil = 571.6786 litres
weight of tube = 246.7143 kg
Total Material Cost = (31*weight of core)+ (445*weight of copper)+ (total volume of oil*15)+ (weight of tank*50)+ (weight of tube*50) = (31*719.3606)+(445*228.1570)+ (571.6786*15)+ (177.5301*50)+(246.7143*50) **= 1,53,595 Rs**

CONVENTIONAL TOTAL COST AND EFFICIENCY

Energy transformed:
300 kVA * 0.95 * 8,760 = 2,496.6 MWh / year
Efficiency
η = (kva*power factor)/((kva*powerfactor)+total losses))*100= (300*0.95)/((300*0.95)+5354.2)*100 = **98.156 %** **Lifetime cost:**

Transformer:	1,53,595 Rs
Iron loss:	8,05,330 Rs
Copper loss:	10,61,575 Rs
Total	**20,20,500 Rs**

III. ESTIMATION OF TOC USING GENETIC ALGORITHM

A. PROCEDURE

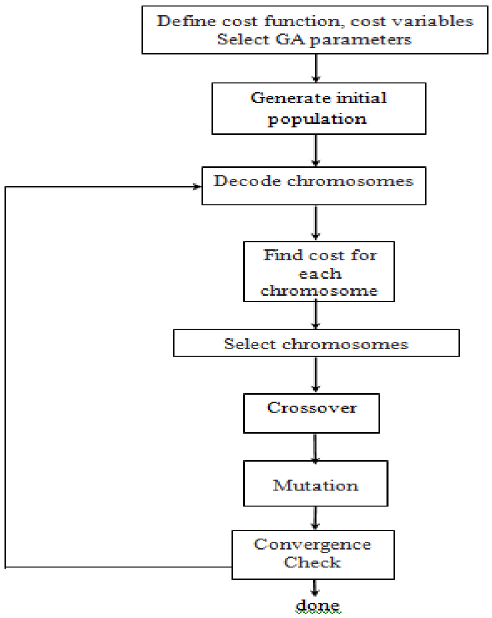

Fig II: Flowchart of Genetic algorithm

B. PROBLEM FORMULATION

Step 1: Objective Function definition

$\boldsymbol{Min}\{C_{Fe}XG_{Fe} + C_{Cu}XG_{Cu} + C_{tu}(G_{tu}+G_{tk}) + C_{ol}XG_{ol}+c_e\,(h_oXP_o + kXh_r\,XP_r\,)\}$

c_{Fe} , unit price of iron, (Rs/kg)
c_{Cu} , unit price of copper conductor, (Rs/kg)
c_e , average power cost
h_o , average no-load running time during life period
k , average load rate during life period
h_r , load running time during life period
G_{Fe} , weight of iron
G_{Cu} , weight of copper conductor
P_o , no-load running loss of transformer
P_r , rated load loss of transformer
C_{tu} , Cost of tube material (Rs/kg)
G_{tu} , Weight of tube
G_{tk} , Weight of tank
C_{ol} , Cost of oil (Rs/litre)
G_{ol} , Volume of oil

Step 2: Basic design variables

There are six design variables:
1.Maximum flux density, B_m
2.Current Density, δ in LV winding
3.Current Density , δ in HV winding
4.Window space factor, k_w
5.Yoke area in terms of core area,%
6.K factor

Step 3: The Constraints considered are,

Weight of the Iron <Conventional results
Weight of the Copper <Conventional results
No-Load loss in a transformer < Rated no load loss
Load loss in a transformer < Rated load loss
Impedance percentage <Specified impedance percentage

Step 4: Set,

Population size = 100
Crossover probability = 0.8
Generations = 50
Stall generations = 50

Step 5: After 7 to 10 GA runs, the global optimum is reached for the problem.

Thus, the design variables are optimized in such a way that a minimized Total Owning Cost is obtained.

IV. ESTIMATION OF TOC USING PARTICLE SWARM OPTIMISATION(PSO)

Particle swarm optimization (PSO) is a population based stochastic optimization technique inspired by social behavior of bird flocking or fish schooling.PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles.Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbors of the particle. This location is called lbest. When a particle takes all the population as its topological neighbors, the best value is a global best and is called gbest. After finding the two best values, the particle updates its velocity and positions with following equation (a) and(b).
v[]=[]+c1*rand()*(pbest[]-present[])+c2*rand()*(gbest[]-present[]) -- (a)present[]=present[]+v[] --(b)

v[] is the particle velocity present[] is the current particle (solution). pbest[] and gbest[] are defined as stated before. rand () is a random number between (0,1). c1, c2 are learning factors. usually c1 = c2 = 2.

The particle swarm optimization concept consists of, at each time step, changing the velocity of (accelerating) each particle toward its p*best* and *lbest* locations (local version of PSO). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward *pbest* and *lbest* locations.

A. PROBLEM FORMULATION

The problem formulation for PSO and GA remains the same but care should be taken while setting up the population size, generations, stall generations, since, both the optimization techniques output should be weighted on the same scale.

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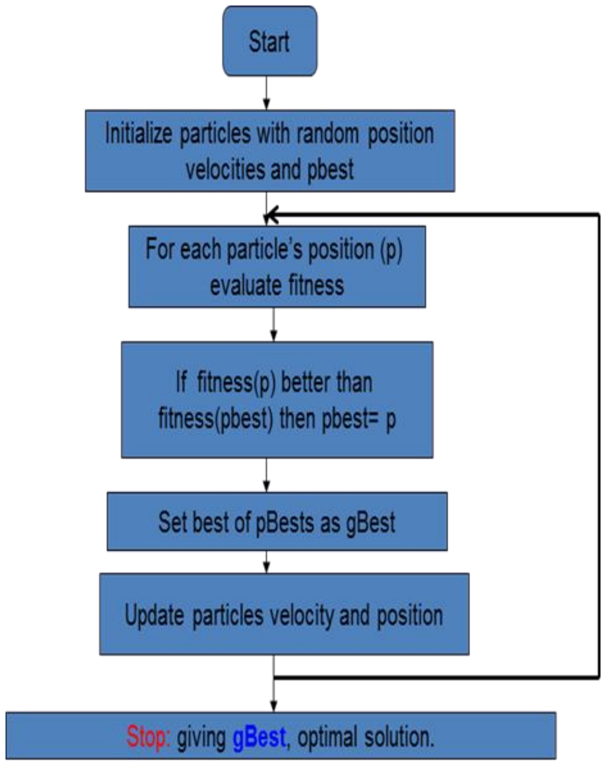

Fig III. Flowchart of PSO

V. RESULT ANALYSIS

TABLE IV. RESULT ANALYSIS

PARAMETERS	**CONVENTIONAL**	**GA**	**PSO**
Cost	20,20,500 Rs	18,32,354 Rs	18,32,294 Rs
Maximum efficiency	98.2677%	98.4419%	98.4420%
Efficiency	98.1560%	98.3757%	98.3757%
No. of tubes	40	32	32
No load loss	1.7511 kW	1.6825 kW	1.6825 kW
Impedance %	2.06%	2.4434 %	2.4439%
Weight of copper	228.1571 kg	249.9899 kg	250 kg
Load loss	3.6032 kW	3.0230 kW	3.0231 kW
Width of tank	41.0093 cm	42.9644 cm	42.9650 cm
Length of tank	107.0093 cm	108.9644 cm	108.9650 cm
Height of tank	138.0976 cm	128.2037 cm	128.2037 cm
Weight of iron	719.3696 kg	703.6916 cm	703.6907 kg
Area of yoke	299.0778 cm^2	316.1203 cm^2	316.0740 cm^2
Thickness of yoke	18.7374 cm	19.6962 cm	19.6954 cm
Window length	55.6628 cm	43.8126 cm	43.8129 cm
Diameter of circumscribing circle	20.8194 cm	21.8846 cm	21.8838 cm
Height of transformer	93.0976 cm	83.2049 cm	83.2037 cm
Width of Transformer	86.7374 cm	87.6962 cm	87.6954 cm
Window Width	13.1806 cm	12.1154 cm	12.1162 cm
Area of window	733.1432 cm^2	530.8061 cm^2	530.8468 cm^2
Area of core	260.0667 cm^2	287.3620 cm^2	287.34cm^2
HV turns	830	754	754
LV turns	32	30	30
EMF per turn	7.7942 V	8.6122 V	8.6116 V
Area of LV winding	1.7116 cm^2	1.6985 cm^2	1.6814 cm^2
Area of HV winding	0.0547 cm^2	0.0686 cm^2	0.0692 cm^2

TABLE V. COMPARISON OF GA AND PSO

VALUE	**GA**	**PSO**
Minimum	18,32,354.2851	18,32,294.1086
Mean	18,32,624.6595	18,32,624.4115
Maximum	18,42,820.0192	18,42,581.6441

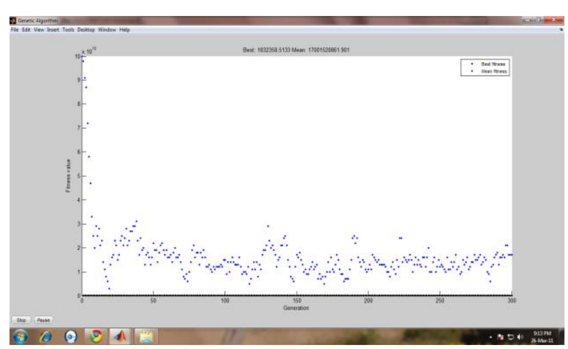

Fig IV: Plot for GA

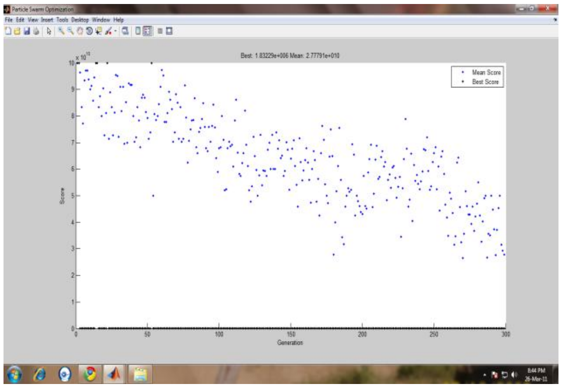

Fig V. Plot for PSO

VI. CONCLUSION

In this paper, the Total owning cost of transformer is minimized using Genetic Algorithm and Particle Swarm Optimization. This objective was achieved through the above mentioned algorithms using Matlab. By using the above mentioned method, both iron losses and load losses have been minimized, thereby increasing the efficiency of the transformer. New enhanced transformer design variables were obtained subsequently which results in overall reduction of transformer owning cost for a period of 15 years and improvement in the efficiency of transformer. Hence it can be inferred that minimization using PSO shows better results when compared with GA. The result shows that both PSO and GA works well and is helpful for optimal design of transformer.

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