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Optimum Transformer Core Design Using Brute Force Search Algorithm

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Abstract*: Transformers annually growth increasing in both consumed and installed in the utility networks all over the world, so it is always required and targeted to build transformers with a most efficiently to achieve the guaranteed characteristics of transformers and the economics. This paper deals to find modern design optimization of three phases oil-immersed, three-legged, core type transformer. The successful attempt for designing the transformer using brute force search algorithm is presented. This method was carried out using MATLAB which significantly reduces the no load loss design margin as well as the cost of transformer main materials.*

Keywords— Optimum Transformer Design; Core Design Using Matlab; Brute Force Search Algorithm

1. INTRODUCTION

Transformers are passive devices for transforming voltage and current, they are usually categorized as power and distribution transformers [1]. Distribution transformers are the most numerous and varied types used in electricity supply network [2]. In Sudan, with the increasing electrical power generation, the electricity networks are spreading daily through the developing country. This spread needs huge amount of different rates of distribution transformers. Hundreds of distribution transformers are produced in Khartoum, Sudan monthly. Additional hundreds are imported to Sudan monthly. The cost of distribution transformer varies according to the vendor, even for the same rating of transformer, and even the fact that all vendors provide transformers for the same specifications. The cost of the transformer includes the material cost, manufacturing cost and losses cost; the main determiner of the cost is the design of the transformer, which determines the material and losses costs [3]. The transformer manufacturers in Sudan are:

i. SUDATRAF (Sudanese Egyptian Electrical industrial).
ii. TRANSUDAN (Sudanese Company for transformers).

So, the main goals are:

i. Obtaining an optimum transformer design using a suitable optimization tool.
ii. Localizing the transformer design practice in Sudan.
iii. Evaluating imported designs by comparing them with the optimum design obtained in this work.

The designs of transformers produced in Sudan are imported from companies in Egypt and Italy, or relying on an earlier design that has been used in manufacturing transformer with similar main characteristics. The transformer design practice in Sudan is modifying imported designs by a trial and error process by varying some of the design variables until achieving the required specification. Those designs are successfully used to achieve designs per acceptable standards, but they do not guarantee a cost effective product. So, there is always that blindness of the uncertainty of the effectiveness of the design.

Implementing the proposed improvement of the design could lead to reduction in the transformer cost, even a slight reduction in cost

Per transformer unit would be huge reduction of the transformers purchasing budget due to the large amounts of them. Also, by applying the improved algorithm, the uncertainty of chance of minimum cost is vanished. By localizing the transformer design practice in Sudan, hard currency could be saved.

2. OBJECTIVES OF RESEARCH

In this paper the following objectives have been formulated:

i. To develop computer based algorisms to give the optimum design of the iron core section with given available sizes and given number of steps, which is very useful program that solves a main problem in transformer core design.

ii. To develop computer based design program algorithms to give the optimum design for the distribution transformers, by selecting design parameters, i.e. copper size, core size, insulation thickness, cost, etc. has been developed.

iii. To compare the total cost of a transformer obtained using the proposed algorithms with the total cost obtained using the currently used design method. This objective is needed to evaluate the gain of implementation of the proposed algorithms in transformer design.

3. BRUTE FORCE SEARCH ALGORITHM METHOD

Brute force, also known as an exhaustive search, is a paradigm in computer science where all possible cases for deriving a problem's solutions are explored [4].It is a straightforward approach, usually based directly on the problem's statement and definitions of the concepts involved. It is a method of computation wherein all permutations of a problem are tried until one is found that provides a solution, in contrast to the implementation of a more intelligent algorithm. Brute Force Search method describes a primitive programming style, one in which the programmer relies on the computer's processing power instead of using his or her own intelligence to simplify the problem [4, 5]. Whether brute-force programming should actually be considered stupid or not depends on the context; if the problem is not terribly big, the extra CPU time spent on a brute-force solution may cost less than the programmer time it would take to develop a more 'intelligent' algorithm. Brute force is a very fundamental approach to problem-solving where every perceivable answer is tested for correctness. The most general search algorithms are brute-force searches since they do not require any domain specific knowledge. So brute-force search is also called uninformed search and blind search. To find all possible solution, search methods are the suitable solution, after finding all the possible solutions selecting one of them based on any desired criteria is a good optimization practice.

All other mentioned methods are already made algorithms and programs. Brute Force Search is a concept, the algorithm would be written according to the problem.

To obtain an optimum design, all possible designs are generated, and then the design is selected according to any desired criteria, like minimum material cost, minimum copper cost minimum iron cost, minimum losses, minimum load losses, minimum no-load losses. These are the most common used criteria. To generate all possible designs, Brute Force Search method is used. The Brute Force Method takes time to execute exponential to the number of the variables, so any reduction in variables number will lead to great reduction in time needed [6]. So, an improved way is used. To reduce the size of tested combinations, early checks may be done; these checks (tests) are done whenever a constraint can be checked for, so the number of combinations those later combine with other variables is reduced. That is typically as applying the Brute Force Search in levels, every level contains producing the combinations, testing them and finally save the successors. These successors are the only ones to be combined later on with other variables. The flowchart of the improved proposed design algorism is shown in the following figure.

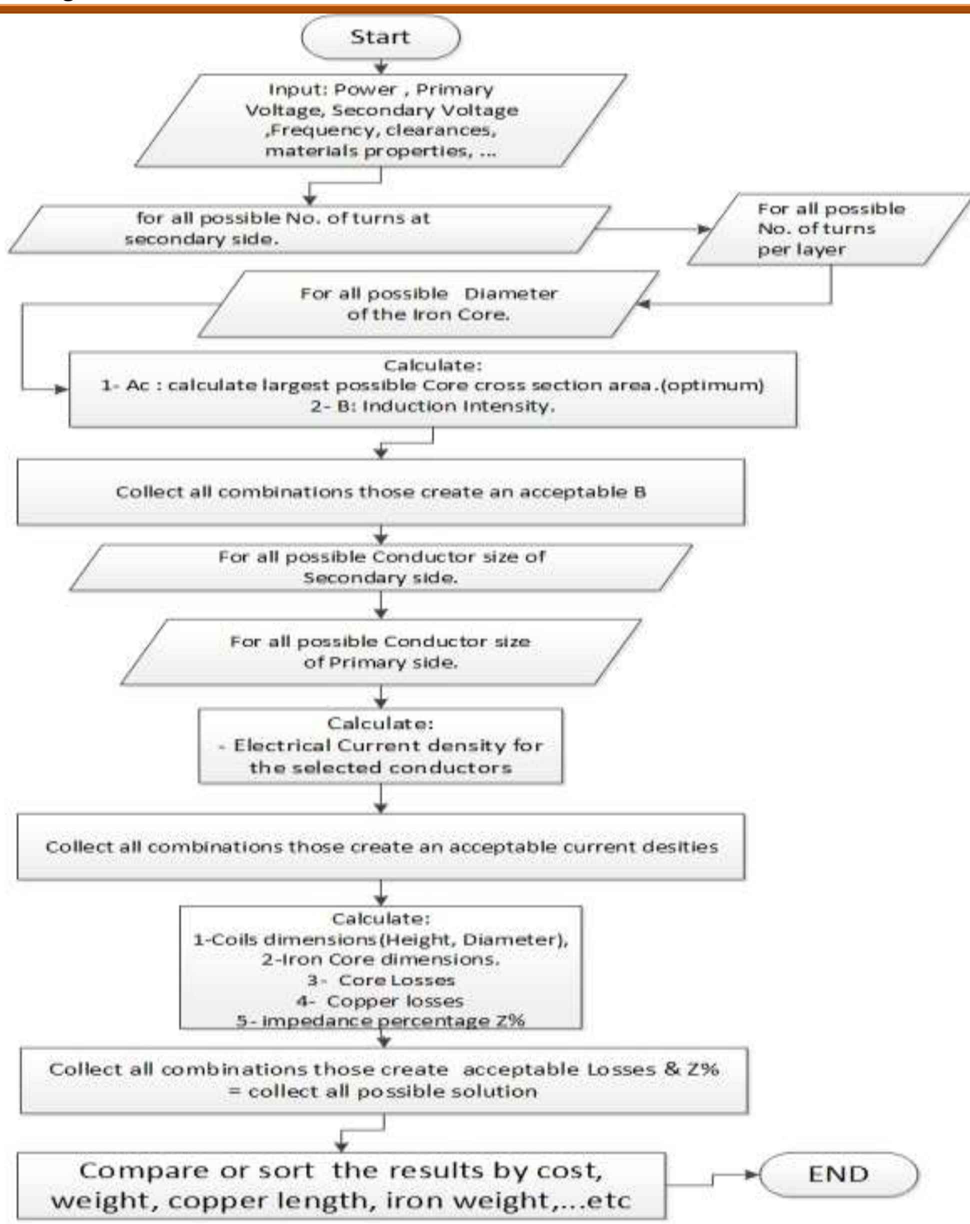

Figure 1: Flow chart improved design algorithm

The problem of finding all acceptable designs is divided into stages:

i. Stage 1

The first stage is to find all possible core diameter (D), and then finding best possible area for every diameter.

Possible diameters could be all range of all possible producible diameters, or could be set by the program user to suitable range depending on the user experience.

The available sizes of Si steel strips are taken from the material book of SudaTRAF [3].

The sizes of the strips have a multiplication of 10, starting from 50 mm up to 280 mm.

The program lets the user to exclude any steps those are not available at the stock. It will run later without considering the excluded

step sizes.

The best area is found by using MATLAB function of (combnk) which stands for combinations, this function simply develops all possible combinations; it is used here to obtain all possible combinations of the strip sizes below the desired diameter with a given number of the combination size (number of desired steps). Then Area is calculated for every combination of strip sizes, the best area is stored for the given diameter, and the next diameter is considered to find its best possible area.

ii. Stage 2

Finding the combinations of core diameter (D) and number of turns at the secondary winding (N), those give an acceptable field intensity (B). Stage 1 and Stage 2 are shown in following figure.

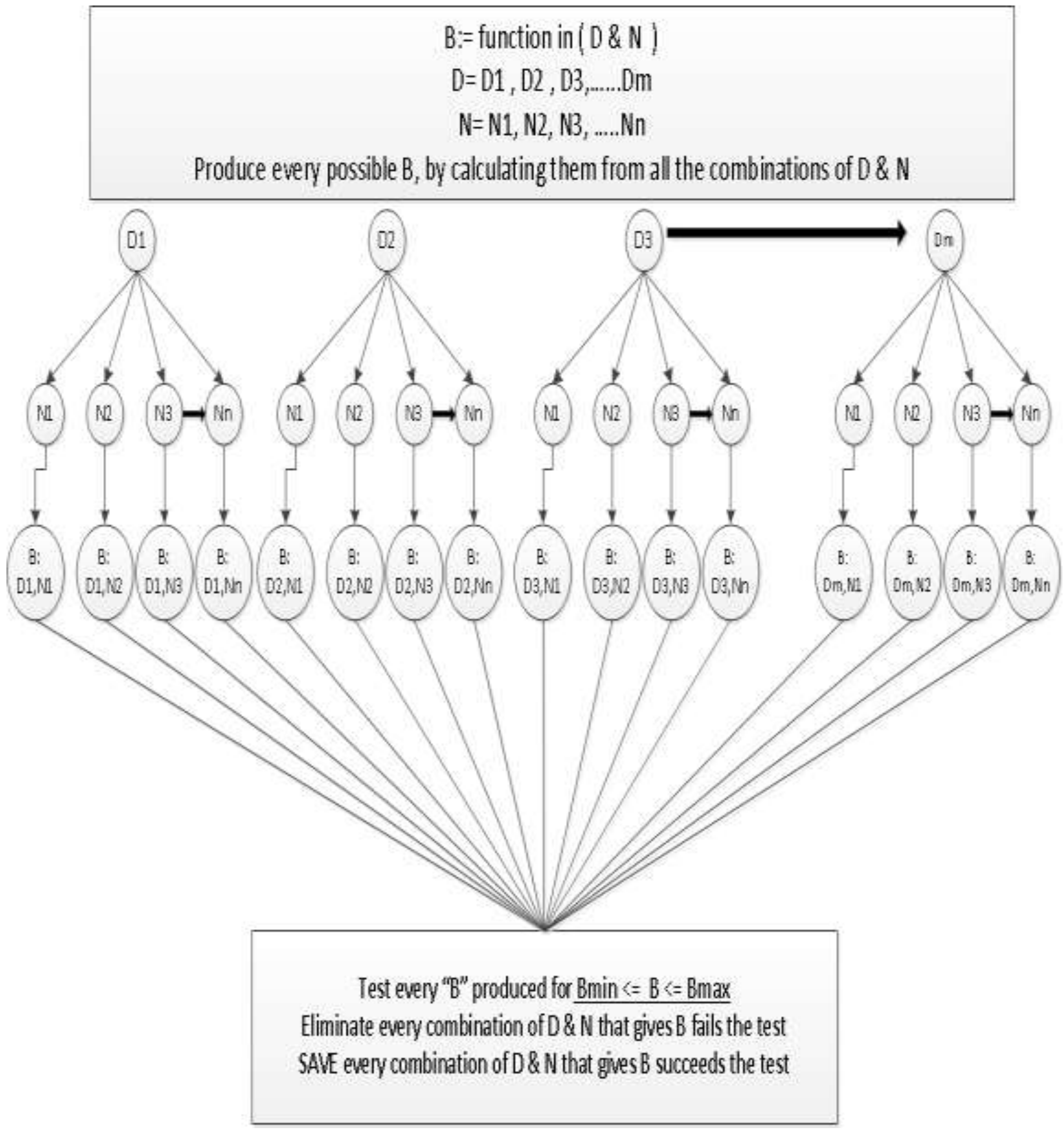

Figure 2: flowchart of algorithm gives combinations with accepted B (stage1, 2)

4. APPLICATION OF ALGORITHM:

The method which gives the optimum solution in less time will be best of methods. The comparison between methods is done based on the two possible conditions; according to the availability of the strip sizes.

i. State 1 is when all of the strip sizes are available.
ii. State 2 is when some pre-specified strip sizes are not available.

The comparison between numerical methods will based also on the model of problem, in the other hand Brute force search method works in different way, it actually tries every option, and so different models for the same problems are seen similar by our algorithm. The input data for all algorithms is:

- Core diameter = 300;
- Number of strip sizes allowed to use = 7;
- Complete set of strip sizes=50 up to 280; with step of 10 mm.
- STATE 1: all strip sizes are available;
- STATE 2: not available strip sizes = 200, 230;

Note:

- These strips specified (200 and 230) are chosen because they will appear in the optimum solution for the full set available (STATE 1).

The output of each program will contain:

- The area obtained.
- The obtained area ratio to the circular area.
- The strip sizes used. (column 1)
- The height of each step on one side. (column 2)
- Number of strips used in each step on one side. (column 3)
- The total height of each step. (column 4)
- Total number of strips used in each step on one side. (column 5)
- Time spent on calculations.

5. RESULTS AND DISSCUSION:

- **Results for STATE 1**

```
n =
      7.00
Best area can  be achieved with your available steps is
L =
   65685.66
The percentage of covered area is
p =
      0.93
Elapsed time is 1.837256 seconds.
design =
 Columns 1 through 4
     280.00      53.85      199.00      107.70
     260.00      20.98       78.00      41.96
     230.00      21.47       80.00      42.95
     200.00      15.50       57.00      30.99
     160.00      15.08       56.00      30.16
     120.00      10.59       39.00      21.18
      70.00       8.38       31.00      16.76
 Column 5
     398.00
     156.00
     160.00
     114.00
     112.00
      78.00
      62.00
```

- **Results for STATE 2**

```
n =
       7.00
Best area can be achieved with your available steps is
L =
    65653.91
the percentage of covered area is
p =
      0.93
```

```
Elapsed time is 0.729719 seconds.
Design =
  Columns 1 through 5
      280.00    53.85    199.00    107.70    398.00
      260.00    20.98     78.00     41.96    156.00
      240.00    15.17     56.00     30.33    112.00
      210.00    17.12     63.00     34.24    126.00
      170.00    16.47     61.00     32.94    122.00
      130.00    11.59     43.00     23.19     86.00
       80.00     9.38     35.00     18.77     70.00
```

- **Observations:**

- In STATE 1: There are 346104 (= 24C7) possible combinations, the program tries each of them, the maximum area combination is saved, this takes time of 1.8 sec.
- In STATE 2: There are only 170544 (= 22C7) possible combinations, the program tries each of them, the maximum area combination is saved, this takes time of only 0.7 sec. So, by only ignoring 2 strip sizes (2 options), the time is halved. Trying to illustrate this effect of options space on the Brute Force Search time, suppose we want to optimize the area of the core with 150 mm Diameter, the options of the design here are: [150 140 130 120 110 100 90 80 70 60 50]; which are 11 options only; the number of desired steps remain 7 steps, the number of all combinations of 7 steps from our option space is (11C7) which equals: 330.
- Running the program with this input: D= 150, steps = 7, Results of time consumed = 0. 002144 sec.
- It is an important to note that by halving the diameter, the time is almost vanished.
- The Brute Force Search method takes time exponential to space of available values for each variables (D and available strip sizes).

Table 1: Results of Problem A, Using Brute Force Search Method

Problem A (Brute Force Search)	STATE 1 With all sizes available	STATE 2 With 2 sizes not available
Optimum obtained in every run	YES	YES
Time consumed (sec)	1.8	0.7

- So, to obtain a time representing this method; an average has been calculated, by averaging of time for all possible diameters (70 up to 300mm), at n=7; and full set of strip sizes.
- A program has been developed to plot the relationship between(time consumed) and (core diameter), the program also calculate the average time, the results are as:

```
average time = 0.25 seconds
```

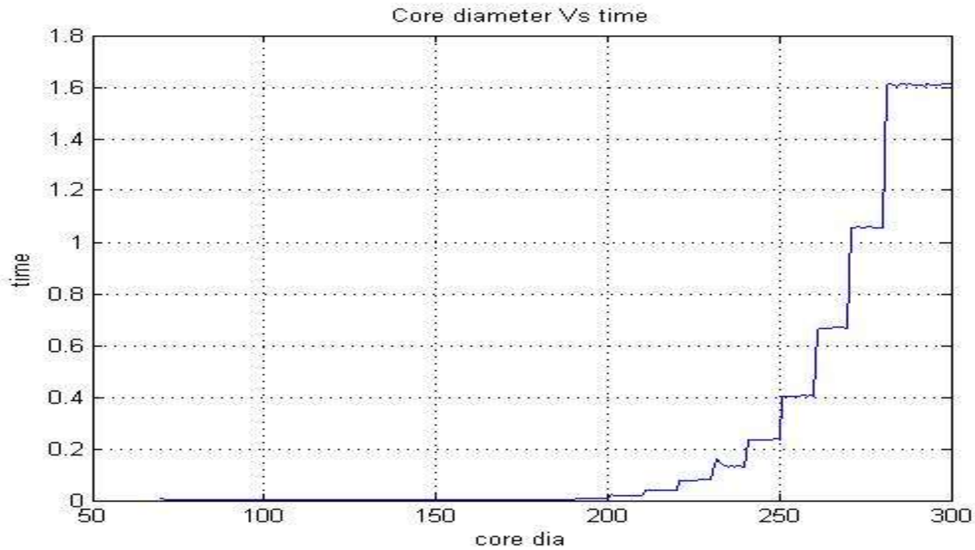

Figure 3: Core Diameter vs. Time

6. CONCLUSION

A computer based design programs were successfully developed. The designs formulation taken from practical design, practice in the field of transformer design and manufacturing.

Brute Force algorithms have been implemented and applied to solve the problem of transformer design problems.

The results obtained by using Brute Force Search Method algorithm were acceptable.

The achievement of research objectives is the effectiveness, success and suitability of using Brute Force Search method, which is rarely recommended in the literature on optimization. Using Brute Force technique in transformer area, with no doubt, is of a high value added from the point of view of saving money, effort and time.

7. REFERENCES

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