

PROGRAM FOR THREE-PHASE POWER TRANSFORMER DESIGN

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Abstract: *This paper presents a program developed for designing three-phase power transformers used in power systems. The program was developed in Visual Basic because this programming language allows us to realize a friendly and suggestive interface with minimum effort. The second reason, which is the most important, is to use Visual Basic, because this language is recognized by the used finite elements analysis (FEA) software, MagNet produced by Infolytica. This software package is designed for calculation of the magnetic field of electromagnetic devices and machines. The 3D components of the numerical model are carried out using CATIA program, automatically, based on the calculated main geometric data.*

1. INTRODUCTION

As it is known the design requires laborious calculations for sizing and verification, calculations for determining the parameters, comparing them with those required by the theme, the return to an earlier stage and choosing other values of the possible, restoration and re-checking calculations, and optimization chosen option.

Once completed, this first step of the design must be checked by simulations of the chosen option. These simulations must confirm the analytical calculations and allow the determination with accuracy of the parameters of the designed device.

Currently, one of the most used methods for simulating electromagnetic machines and devices is the finite elements method. It is widely accepted, verified and confirmed that finite elements method allows obtaining accurate results if the user of the program is well informed of both the operating mode of the program, the principles underlying the method, and the phenomena that occur in the designed device.

Given all this, it is obvious that in order to get a quality apparatus it is necessary that several possible options need to be designed, optimized, analyzed and compared. Computer aided design is the one that solves this problem because it allows, in a short time and with minimal effort, to get more options that meet the requirements imposed by the design theme.

In case of the power transformers, the design calculus is relatively well set, but, depending on how the designer choose certain parameters/dimensions at some point, and depending on the used materials, it can get more options that meet the conditions imposed by the theme. The final decision should always be the one that takes into account both the technical and the economic aspects to finally obtain the best quality/price.

2. THE PROGRAM DESCRIPTION

The developed program is an application that is based on the programming language Visual Basic, and runs under the used numerical analysis program, MagNet. Based on the data calculated in the design phase, a 3D numerical model of the transformer is automatically performed. The analysis of the performed model, enables the transformer parameters determination, the transformer characteristics determination, and the study of some transients regimes such as no-load network connection and sudden short circuit regime.

Main design data of a three-phase power transformer are the rated voltages of primary and secondary phases, the winding connections, the phase-angle displacement between primary and secondary terminals, winding material, nominal apparent power, etc. Other parameters imposed by theme are nominal losses and the short circuit voltage.

Figure 1 shows the program interface. The design data are taken from text boxes when the button "Proiectare" is clicked, and the interaction with the user of the program (designer) is done through the dialog boxes. In the dialog boxes are messages about the parameters which must be established, and information obtained by calculation regarding the recommended value or range of values, out of which the finale value must be chosen, fig. 2.

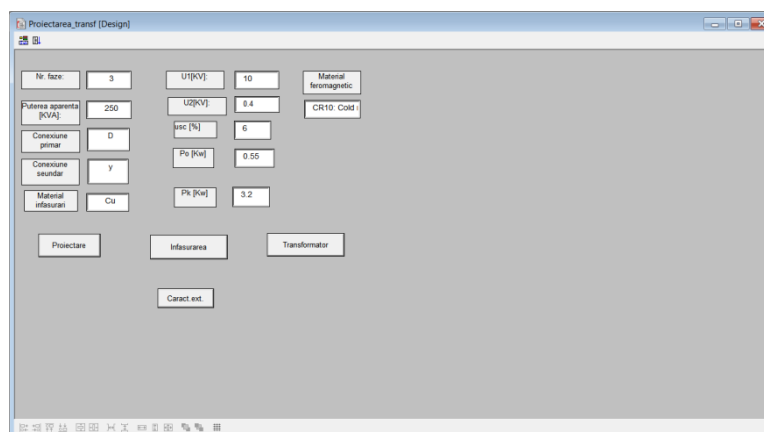


Fig. 1—Program interface

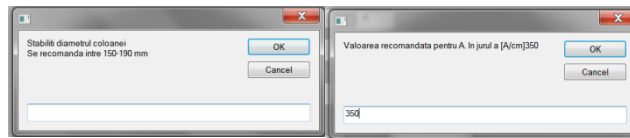


Fig.2 Dialog box

The values set out in dialog box are finale values for that parameter.

Message boxes are also used to inform the designer on the calculated value of a parameter at a time.

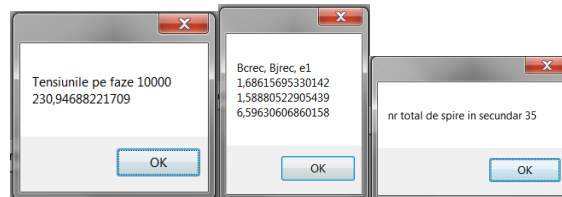


Fig.3. Message box

In case that the quantities do not meet certain conditions imposed by the theme, the message box displays this, and the program returns to the point where we must make changes, fig. 4.

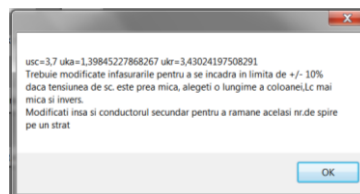


Fig. 4 Conditions are not satisfied. Tips are suggested

The main geometric dimensions once determined, clicking the button "Infasurare" it is created one column of the transformer and the corresponding two windings, Fig. 5. At this moment, the column is performed with circular section, but in the future we want that the program realizes columns/yokes with steps shaped section.

Also, the lamellar construction of the magnetic circuit is defined by the material properties, not by the manner of the transformer magnetic circuit realization in 3D numerical model.

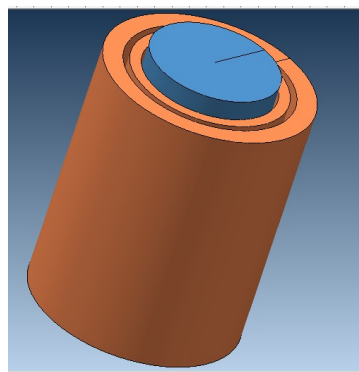


Fig. 5 Column and corresponding windings

Then, clicking the "Transformator" button, the whole transformer (with corresponding columns, yokes and windings) is constructed, fig. 6. At this time the program does not

automatically set the number of turns of the windings, this should be done by the user, fig. 7. In the future we will add features to do this automatically, based on the design calculated data.

Also, the boundaries of the calculus domain and the boundary conditions should be set by the user. In this case an air box around the transformer has been built, fig. 8, so that the leakage flux is not diminished, and the established boundary conditions were "tangential flux".

The initial mesh is showed in fig.9.

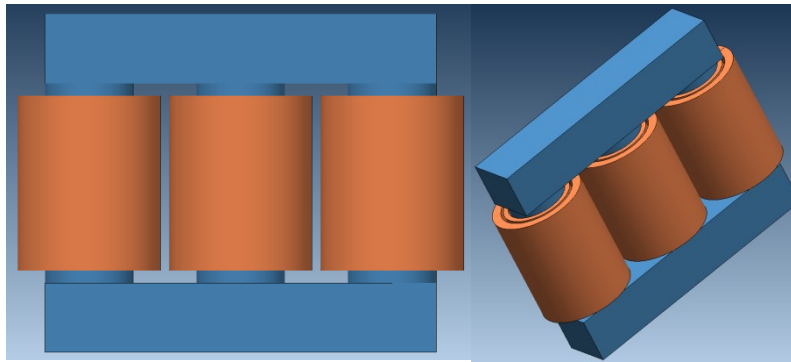


Fig.6 The whole transformer

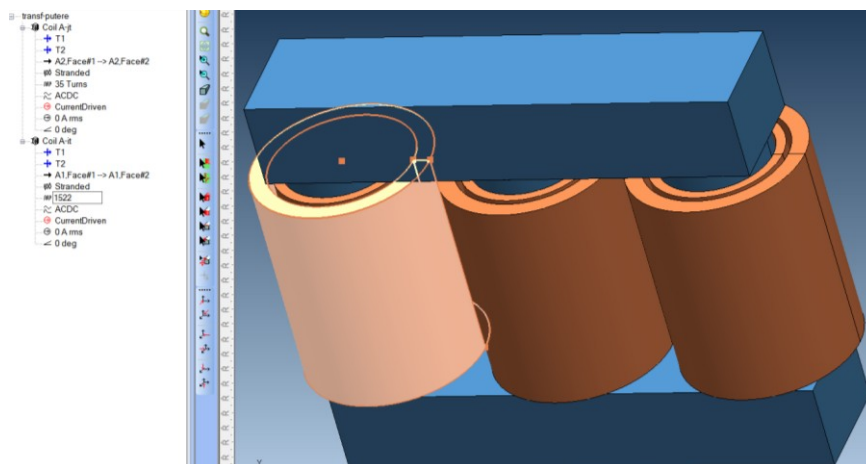


Fig. 7 Turns number of the windings establishment

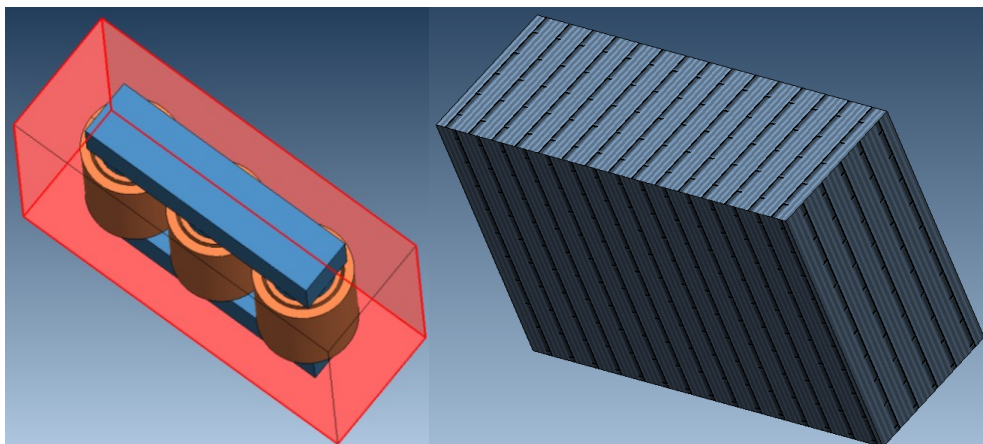


Fig. 8 Airbox and boundary condition

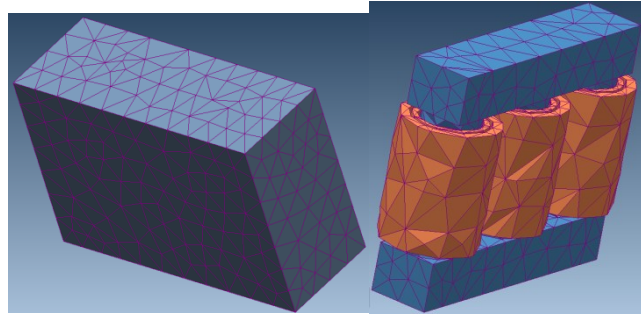


Fig. 9 Initial mesh; air box and transformer

3. MAGNETIZING AND LEAKAGE INDUCTANCES DETERMINATION

Leakage inductances of the transformer can be determined by finite elements analysis as described in the following. The imposed winding currents must satisfy the relation,

$$N_1 I_1 = -N_2 I_2, \quad (1)$$

where N_1 and N_2 are the turns number per phase for primary winding and secondary winding respectively, and I_1 and I_2 are the rms phase current of primary winding and secondary winding respectively. The primary and secondary phase (A-a, B-b and C-c) currents must be in relation,

$$I_{A,a} + I_{B,b} + I_{C,c} = 0, \quad (2)$$

A 3D magnetostatic analysis may be performed and the currents are in relation,

$$\frac{I_{A,a}}{2} = -I_{B,b} = -I_{C,c}, \quad (3)$$

Because the magnetic circuit is non-saturated, the phase leakage inductance (the short-circuit phase inductance) can be determined from the magnetic energy stored in the whole domain with relation,

$$L_{sc} = L_{\sigma A} + L'_{\sigma a} = \frac{4W}{3I_A^2}, \quad (4)$$

In this case, the separation of the primary leakage inductance from the secondary leakage can be performed considering them equal or in the same ratio with the resistances.

Also, since at short circuit regime each phase winding is linked only with its own magnetic flux, leakage inductance of each winding can be determined as the ratio between the magnetic flux and the winding current. In this case, all computed inductances are not in reported values.

The magnetizing inductance depends on the value of the supplied voltage. Determination of the magnetizing inductance can be achieved for any value of the supply voltage, proceeding as follows. The primary phase winding will be feed by voltage sources, being careful that winding resistance to be equal to that analytically calculated (or real one). If the harmonic analysis at rated frequency is performed, the phase currents will result (secondary being no load). The ratio between voltage and current of one phase represents the phase impedance. Since the phase resistance is known, one can determine the phase reactance and inductance respectively. The inductance determined in this way is the sum of the magnetizing inductance and leakage inductance of one phase.

The numerical model once performed, all the transformer characteristics can be determined by simulations, the transient regimes can be studied and also the influence of the winding connections on the no-load regime or unbalanced regime scan be studied.

4. CONCLUSIONS

The design program of three-phase power transformer is a useful tool in computer aided design of these devices. Based on the classic design, after establishing geometric configurations, the numerical model required to 3D finite element analysis can be achieved. Finite elements analysis program allows the simulation of all stationary or transient operating regimes encountered in the operation of power transformers, the accuracy of the results being dependent on the accuracy of the performed numerical model and the analysis conditions set by user. Finally, it must be specified that the interpretation of the numerically obtained results and then their usage for the determination of some parameters, or the transformer parameters variation in certain conditions, requires that the user knows very well the characteristic phenomena of the analysed device.

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