Abstract: - In this paper, an automated computer-based environment is proposed in order to reduce the transformer industrial cycle. This environment comprises a transformer study program, a software tool appropriate for the automation of design of transformer constructional drawings, a database management system for the bill of materials and an integrated transformer quality control system. After more than two years of the application of the proposed environment to a transformer manufacturing industry, a remarkable reduction of the industrial cycle has been achieved.

Key-Words: - Power Transformer, Industrial Cycle, Computer-Based Environment, Transformer Manufacturing, Transformer Study, Constructional Drawings, Materials Management, Quality Control.

1 Introduction
In an industrial plant, the time needed for the delivery of a product to the customer is of primary importance. Nowadays, since competition has become more and more aggressive [1], an important problem for the industry is the adaptation of the products to customer requirements. Particularly in an industrial environment dealing with power transformer manufacturing, almost for every new product, a new design is required. Thus, the creation of the appropriate tools for the reduction of the study-design-production time (industrial cycle) becomes crucial [2,3]. The industry considered is focused into a market with many customer orders of small quantities and different transformer specifications. Moreover, for a new transformer, the study-design time (SDT) is independent of the number of the total pieces produced. For small orders, the SDT significantly affects the total cost of the product, so in this case, its reduction is vital.

In this paper, suitable software systems have been developed so as to increase the competitiveness in the production of non-standard transformers. This software automates the whole process and data exchange among the relevant departments of the industry. Moreover, a customer satisfaction survey has been used to provide customer opinion for the product and service.

In Fig. 1, the information flow is shown from the time the customer requirements are known until the time the transformer is delivered to the customer. This figure illustrates all the intermediate steps of the industrial cycle, namely study, data sheets, drawings by computer-aided design (CAD), bill of materials (BOM), manufacturing software system (MSS), production and quality control (QC). The aim of the computer-based environment developed is to reduce this industrial cycle.

This paper is organized as follows: the transformer study program is presented in Section 2 and a method for the automation of design of constructional drawings is described in Section 3. The appropriate database management systems for BOM and for transformer quality control are described in Sections 4 and 5, respectively. The obtained results and conclusions are finally presented in Sections 6 and 7.

2 Transformer Study Program
The objectives of transformer design engineers are satisfaction of customer requirements, cost reduction, standardization and simplification of transformer construction and continuous adaptation to the new demands of the market [4,5]. To achieve these objectives, new materials are tested, whose physical and/or electrical properties are different from the ones previously used [6-8]. Additionally, due to continuous improvement of production lines, many tolerances used for transformer construction change [9,10]. Furthermore, the periodical evaluation of quality control historical data by transformer design engineers usually leads to re-estimation of design empirical factors (e.g., empirical number to be added to impedance, load loss increment factor, etc) [11].

In this paper, a transformer study program has been developed to optimize power transformer design. This software [12] concerns the optimization of transformers with the following technical characteristics:
Three-phase, oil-immersed power transformers.
Magnetic circuit of shell type and wound cores.
Foil, round wire, or rectangular wire technology for both low voltage (LV) and high voltage (HV) conductors.

The software requires 8 types of input parameters in order to make the transformer program as parametric as possible. The input parameters are:

- **Description variables** (e.g., rated power, rated LV and HV, frequency, material of LV and HV coil, LV and HV connection, etc)
- **Variables that rarely change** (e.g., LV and HV BIL, core space factor, turns direction space factor, short-circuit factor, etc)
- **Variables with default values** (e.g., LV and HV taps, guarantee value and tolerance for load loss, no-load loss and impedance, etc)
- **Cost variables** (e.g., cost per weight unit for LV and HV conductor, magnetic steel, oil, insulating paper, duct strips, corrugated panels, etc)
- **Optional variables** (e.g., variables that either can be calculated by the program or defined by the user)
- **Various parameters** (e.g., type of LV and HV conductor, number of LV and HV ducts, LV and HV maximum gradient, maximum ambient temperature, maximum winding temperature, etc)
- **Variables for conductor cross-section calculations** (LV and HV conductor cross-sections can be defined by the user or can be calculated using current density, or thermal short-circuit test)
- **Solution loop variables** (e.g., LV turns, width of core leg, height of core window, magnetic induction, LV and HV cross-section area).
A table sorted by cost price gives the results of the optimization. The technical and economical optimum solution is the one with the minimum cost. The transformer design engineer selects the technical and economical optimum solution calculated by the software. After that, the optimum solution is stored into two files.

The first file contains all the appropriate results for the production of transformer design data sheets. These data sheets (main materials, losses, impedance, core, LV coil, HV coil, tap changer, cooling calculation, active part, insulating materials, duct strips, oil and transformer test data sheet) are automatically generated using a Visual Basic program. An example of a typical HV coil data sheet is presented in Fig. 2. This data sheet shows turns per layer, position of ducts and insulating materials and arrangement of HV terminals.

The second file contains the data to be imported to the programs responsible for the automatic design of constructional drawings. These programs are described in Section 3.

3 Automation of Design of Constructional Drawings
Power transformer constructional drawings are designed using parameters evaluated during transformer design [13,14]. One completed transformer dossier should include the drawings for the non-standard parts, the part numbers for the standard parts and the bill of materials.

The non-standard parts are different for each transformer and depend on the specific transformer design parameters. The following parts are non-standard: active part, cover, frame, gasket, corrugated panel, tank, tank bottom and upper tank flange. From the non-standard parts, the following 3 bills of materials can be extracted: cover, frame and tank.

For the standard parts, only the part number and quantity should be included in the transformer dossier. Based on their unique part number, these parts can be either constructed or purchased.

The conventional way of producing the drawings of the non-standard parts is based on a computer-aided design program. In this application, the drawings are generated using AutoCAD. For the automation of design of constructional drawings, AutoLisp programs have been developed. The software is fully parametric using for each transformer the appropriate parameters provided by the transformer study program. The programs are executed within the AutoCAD environment using the “Transformer Applications” pull down menu as shown in Fig. 3. This pull down menu consists of three parts: the first one contains all the programs responsible for the automatic creation of drawings,
the second part includes programs for the creation of files with the list of blocks (objects) contained in the drawings, while the last part contains the appropriate blocks for the creation of transformer drawings. For example, executing the command “Cover” from the pull down menu, the user is prompted to select the file containing transformer design data. Afterwards, the program automatically creates the constructional drawing of cover, as shown in Fig. 3. Executing the programs of the second part of the “Transformer Applications” pull down menu, ASCII files are created, containing, for each block included in the drawing, its name, quantity and dimensions. These files are used as input in the BOM management system (Section 4). Using this method, the cover list, frame list and tank list files are generated.

4 Bill of Materials Management System

The manufacturing software system aims at having just the right quantity of stock available at the right time. It includes the following packages (Fig. 4):
- $S_1$, to find out commercial needs
- $S_2$, to find out manufacturing needs and stock resources
- $S_3$, to find out production portfolio resources and release work orders
- $S_4$, to find out supplier portfolio resources and release replenishment orders

![Fig 4: Manufacturing Software System (MSS).](image)

Materials requirement planning provided by $S_3$ is based on the bill of materials managed by $S_2$. The bill of materials is an analytical description of the structure of the product. BOM analyses the product in sub-products and each sub-product in standard components (purchased materials). Especially for the transformer, the sub-products are the tank, cover and frame.

The bill of materials management system is responsible for two procedures: first to create the BOM using data from the constructional drawings and second to feed the $S_2$ program with the BOM.

Transformer sub-products are listed into three different levels in BOM database. The transformer analysis is described in the general level, the sub-products analysis in the list level and all other components are described in the standard database (Fig. 5).

![Fig 5: Contents of BOM database.](image)

The standard database contains four tables:
- **Item Units**
  This table contains all the units used by the BOM application (kilogram, meter, etc).
- **Item Type**
  This table contains all types of components used by the BOM application (coil, angle, plate, etc).
- **Item Blocks**
  This table contains all blocks used by the AutoCAD to create the transformer.
- **Item Table**
  This table contains all the items from the MSS system.

![Fig 6: BOM main menu.](image)
The BOM management system has been developed using Microsoft Access. The first screen (Fig. 6) of the program allows the user to move through the different options of BOM. The options can be accessed through the buttons or the menu bar.

The application of this program has resulted in both the reduction of the time spent for the creation of BOM and the shortening of the time needed for entering the structure of a new product in the MSS.

5 Quality Control System

In order to collect, store and report the industrial measurements needed for transformer quality control, a database management system has been developed. This system is responsible for the quality control of cores, coils, transformer tanks and assembled transformers (final products). Moreover, this software manages quality control measurements for repairs (transformers in guarantee and out of guarantee). All tests defined by the international standards (routine, type and special tests) [15-18] are executed within this integrated quality control system.

The above multi-user software environment allows transmission of data among its various subsystems and produces results in tabular or graphical format. In Fig. 7, a typical record of no-load loss and load loss measurements of a three-phase transformer is shown. This report is provided when the “view” option in the subsystem of the three-phase transformers is selected.

6 Results

The results from the application of the automated computer-based environment are the shortening of the production cycle and the reduction of cost. More specifically, the industrial cycle is reduced from 3 months to 10 days for a new non-standard transformer. For a non-standard transformer with study and drawings already prepared, the industrial cycle is reduced to 5 days. The application of the new process offers high flexibility in production planning and control. This process strongly contributed to reduction of idle time. The latter, in combination with substantial decrease in the number of materials used has resulted in cost reduction (both direct variable cost and overheads). Cost reduction has given the industry the ability to sell at higher gross margins at competitive prices. In addition, customers’ appreciation for product quality and service are expressed.

Another benefit is the reduction of the time needed for entering the structure of a new product to the MSS. In the previous situation, more time was needed to control the BOM and more work to fill the void fields with suitable part numbers. The current practice allows elimination of these actions and the time has been reduced to half.
Application of the proposed environment has helped the users of the software to be more efficient, creative and flexible. Substantial training to the new working environment has given the users the ability not only to use the specific applications, but also to be acquainted with modern computer tools. The abilities offered by modern technology are highly exploited.

### 7 Conclusion

The development and application of an automated software environment for the reduction of transformer industrial cycle is presented. This software is created in order to reduce the time needed for transformer study, generation of data sheets, creation of drawings and bill of materials, transmission of data to MSS and automation of quality control measurements. After more than two years of the application of this system to a transformer manufacturing industry, reduction of the industrial cycle, improvement of customer satisfaction and cost reduction have been achieved.

### References:


