Development of the Educational Database on Three-Phase Power Factor Correctors

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Abstract

Three-phase power factor correctors exist in a wide variety. A large step in improving the education on this important field is accomplished by integrating a detailed cognitive part (all circuit structures, basic properties, operation) and a practical part (mathematical analysis, structural synthesis, design, simulation) into an Microsoft © Access® database environment. The data base exhibits the opportunity to select by query the corresponding topologies and circuits of pre-defined properties, and to have full access to the original publications of all included circuits and the variations and improvements. Selecting the most suitable circuit for a specific demand is supported by integrating standard and advanced power quality factors and numerical parameters on cost and performance. The data base allows a favourable overview on power factor correction circuits during learning and also for developers of industrial circuits.

Basic requirements of the process of power electronics development

The modern world is characterised by an increase of competition in all markets. Companies as well as universities are forced to search and create competitive advantages which go beyond standard rationalisation processes. With reference to education in the area of power electronics, an optimised preparation of the coming young experts which are presently students is definitely necessary. With completion of their specific studies, the young researchers and engineers must be capable to create, design and realise competitive power electronics units. In the first educational detail, the task to be carried out is that students shall master a methodological process of designing optimum power converter systems including also the economical part, now with the help of new information technologies. Special emphasis is given to the most crucial point: It is the initial stage of design. Mistakes done here that have to be corrected afterwards result in extremely high costs, and it might be very difficult or even impossible to achieve a full correction within restricted time frames (Fig. 1) because you might have to start again at the very beginning.

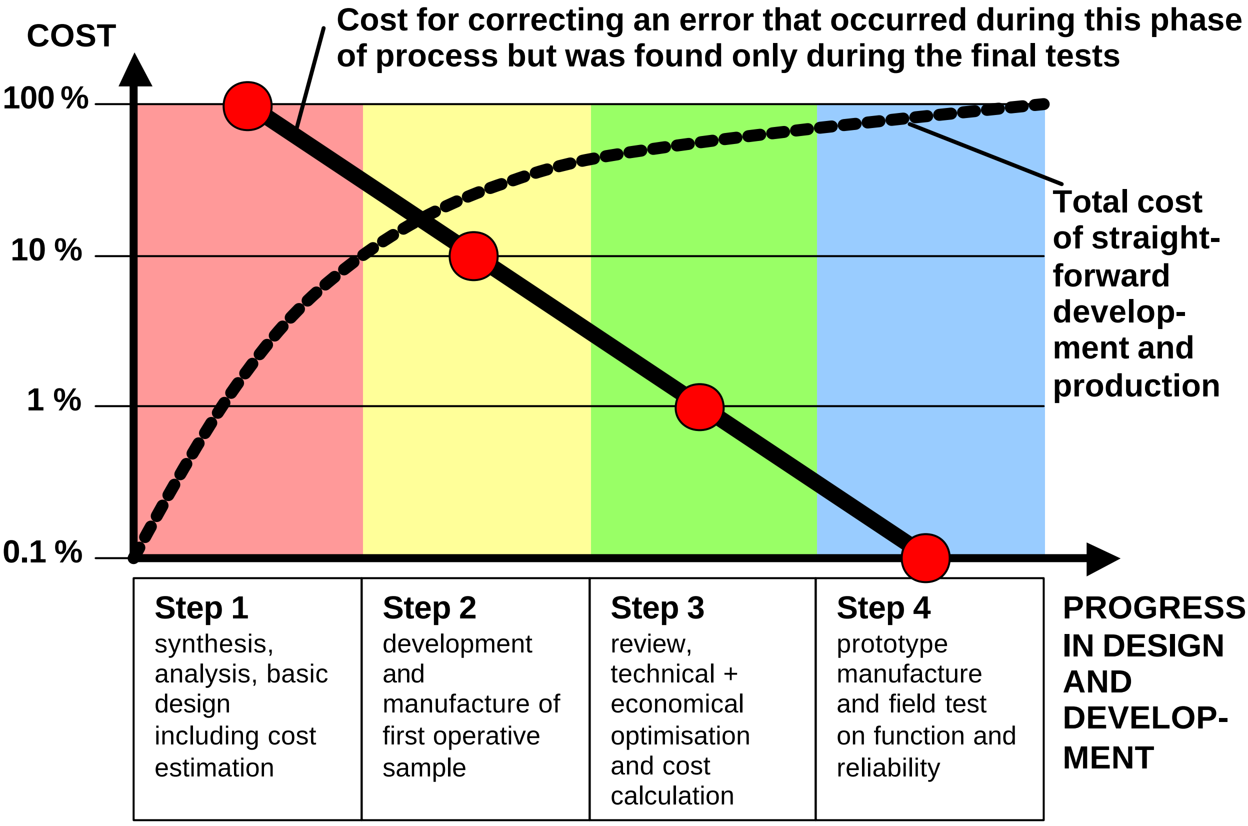

Fig. 1: Product development process and cost issues on development and errors

In a simplified approach, four steps are identified that are prior to the actual series production. The first step includes basic definition of demands, synthesis ideas (comparing and combining the different opportunities to solve the given problem), analysis of special properties of the mentioned solution opportunities), a first sketch of dimensioning and – very important – a rough cost estimation. The second step with the actual development requires the first and fully relies on the results of the first step. If the first step is not done with extreme care all following costly work (see Fig. 1) might be useless if the troubles are recognised maybe only during the field tests in the forth step.

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The problem of designing any power electronics unit or device for the transformation respectively control of electric energy begins with a stage of structural synthesis of this device. As a first result, a principle of transformation of electric energy at a level of a class of the converter and its basic circuit should be determined. This design stage in the power electronics circuits of today is - as a matter of fact – truly heuristic, based on experience and technical intuition of the expert. (However, it takes some years of work in this area to become an expert.) Works on formalisation of the process of synthesis of circuits may be carried out on the basis of matrix-topological methods, tensor method, fuzzy sets. However, operational methods [1] for certain types of power electronics converters and the opportunities of these methods for the synthesis of these converters are successfully applied, too.

Synthesis and analysis process

Beginning with synthesis, the expert should have well structured information on all possible alternative decisions with sufficient characteristics for each decision. These characteristics of structures of converters should include the utmost set of parameters which may be present as a whole or in part clearly defining the requirements for the converter design. Based on this, the problem of informal synthesis of converter structure will be reduced to taking a choice out of several alternative variants. This is followed by a formal (mathematical) analysis of these variants for quantitative comparison and acceptance of the final decision on structure of the converter.

During this phase, financial aspects are covered as an expenditure and cost comparison is accomplished. However, the cost issues should not be over-valued – a product with poor operation may be cheap but will not be bought if not working properly. The main target must be fulfilling all technical and functional demands, but with a keen eye on cost-effective solutions (maximum performance-per-cost value).

The quality ensuring process of documenting each decision in a fully reproducible way inside a precisely defined procedure is completely accomplished.

Preparation and realisation of project

The whole task is realised inside a database. This database is established first with educational character for electronic power converters of a class of three-phase power factor correctors. The choice of rectifiers as first object for realisation of this work is connected to their wide circulation, the most numerous set of their structures among other classes of power converters, and their importance in daily life due to new directives concerning harmonics and reactive power of a majority of standard loads. The opportunity of transforming some subclasses of this class of converters (rectifiers) into other classes of power converters, such as inverters (considered as the inverted rectifiers), direct converters of frequency (considered as the reversing rectifiers in a mode of a periodic reversal) also is taken into account. Besides that, according to new national and international standards on quality of consumption of electric energy, the realisation of such structures of rectifiers which provide correction of their input power factor in comparison with classical rectifiers is definitely required.

Some years ago a simpler database in hard copy form (a book) on weight - dimensional parameters of components of power converters was produced [1]. The new development is focused on the creation of an electronic database on all parameters of converters. This allows an interactive and thorough solution, including the opportunity to update and improve the database constantly. The database program Microsoft Access ® is selected because of its general availability.

Data base development process

With reference to power factor correction converters, some tens of different known structures of power factor correctors are listed and a regular procedure for the selection of suitable alternative designs is defined. On this subset of structures the formal comparison and decision making about the most advantageous variant is carried out, in order to meet every basic requirement and most of the demands of a special design assignment.

Table I: Static view on first draft of data base fields

Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10	Field 11
Scheme of PFC	Key-words	Authors	Title of publication; conference, town, country	Year of pub-lica-tion	Type of PFC	Signifi-cance of voltage co-efficient	THD of current	ITHD (integral coeff. of harm. of current)	DTHD (differen-tial coeff. of harm. of current)	Character of input current (continuous or discont.)
Fig. 1	step-up; recti-fier	ERTL, Hans, KOLAR, Johann	Overview on three-phase rectifiers for high loads on the line	1999	step-up	....	....	....	....	....
Fig. 2	....	....	....	....	....	....	....	....	....	....

The data base represents the table as an array of lines and columns (Table I). Each column specifies a certain parameter of the circuit on which the further comparison of circuits is conducted. The first fields (field 1 –6) give information on circuit schematic(reference to specific figure of schematic), keywords, publication details, year of publication and the basic type of PFC circuit (like step-up, step-down, forward, ...). With these parameters it is possible to allocate the basic properties. The next parameters describe the character of input current (field 7 - field 12).

For an efficient work in a data base, numerical expressions have to describe the properties rather than a text. Thus it is necessary to use also advanced characterisation coefficients in the data base, such as “integral total harmonic distortion” ITHD and “ differential total harmonic distortion” DTHD. They are derived from current harmonic factors [6]:

$$\overline{K}_{h.c.} = \sqrt{\sum_{k=2}^{\infty}\left(\frac{I_{(k)}}{k \cdot I_{(1)}}\right)^2} \qquad \text{Integral total harmonic distortion} \qquad \text{ITHD} \qquad (1)$$

$$\hat{K}_{h.c.} = \sqrt{\sum_{k=2}^{\infty}\left(k\,\frac{I_{(k)}}{I_{(1)}}\right)^2} \qquad \text{Differential total harmonic distortion} \qquad \text{DTHD} \qquad (2)$$

Additional parameters describe the character of the output voltage (field 13 – field 15); some further parameters describe the character of influence on grid voltage (field 16 - field 18) [6]; and other parameters describe converter components like semiconductor devices, transformers, filters and the converter as a whole (field 19 - field 27).

Each line directly carries the full information about the specific type of the three-phase PFC (power factor correctors), respectively the file name where to find it if a complex information is stored. The data base totals already more than 60 circuits of three-phase converters and continues to replenish. Both known and applied circuits as well as new, still insufficiently studied circuits of three-phase PFC are collected. Each circuit given in the table may be overlooked with the help of a thorough and unified description written in Microsoft Word ®. For this purpose, it is necessary to click the mouse twice in column "Circuits" of the appropriate line of the table. A window with Microsoft Word ® will open and the circuit diagram and its name will be submitted. In a similar way, when opening a cell in column "Model", it is possible to receive the image of the mathematical model of the PFC constructed in the universal program of modelling Pargraph-Parus [1] in a new window. The mathematical model is used for checking conformity of parameters of quality of the chosen circuit to requirements of the design assignment once the parameters of components of the circuit are designed.

As an example, a part of one line from the database (with the first eleven fields shown out of 30 available). For simplicity reasons of explanation, the database is drawn in Table II and Table III as a static table (by taking a screen shot of the program during operation).

According to the international character of this co-operation project, the results shall be available in several languages, finally. Translation is performed easily. Table II shows the Russian version in design state (including some fields for preliminary comments). [5]

Table II: Preliminary version of database (screen shot) in design state (Russian language)

Поле1	Схемы	Поле2	Поле3	Поле4	Статья	Поле5	Поле6	Поле7	Поле8	Поле9	Поле10	Поле11
Схема выпрямителя		Ключевые слова	Авторы	Источник		Год издания	Тип выпрямителя	Значение коэффициента мощности	Коэффициент несинусоидальности тока	Интегральный коэффициент гармоник тока	Дифференциальный коэффициент гармоник тока	Характер входного тока
Рис.1.	Документ Microsoft Word	Повышающий выпрямитель	Ханс Ертл (Hans Ertl), В.Колар (W.Kolar)	Обзор трехфазных выпрямительных систем с низкими нагрузками на сеть		1999	Повышающий					

Work Details

Some review on the work accomplished in the first part of the project led to an advanced version (Table III) now finally in English language.

Table III: Advanced version of data base (11 fields of 30 shown, only line 1 (code = 1) out of about 60)

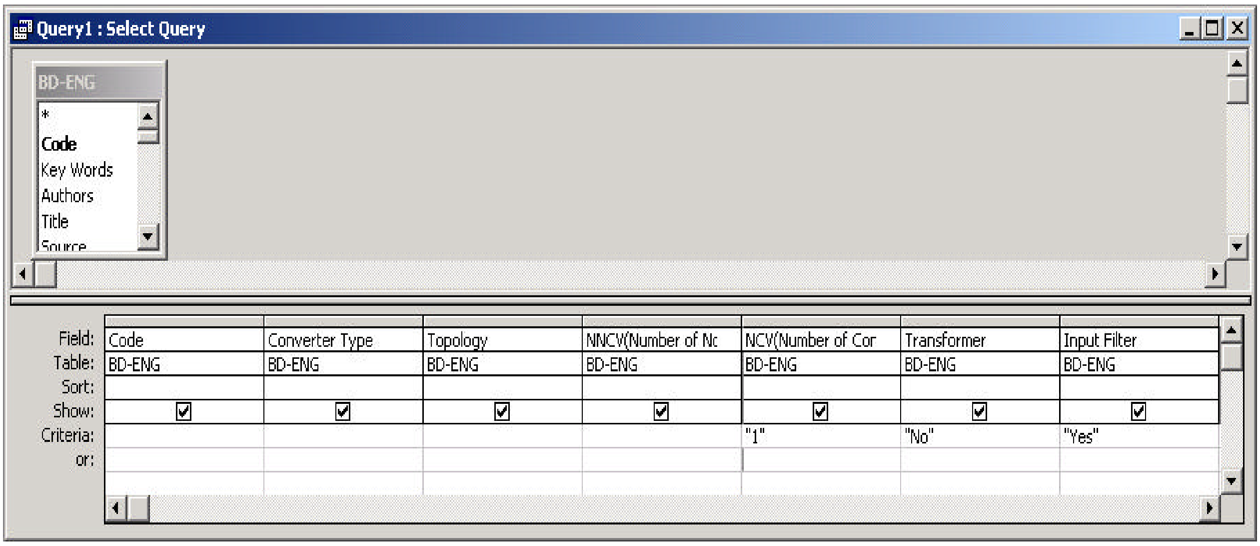
Code	Key Words	Authors	Title	Source	Year	Converter Type	Topology	Original	Model	PF(Power factor)
1	Boost	Hans Ertl, Johann W.Kolar	Status of the Techniques of Three-Phase Rectifier Systems with Low Effects on the Mains	21st INTELEC, June 6-9, 1999, Copenhagen, Denmark	1999	Boost	Microsoft Word Document	Пакет	Пакет	0.967

First of all, a search in this database is carried out based on the information of field 2 ("Key words") in which key words in English (and Russian for the Russian version Access) language are written.

In the field “Topology” one can find the reference to the specific document (e.g. by paper number of the corresponding conference), to the data file (e.g. pdf document, table /circuit schematic number). Such a link is set up and the corresponding specific information can be found, but how to evaluate against other solutions within the data base concept? Precise numbers describing the performance in detail, numbers for the complexity of the circuit and the effort in components must be inserted. When the final data base is completed we need a tool to work with the extremely high amount of numerical data and non-numerical data in an efficient way.

The data base program directly includes this tool: Query (Table IV).

Table IV: “Query” function of Access ® used for valuation and comparison tool, here for fulfilling defined requirements respectively properties.



Inquiries are used for viewing by various ways. In Microsoft Access, there are some types of inquiries. The inquiry about sample is the most frequently used type of inquiry. Inquiries of this type return the data from one or several tables and display them as a table, yielding records which can be updated (with some restrictions). In a developed database, inquiries about sample can be used e.g. asking for a group of converters on certain values of power parameters. For example, it is possible to select circuits only with a value of power factor greater than 0.97. Additionally, the conditions of selection may be more than one. To create an inquiry it is necessary to fill in 6 lines in a screen displayed in table IV.

In the given inquiry we choose circuits fulfilling the following four requirements:
- One controlled semiconductor device
- A minimum of diodes
- Without transformer
- Presence of input filter.

The table of inquiry for this case is the example shown in table IV. The result is displayed in table V.

Table V: Result of "Query" of requirements and properties as demanded in table IV.

Query1 : Select Query

Code	Converter Type	Topology	NNCV	NCV	Transformer	Input Filter
1	Boost	Document	7	1	No	Yes
2	Boost-Buck	Document	7	1	No	Yes
5	Boost-Buck	Document	7	1	No	Yes
6	Boost-Buck	Document	7	1	No	Yes
7		Document	7	1	No	Yes
8	Quasi-resonant	Document	7	1	No	Yes
9	Multi-resonant	Document	7	1	No	Yes
(AutoNumber)						

Record: 8 of 8

NNCV number of non-controlled valves of circuit (= diodes)
NCV number of CONTROLLED valves of circuit (= MOSFET, IGBT)

We see in table V that seven circuits were found satisfying all conditions of our selection.

Data base system as education tool

The given data base structure can also act as a promising education tool. Starting from a small data base (just holding the very basic designs, having a high number of intentionally created "white spots") it can be enlarged by introducing plentiful other variants. For that, it is necessary that students study in detail reports on those variants, analyse them and make own calculations, simulations and considerations to fill the data base with the necessary information. Any student work of "learning by doing" like this produces good results generally.

It is evident that creating bases of knowledge - being a basis of any expert system for designing power converters - represents a very difficult problem and demanding task. When reaching an advanced state, the created database may be used intensively in education in the form of rules of a kind: If... Then.… Such a form of inquiries in a database are under construction now. The final version will provide a detailed learning aid for students, allowing a knowledge-based choice of PFC circuits, and an expert system for designers, finally.

Methods of an intensification of the training process in the discipline Basics of Power Electronics" with the help of the above-stated databases and knowledge have found great approval at students. Moreover, performing this work has involved a vanguard part of students in the procedure of development of such results of information and knowledge (two students are co-authors of this report).

Conclusion and future work

The data base system presented proved to be a valuable part in modern education of power electronics. The described work is executed within the framework of the concept of a computerisation of training of a course on "Basis of Power Electronics" [2]. A next step shall be the integration of a corresponding lab [3]. Animations in the description of the circuits can be included in some advanced version [4],[5]. Here we go the way of introducing also animations into the education tools.

The data base shall be living thing, all students and expert designers as well as university staff researchers are asked to increase the data base with their experience and knowledge on further advances (realised circuits and new proposals at conferences). Herewith the data base should emerge into a multi-author state-of-the-art expert system.

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