

REQUIREMENT ANALYSIS FOR E-CAD VARIANT MODULES

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Abstract

In the area of computer aided design for mechanical engineering (MCAD), one of the most important innovations of the last decade has been the introduction of parametric modeling. In this paper parametric modeling will be extended to the field of computer aided design for electrical engineering (ECAD). Here, parametric modeling is employed to realize new kinds of variational design and will release a tremendous potential of cost and time reduction, going along with a considerable improvement of quality. Hence, this technique can be considered as a significant base technology for next generation ECAD systems.

It has been investigated in detail what variational design means in the context of electrical engineering, which functionality one really needs, as well as what has to be regarded in developing and building up full automatic variant modules. To get comprehensive and precise information what exactly users demand, we have established a special working group of experts from CAD system developers, CAD users and research fellows.

As a result, we achieved a requirement analysis for ECAD specific automatic variant modules from a rather practical point of view that is summarized in this paper.

Introduction

Contemporary CAD environments for electrical engineering are usually based on first or second generation ECAD systems. Typical for those generations of ECAD systems was the insufficient support of the entire engineering process. Besides that, the paradigm of object-oriented programming had been rejected in those days in contrast to other paradigms. Error-prone styles of programming together with insufficiently organized data structures led to the situation that in recent years improvements and extensions of those systems became harder and harder to realize. The expense of maintenance and servicing soon exceeded the gained benefits by far. Relating to their insufficient efficiency and their monolithic architecture those systems have exceeded their zenith and are going to be replaced by a new generation [1].

From a users point of view, one of the most important drawbacks of contemporary ECAD systems is the fact that existing drawings cannot be reused in an efficient manner. In view of continuously increasing pressure on competition, the market demands products that can be designed in shorter times, with reduced costs, simultaneously with an improvement of quality. Hence, one significant point of scope that has to be taken care of at the development of next generation ECAD systems is that they fulfill the requirement for existing constructions to be reusable in an efficient manner.

Furthermore, future design environments have to support intelligent approaches for realizing design modifications as well as highly sophisticated techniques for practicing variational design in an efficient, i.e. fully automatic manner. As a matter of fact, the introduction of variational design into electrical engineering will release a tremendous potential of cost and time reduction.

Philosophy of Development

In order to develop a variant module that will fulfill future market requirements to a high degree, the first thing to be done was to determine these severe requirements in detail. For this reason, a special working group consisting of experts from research facilities, experienced design engineers

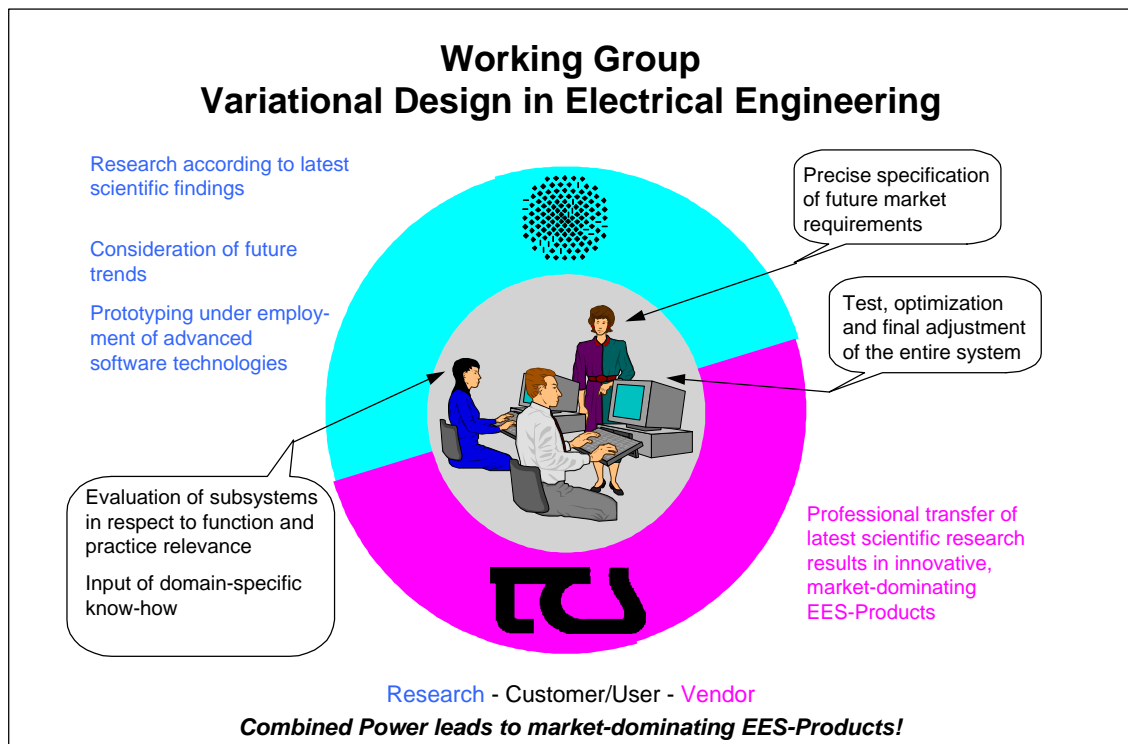


Figure 1: Establishment of a special working group to realize an optimized developing process

from several companies and representatives from software industry was established. The primary good for CAD systems is to support their users. Hence, we wanted explicitly the users to bring in their specialized knowledge gained in many years of vocational experience into the developing process. Eventually, nobody else is more able to rate a CAD system in relation to practice relevance and application specific intuitive handling than experienced CAD users whose daily job is to work with these systems. Because researchers and software engineers usually have a rather special point of view concerning user requirements and desires, those topics should be discussed together to determine all the aspects that have to be considered in different states of system development later on. The more points of view are taken into account, the better the developing process can be specified and organized.

In the past, CAD systems were usually developed either by research institutes or by software companies in an ownstanding manner. This resulted in an increased number of isolated applications. Universities and other research institutes mostly concentrated their activities to analyzing future trends and doing intensive basic research. Furthermore, they sometimes developed innovative software prototypes that often lacked practice relevance, i.e. they were hardly realizable within commercial CAD/CAM environments, or on the other hand were as progressive, that market was

not even mature for such advanced technologies. Other kinds of problems occurred on the part of software companies: In spite of intensively considering practice relevance and realizability, the continuously decreasing time to market (new system releases had to be presented often within the time from one trade fair to another) enforced the software companies to bring up systems, that either were of a short market life cycle and/or were hardly to maintain in the end.

Provided that CAD users transfer their requirements and desires in terms of detailed functional specifications and style guides to their collaborating software companies and research institutes, things can be analyzed in common to intend appropriate concepts and solutions for the relating problems. The acquirement of essential technical foundations as well as the development of prototypic systems and subsystems, respectively, should still be on the researchers part. However, there should be a continuously close coordination with software engineers who later on have to transfer the latest scientific research results in professional, innovative, and commercial electrical engineering solution (EES) products.

Whenever so-called milestones have been reached, i.e. after prototypes of sub-systems have been completed or solutions for special parts of the entire problem have been found, the users should intensively be involved into the developing process again. A rather practical way to do this is to place prototype systems at the users disposal as soon as a new release of such a prototype has been completed. Then the users are responsible for detecting any deficiencies and for suggesting improvements. By actively engaging the users this way, it is possible to integrate practical know-how and rules of thumb gained in many years of vocational experience into the ongoing system development process. In cooperation, the participating companies and institutes can check their previous development strategies and their future requirements to determine a non empty domain of overlapping tasks for which corresponding concepts and solutions can be acquired together. Furthermore, in the course of the developing process, single subsystems as well as finally the entire system accurately have to be checked up and rated by the CAD users under practice relevant conditions and sometimes even beyond that. Recapulating, our philosophy of system developing is to combine the power of research institutes, software developing companies and last but not least experienced CAD users to achieve superior solutions that will meet the requirements for the future as close as possible.

Motivation

Often, several electrical constructions differ from each other only in a few details. Unfortunately, in contemporary ECAD systems existing drawings can only be reused to an insufficient extent. Today, the word "reusability" confines merely to copying an existing drawing and altering this copy in a manual manner. Furthermore, in conventional ECAD systems modified constructions or variants of constructions, respectively, have to be stored completely. Because of the complexity of today's industrial constructions, this quickly results in a tremendous demand for memory capacity and hence in a significant cost factor. Summarized, conventional ECAD systems have the following drawbacks:

- The main application field is often limited to the drawing of ladder diagrams.
- Modifications are realized in a manual manner, sheet by sheet.
- Reusability is restricted to copying and altering the original.
- Each variant of a construction has to be stored completely.
- Altered constructions are error-prone and lead to loss of quality.

As already mentioned, the technology of variational design represents one of the most promising approaches for eliminating the drawbacks stated above. In electrical constructions, designed within a variant module based ECAD system, all kinds of properties and technical data, as well as the representation of the whole documentation should be described and controlled by variable

parameters. Herein, each type or kind of variant bears some specific characteristics to be parameterized. In each case, this parametrisation should take place by editing the desired values in corresponding attribute tables. Strictly speaking, any modification of just one single parameter, no matter what kind of variant is regarded, results in a specific variant of the construction being under revision. The evaluation of a special variant takes place after concrete attribute values for the related parameters have been determined and fed in. Hence, to modify an existing design it is not necessary to modify the model itself. Just the attributes related to the intended modification have to be adjusted. Parametric driven ECAD systems are also superior to non parametric systems in the way constructions and variants of constructions are stored and managed. In non parametric systems each variant has to be stored completely as an absolutely independent project. However, in parametric driven systems, only design patterns are stored completely. Different attribute tables, e.g. stored as ASCII files, can be loaded and combined with a special design pattern by using a corresponding reference (pointer) to the desired pattern. To get a variant of an existing construction according to the designers intent, the corresponding design pattern is evaluated using the actual loaded or entered parameter values. The benefit is, that this way only one design pattern is needed and as many parameter tables as required can be stored, loaded, and used for evaluating different variants. In this way, storage capacity can be reduced enormously, at the price of an increased calculation time for retrieval. It also is possible to use an existing variant as a starting point for another variant, so we are able to create variants of variants.

In the field of mechanical computer aided design (MCAD), one of the most important innovations of the last decade has been the introduction of variational design which has been based on classical parametric modeling in that context [2]. Until today parametric modeling has been examined in detail, well developed and very successfully been employed in many MCAD environments. In industrial practice, above all in middle-sized and small enterprises, generally the areas of mechanical and electrical engineering are equally involved in the entire process from design to manufacture. Often, all engineering activities are realized within one company. Although the technology of variational design cannot be transferred from mechanical to electrical engineering without further ado, in principle it may and will be of the same potential of benefit for the area of electrical engineering in future as it has been for its present day's areas of application.

General Requirements

In order to fulfill the main objectives of variant modules for ECAD environments and to develop novel tools for facilitating various tasks of the mentioned application fields, some general requirements shall be stated here which are to be met by future ECAD variant modules:

- *Classification of variants*
Variants can be created in different logical granularity levels, e.g. an entity may be a project, a component, a sheet, a design primitive and so on. A variant module should be subdivided into sub-modules dealing with the specific properties and functionalities of each kind of variant according to the classification that has to be found.
- *Data management*
Variants shall be stored without redundancies. This means that a variant should be stored in a way, that only a reference to the original as well as explicitly those parts or data, respectively, that differ from the original have to be stored.
- *Retrieval*
Efficient mechanisms and intelligent methods to search for former design results are needed. Often, the parameters of a query are incomplete and vague. In this case, the part that is most similar to that described in the query has to be found to be reused as a pattern for another variant.

- *Modeling tool*
A modular and powerful modeling tool is necessary that allows to support complex objects and abstract data types. An object-oriented representation of variants seems to be an appropriate method for that.
- *Different types of constraints*
Besides the well known geometrical constraints, mainly logical constraints are under scope in electrical engineering. Logical constraints are needed to describe technical relations between different parts or different kinds of variants as well as to support inference chains. Furthermore, interdisciplinary constraints have to be dealt with in respect to describe interdisciplinary relations, for instance between electrical and mechanical engineering. One example for this would be an automatic mechanical design of cabin layout according to a corresponding electrical ladder diagram. It is also necessary to realize some kind of user defined constraints.
- *Modeling of dependencies*
Additional to design objects, dependencies between them have to be visualized by a graphical user interface in order to be comprehensible to the users. Dependencies are also subject of design, i.e. users need to have mechanisms to edit, to delete and to insert them. Different editors for different types of variants are required. Furthermore, an interaction with the user should be possible whenever the system is not well constrained, i.e. over or underconstrained.
- *Support of parametric data models*
To realize efficient methods for modifying and reusing existing designs, the general concept of parametric modeling should be supported as a base technology.
- *Advanced database management*
Within a variant module there is an extensive communication with special databases for different kinds of variants (e.g. standardized components), the main systems underlying product data base, mostly an EDM system, and also - due to the advanced and interdisciplinary constraint modeling - an active knowledge base and its mechanisms. So a rather complicated variant management systems is required to handle all the data flow within the variant module, the databases and the whole ECAD system.
- *Standardized Exchange of product data with other CAD systems*
From a users point of view, one of the most important tasks is to realize standardized methods for the exchange of product data with other systems. This means, that concepts such as STEP have to be extended to parametric modeling in general and to parametric modeling in the context of electrical engineering in particular.
- *Integration into the CAD reference model*
Future ECAD systems will be based on an architecture known as CAD reference model [3]. This architecture foresees a special part to integrate additional external systems into the underlying electrical engineering environment. So the variant modules being under scope should be designed to be external systems within the CAD reference module architecture.
- *Application programming interface*
Sometimes, users need to adjust a variant module according to their specific requirements. An example for this would be the implementation of user defined constraints which cannot be made available in an universally valid manner. For this reason, an API for realizing extensions and specifications should be foreseen.

Application Fields

By introducing parametric modeling into the area of electrical engineering, many problems in different application fields can be solved most efficiently in future. One of those problems, for instance, is the efficient construction of electrical product families. Different product variants belonging to one special product family are usually of the same functionality but different in regard

to equipment or technical settings. For example, power supplies for cranes have to be employed for very different loads. Machines that have to be developed for the employment in different countries of the world, accomplishing identical functionality, are another example for product families that arises in the context of a global market competition.

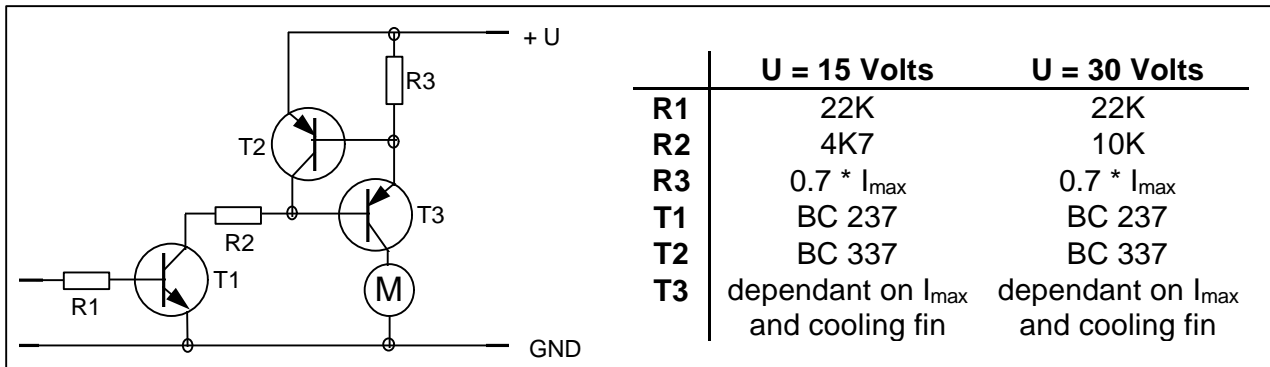


Figure 2: Two instances of a parameterized product family of a control unit for DC motors

Problems of that nature can be solved in an efficient manner by reusing existing constructions. From those projects, suitable groups of functional independent units or components can be chosen and integrated into a new project to form a basis for the desired construction or variant of a product family, respectively. Special tools are required to select suitable projects, functional independent units and components,. For instance, the so-called configurators described in detail in [4] are being employed with great success in many companies.

Probably the most important application field in the area of ECAD specific parametric modeling is that of component-based assembly modeling. In view of the continuing standardization that occurs in the field of electrical engineering, constructions and electrical plants are more and more decomposed into independent modules [4]. In future, electrical constructions will be composed using suitable, standardized, normalized, and ISO 9000 certificated components, similar to the technique called "box of bricks" which has been introduced in the area of mechanical engineering a few years ago. For the time being, the elements used to compose a component are considered from

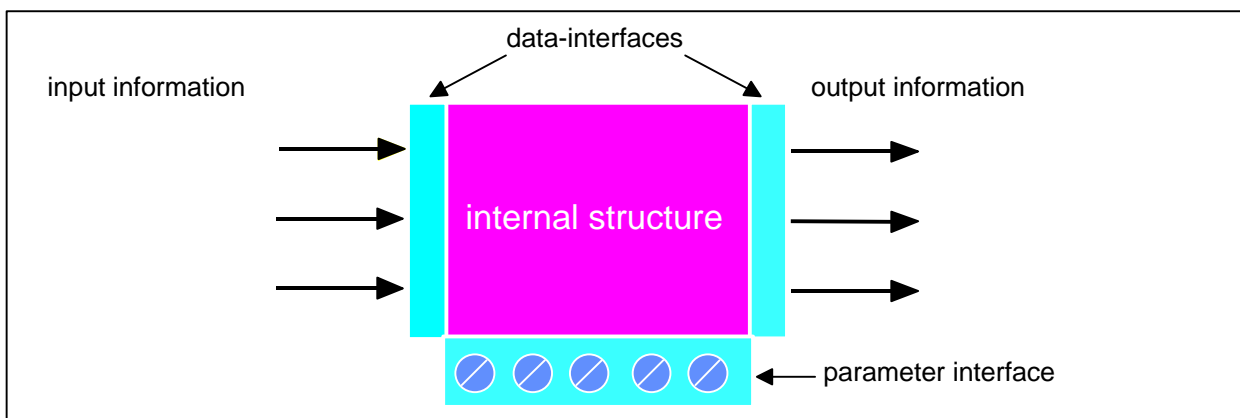


Figure 3: Abstract representation of an electrical component

an abstract point of view and will be called "black boxes" in the following. Such a "black box" consists of a description of the components internal structure, input and output interfaces as well as a specific interface for parameters (cf. figure 3).

Input and output interfaces are used to adapt the components to their relevant operating options. For instance, a components currency, power, or frequency can be controlled in that manner. The above mentioned parameter interface is used to adapt the components technical and functional properties according to the designers specific requirements.

Let us now consider a simple situation: A plant has been developed for the German market. The technical data concerning the power supply are 220V, 50Hz. The same plant has to be manufactured for the American market, that means the power supply has to be changed to 110V, 60Hz. In conventional systems the plants technical data would have to be re-calculated completely according to the changed operating options. Also the representation of the construction, that means the drawing, as well as the whole documentation would have to be adapted in a manual manner. However, employing a variant module-based ECAD system, all these modifications can be limited to adjusting only one attribute of the corresponding operation option variant. After that, all the resulting graphical and logical adaptations are carried out automatically by the system. All the components which technical data have to be recalculated are shown to the user by the system. One opportunity for recalculating all engineering data automatically would be to employ expert system technology and active knowledge bases. In that way configurable components can be provided with some kind of intelligence. Relative to the constructions representation and documentation even special national norms or enterprise-specific standards can be activated by adjusting only one parameter. The drawing as well as the whole documentation are automatically re-evaluated according to the selected norm or standard, respectively. In this context one speaks of so-called standard variants.

Examples

In this chapter some concrete examples taken from [5] are presented to show further possible application fields and requirements for the employment of variational design from an users point of view:

- *Different voltage*
There exists a machine which works well in Germany and now has to be redesigned for an US customer. This implies a variation in voltage and frequency from 220V / 50Hz to 110V / 60Hz.
- *Different power consumption*
There exists a machine which almost does the job of the new desired design. However, if the parts that need to be moved by the machine become heavier, the used motors need to be exchanged by more powerful ones. Of course, this influences other parts of the main circuit, such as circuit breakers and fuses.
- *Project parameters*
Typically, constructions depend on certain numbers of project specific parameters. Examples of such parameters are the number of floors within an elevator design, or the number of printing stations in the design of printing machines.
- *Different manufacturer of components*
In practice, many companies demand the use of components of a specific manufacturer. In the re-use of a machine design the components may have to be exchanged by components of another manufacturer. As long as there are equivalent components from both manufacturers this might be performed just as a change in the part list. However, if some dimensions differ, it could influence many other parts of the design, even the control cabinet layout. If there is no direct equivalent of the second manufacturer, there will be the need to redesign parts of the construction.
- *Different security standards*
Depending on the country a machine is to be operated, the particular country's security standards have to be met. This can obviously affect a design in a rather complex way.
- *Different documentation type*
There are local differences in the documentation of electrical designs, for instance horizontal vs. vertical control flow. Therefore, one design can lead to completely different sets of documentation.

- *Different naming*

There exist a number of different ways to designate components. Often, users demand one particular way of item designation. This implies a completely different name set for components which has to be consistent with the overall design.

This enumeration just gives a glance how variational design needs to be viewed within an ECAD environment. In practice, there is even the need of arbitrary combinations of the mentioned variants. As an example, the variation of an elevator, originally designed for the German market, would imply the application of virtually all of the above mentioned variational design aspects for use in buildings in the USA.

Advantages

Let us now throw some light on the advantages resulting from the integration of a variant module into an ECAD-system:

The meaning of reusability within a variant module is not restricted to simple copying in the usual sense. By copying components of a wiring diagram also the components corresponding logical data and information which are laying behind the graphics are copied. A new design can be created simply by altering the attribute values of an existing one. In that way, independent working ladder diagrams can be created from existing standardized schematics. Furthermore, variants of a product family can be created efficiently in that manner. As well, it is not necessary to store all variants of a product family completely. It is sufficient to store one design pattern together with a corresponding attribute table for each special variant desired. Instead of storing the whole attribute table, sometimes it may be more sophisticated to store just that data, the design pattern and the variant or a variant and another variant, respectively, are different in. This leads to a considerable saving of memory resources.

Often, in an early stage of design, not all the data needed is known. By employing parametric based design models designers are enabled to create a rudimentary design concept that later, for instance after an extended analysis of the suggested concept, can be specified with the correct parameters. The design time can be reduced once more in a considerable manner by using parameterized components. In this context the term „component“ stands for a combination of design parts, keeping the graphical representation and the technological description, as well as the documentation of all the parts integrated within the component. Each component represents a specific functionality of the whole construction.

Within the variant module, constraints can be defined between electrical devices or different variants, respectively, by parameters. These constraints are necessary to make modifications and adaptations easier to manage. Whenever a modification of parameters occurs, all parameter values of devices and components related to the modified parameters are adapted automatically. Herein the defined constraints have to be met. By using this approach, logical design errors as an inference of modifications that have been carried out can be excluded extensively.

One important side effect going along with variational design relates to marketing productivity. As mentioned earlier, machines and plants can be combined of components belonging to a box of bricks. This is done by special configurators. From a marketing point of view this leads to the following situation: A customers demand can be entered into a special configurator. Because of the availability of the documentation created and updated interactively, it is possible to calculate rough plant projections based on existing constructions similar to a planned project. In this way approximated offers can be submitted to customers within minutes, causing almost no costs. Summarized, a variant module bears the following substantial advantages:

- Efficient reusability of existing drawings
- Efficient construction of product families
- Differences between variants are comprehensible
- Compact storage of construction variants
- Simple sketching of constructions
- Efficient modifications by using parameters
- Design by components
- Determination of the effects of design decisions
- Improvement of quality
- Improvement in marketing productivity

Conclusions

During the past twelve month we had lots of discussions with CAD experts from different research facilities, with many ECAD system users from various companies as well as with professional software engineers and system vendors. They all have told us about their future requirements, practical and workflow relevant details that have to be taken care of as well as ECAD specific Know-how from different points of view they have gained in many years of vocational experience. As a result, we now do know in detail what has to be done to realize a variant module for electrical engineering environments. A comprehensive requirement analysis of about fifty pages in length has been drawn up and a system architecture has been developed. Furthermore, a first software prototype of an ECAD variant module is being under development, the focus being on developing our variant module in a universally valid manner, that means independent from a specific underlying ECAD system.

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