Enhancing the Human-Computer Interface of Power System Applications

Gilberto Pires de Azevedo
CEPEL
Caixa Postal 2754
200001-940 - Rio de Janeiro - RJ - BRAZIL

Clarisse Sieckenius de Souza - Bruno Feijó
Departamento de Informática - PUC-RIO
Rua Marquês de São Vicente 225
22453-000 - Rio de Janeiro - RJ - BRAZIL

Abstract - **This paper examines a topic of increasing importance: the interpretation of the massive amount of data available to power system engineers. The solutions currently adopted in the presentation of data in graphical interfaces are discussed. It is demonstrated that the representations of electric diagrams can be considerably enhanced through the adequate exploitation of resources available in full-graphics screens and the use of basic concepts from human-factors research. Enhanced representations of electric diagrams are proposed and tested. The objective is to let the user "see" the behavior of the system, allowing for better interpretation of program data and results and improving user's productivity.**

I. INTRODUCTION

Research on electric power systems has traditionally been directed towards the improvement of methods and algorithms to provide reliable data to planners and operators. However, even the most accurate data has little value if it cannot be properly understood by the end user. Today, challenges are shifting from production to interpretation of the massive amount of data available to utilities' engineers [2-5].

Since most data are processed, examined and modified in computers, their interpretation is a problem related to human-computer interfaces. The initial generation of power system applications implemented batch or non-graphical interactive interfaces. They were followed by the first "graphical" interfaces, developed for character-based limited-graphics screens. Those interfaces have been a great advance over the conventional way of interaction; however, their intrinsic limitations imposed many constraints on the quality of the interaction. The range of possible representations of elements of electric diagrams was small. The nature of the elements was essentially static; the dynamics was usually limited to blinking and changing colors or symbols, or to digital values displayed on boxes. The limitations of that computer media led to the development of representations of electric diagrams that were similar to those used in diagrams drawn on paper. They basically displayed the connectivity, with little, imprecise, or no information at all, about the relative importance of the components.

In the 80's, the new graphics hardware encouraged the development of full-graphics interfaces. However, many of these interfaces still use diagrams that are very similar to those developed for limited-graphics interfaces. Again, the dynamics is often restricted to changing colors, symbols and values displayed on boxes. The most important enhancements were the inclusion of general usage interface components (see Section II), 2D or 3D graphs and the use of concepts like scrolling, layering and zooming. If we focus our attention on the representation of the power system, it is easy to notice that the new full-graphics interfaces present little more information than their ancestors. The large amount of resources available on full-graphics screens remains very under-explored by the representations. The absence of information about the relative importance of the components is almost complete.

In most cases, users are interested in information concerning general and approximate values (e.g., areas where the voltage is low or high) or states (normal/emergency, high/normal/low); the search for exact values is much less frequent. However, what they get from most interfaces are boxes displaying digital values of system variables. Users interpret those values on a one-by-one basis: a slow process, from which it is hard to extract generic information concerning sets of elements. This is so because the adopted representation of power system elements is dictated by tradition and not by current research studies about the factors involved in human-computer interaction. This factor, together with the sub-utilization of the new full-graphics media, results in low productivity in learning and using the programs. However, the most undesirable effect is that users tend not to adequately explore the resources provided by programs and algorithms, since they cannot efficiently evaluate the information presented. Programs that implement a friendly interface - no matter if the algorithms underneath are not the best and most efficient ones - quickly gain more acceptance than others that have excellent algorithms but poor interfaces. From the user's point of view, the best data set is the one he or she can easily understand and manipulate.

In this paper, we propose some general guidelines as a starting point for the development of more efficient representations of power system diagrams. An analog style of representations is suggested to be more efficient than the classical ones, because it allows for better interpretation of program data and results, improves user's productivity and reduces overall usage costs. We also try to explore more extensively the resources provided by current full-graphics hardware. If possible, the interface should let the user "see" the behavior of the system. The background for this development is provided by studies in human factors and by a semiotic approach to user interface languages.

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II. TOWARDS BETTER INTERFACES

Because the one-line area diagram is probably the most important kind of electric diagram for power system network analysis, we chose to concentrate our analysis on it although the same general principles can be applied to other types of diagrams. We will concentrate on representational aspects of the interface, and postpone research on interaction requirements for a later time.

Components of a typical power system program's interface can be separated in three categories:

1. *General usage components*: These are elements common to any graphical interface, like pushbuttons, pulldown menus and popups. They are provided by widespread toolkits and are wielded mainly in the implementation of common dialogue protocols.
2. *Two-D and Three-D graphics*: These are used to plot variables, often allowing for some kind of interaction. Like the previous components, there is a growing number of commercial libraries of such objects.
3. *Power system specific components*: They represent symbolically the relevant components and processes of a power system. In spite of being the most relevant elements for the achievement of the interface's goals, they are habitually constructed by the interface programmer without any further research effort in terms of efficiency.

The first two categories of components may be considered "mature", since they have been submitted to research and extensive usage in different fields. The situation of the representations of the power system components, unfortunately, is quite different: amateurish design has been the usual solution.

The representations of specific power system components can be separated into the following classes:

- Connectivity - Shows how the system components are connected.
- State - Shows the state of some components. The states are usually indicated by symbols or colors (e.g., different colors or symbols for open/closed circuit breakers).
- Magnitude - Shows the magnitudes of relevant variables. In most cases the magnitudes are indicated in boxes presenting numeric values or by graphs.
- Trend - In many situations, and specially in on-line applications, the trend of some system variables can be more important than their absolute value. However, the representation of trends is not addressed at all by many applications interfaces.

Connectivity

Traditionally, electric nodes are represented as vertical or horizontal bars, where some transmission lines are connected (Fig. 1.a). This one-dimensional representation is an important source of "visual confusion" in the diagrams. The shape of the bars often leads to unnecessarily complex representations of transmission lines. Since it is "impossible" to connect lines to the extreme points of the bars, we may need to break the representation of the transmission lines in two or three segments. The diagram becomes even more confusing if only vertical and horizontal segments are used, like on limited-graphics screens.

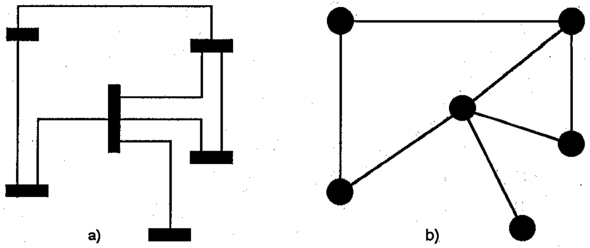


Fig. 1. Connectivity: two alternative representations.

Attaining to visual clarity, we propose one alternative that helps obtaining simpler and more readable diagrams: the use of two-dimensional representations (e.g., circles) of electric nodes, as shown in Fig. 1.b. This representation is not new; however, it is easy to prove that it allows for faster recognition of the connectivity of the diagrams. This was done by presenting Fig. 1.a and Fig. 1.b, which represent the same diagram, to a test group. After examining one figure during 5 seconds the persons were asked to draw the nodes and their connections. This was repeated with the other figure, rotated by 90 degrees to create the illusion that the diagrams were different. The amount of nodes and lines correctly placed was then computed:

TABLE 1
COMPARISON OF CONNECTIVITY REPRESENTATIONS

representation	precision
bar	59 %
circle	85 %

The higher precision achieved by the alternative representation of electric nodes should not be a surprise, since any visual inspection of Fig. 1.a and Fig. 1.b shows that the use of circles and one-segment lines produces "cleaner" diagrams.

State

In this context the definition of *state* is flexible: it may vary from obvious and fixed ones (e.g., open/closed circuit breakers) to more dynamic concepts (e.g., values above, inside or below a range defined instantly by the user). Information concerning state is of great importance in power system studies. Very often, perhaps in most cases, users are not interested in exact information, but in qualitative (or *state*) data. This is true at least during early steps of the work. The many different types of qualitative information that users will need will usually vary during different work phases, and are almost unpredictable by interface programmers. In some interfaces there exists a small number of pre-defined states, conceived by interface developers. However, these usually constitute only a subset of the state information users will actually need. In the other cases, users have access to magnitude values presented digitally and have to extract state information from it. The conversion from digital magnitude information to state information roughly involves the following steps:

- reading the value;
- consulting a "table in memory" to retrieve the limits that define the state for the specific situation in which the user is interested (e.g., limits defining low, normal and high values);
- comparing the value read against those limits;
- deciding the status of the value (low, normal or high).

This is certainly an inefficient process. The interactive aspects are very important here: It is essential that the interface permits a dynamic definition of state (i.e., the range of relevant variables and their respective representations).

Magnitude and Trend

The representations of magnitude and trend are intimately related, and will be analyzed together. In spite of its importance in many studies, the representation of trends is rarely addressed by power system application interfaces. To identify the trend of a certain variable in a conventional digital indicator, the user must spend a relatively long time observing the fluctuation of the value and finally conclude if it is increasing or decreasing. For a second variable, the whole process has to be repeated, and the conclusion will be separated in time from the first. If the user wishes to have an overview of the trends of a set of variables, it is easy to notice that this process is very inefficient.

Two-D and three-D graphs are the most common interface objects used to represent trends. Nevertheless, more compact representations are possible. Fig. 2 shows simplified examples. In Fig. 2.a the arrow - an universal symbol for trend - is used. Its length, for instance, may be proportional to the weighted mean of the last few deltas between consecutive values. However, if the variable oscillates around a certain value the mean can be small, even if the oscillations are large. In Fig. 2.b a different principle is used: the temporary memorization of past values. Together with the current value, the last few values are also presented. A scale of colors between the indicator's color and the background is used. More recent values have colors proportionally closer to the indicator's color; older ones have colors closer to the background. As time goes by the representation of the value at a given moment becomes less visible, until it completely disappears. In Fig. 2.b it is possible to see that the oldest recorded value was high, and that values have been decreasing with reducing speed. This seems to be a rich and compact source of information. The proposed representation also enables the identification of oscillatory behaviors.

Another category of representation that can be greatly enhanced in full-graphics screens is the representation of the magnitude of system variables. If the qualitative information concerning the state of relevant variables is not enough to the current step of the work, users may wish to examine their intensities. In one-line diagrams the representation of intensities is traditionally implemented by displaying numbers in boxes placed near the components to which the variables are related. However, once more, users are rarely interested in exact values. Typically they want to have a general overview of the system's behavior and/or an approximate idea of the relative values of some important variables. In this general situation the use of numerical representations has at least two serious drawbacks: (a) the interpretation of the relative values is inefficient and (b) it is done in a one-by-one basis, making it difficult to provide a general overview.

In many cases, digital representations can be replaced with great advantages by analog ones. Analog representations of variables may enable faster interpretation, better recognition of special situations and more efficient grouping of information presented in different parts of the diagrams.

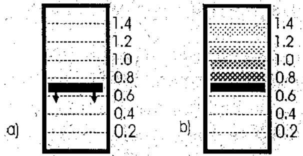


Fig. 2. Trend representations.

The 2D representation of electric nodes proposed in the previous subsection can be used as the background for analog representation of a node's variables. Fig. 3 shows a few possible representations already used in other contexts. In Fig. 3.a [11], one of the simplest is seen - the extent of the arc is proportional to the relative deviation of the voltage from its nominal value (which is often the relevant information). In Fig. 3.b, a similar representation uses an arm instead of an arc; Figs. 3.c, 3.d, 3.e and 3.f show two-variable representations. Developers' creativity can easily produce other representations. Some of them can be enhanced by the indication of variable's trends. Colors should be used to emphasize special conditions (states).

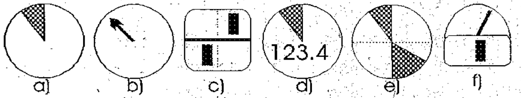


Fig. 3. Possible representations of voltage magnitude/angle in nodes.

The use of nodes as background for presentation of analog information related to them is a compact and efficient source of information. Analog information is more readily interpreted; the values, states and trends are immediately associated with the nodes. This could not be true if they were presented in boxes placed near the nodes. Finally, the elimination of those boxes produces "cleaner" diagrams. The most important restrictions to the quality of analog representations are those imposed by screen resolution; obviously, hardware evolution tends to gradually diminish this problem.

Now let's take a closer look at the classical representation of transmission lines. In power system applications, the "importance" of a line is often directly related to one of its power flow capability limits (normal, long term, emergency). However, that value is only suggested indirectly by the color indicating its voltage level. The process of evaluation of the importance of the line follows the steps:

- identifying the color;
- consulting a "table in memory" to identify the voltage level that corresponds to the color;
- consulting another "table in memory" relating voltage to the approximate power flow capability limit, or mentally calculating it.

Since the voltage level is not the only factor in the determination of the limit, this process is intrinsically imprecise even for skilled users. For less experienced users, this will probably lead to large evaluation errors when comparing the importance of lines in different voltage levels.

An alternative representation of a transmission line is by means of lines whose thickness is directly proportional to one of the power flow capability limits. Users intuitively interpret *size* as an indication of *power*, resulting in faster and more precise understanding of the system's behavior. This representation can be complemented, for instance, by an indication of the direction (symbolic) and magnitude (analog) of the active power flow, as shown in Fig. 4. The arrows indicate the directions; the intensities are represented by the thickness of the inner lines. A similar representation has been studied by Mahadev and Christie [10]. This representation enables users to virtually "see" the power flowing. They can quickly identify the overall status of the system and, what is perhaps the main benefit, can easily identify the relative importance of system events.

The traditional color code used to indicated the voltage level can be applied here. However, colors like yellow and red should be reserved for emphasizing abnormal conditions. The selection of colors should try to avoid undesired focusing of user's attention in non-relevant parts of the diagram.

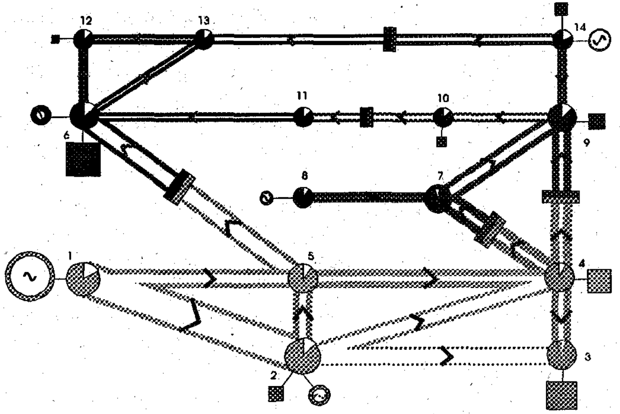


Fig. 4. The aspect of the proposed representation in a 14-bus system.

The main limit to this representation is imposed by the combination of the relatively small resolution of computer screens and the possibly wide range of values of the variable to which the thickness of the line is proportional. In the case of the power flow capability, it is easy to find relatively large variations in the same diagram. If this becomes a problem the developer may have to sacrifice the proportionality in one or both extremes of the range.

Alternative representations of other system components are also shown in Fig. 4. Transformers are frontier elements among different voltage levels, which are indicated by colors; so they are represented as frontiers among different colors. Generators are represented by circles with radius proportional to their maximum power generation; the actual generation is indicated by the innermost circle. Loads are represented by squares with sides proportional to their values. These representations were designed obeying the principles provided by current research in such fields as human factors (HF), human-computer interaction (HCI), and computer semiotics. They are an attempt to achieve a theoretically motivated exploration of full-graphics resources available in today's computers.

In order to compare the efficiency of the alternative and the classical approach to the representations, a test program was developed. In the program, which used a simplified model of a small power system, users had to adjust generations to supply some loads, restricted by line capabilities limits (within a certain precision), as seen in Figs. 5.a and 5.b. For each of the 60 users (most of them power system engineers proficient in the interpretation of the classical representation) the program selected one of four possible representations of the same system: classical (Fig. 5.a), classical including colors to indicate states (insufficient or excessive energy in loads, overloaded lines), alternative representation (Fig. 5.b), alternative representation including colors. The mean time consumed by users to reach a solution is shown below. The results show that the alternative representation induced a better understanding of the system's behavior, which led to shorter time intervals to reach the solution. This difference is expected to increase with systems complexity and users experience with the new representation and, also, with new enhancements in representations. The similar results achieved by the two modes of the alternative representation suggest that analog representations alone provided sufficient information about states, in this small system. In larger systems, however, state information is expected to become more important.

TABLE 2
COMPARISON OF DIFFERENT REPRESENTATIONS

representation	simple	using colors
classical	126.6 s	78.1 s
alternative	60.6 s	59.5 s

III. THEORIES And GUIDELINES For The DEVELOPMENT Of A NEW GENERATION Of INTERFACES

The development of a new generation of better interfaces for power system applications still relies quite heavily on the creativity and intuition of programmers. However, HCI research has made programmers realize the need for a full two-way communication approach to interface design. Not only do users send messages to application programs, but they also receive and interpret messages coming from or *through* the application.

A communicatively-oriented view of interface design is one in which designers communicate with users *via* computer systems [8]. In a previous paper [1], we have discussed in detail the nature of computer systems in this light, and have proposed that they are actually metacommunication artifacts designed to be performing messages sent from programmers to users. A critical design issue is then to understand the process of elaborating this complex message. In our specific power systems case, the interface design issue is to use representations that can correctly convey the messages related to the underlying power system model's structure and behavior.

Eco [9] proposes that in communicative processes - i.e., in semiotic systems - the production of signs (communication units) can be analyzed into four parameters. The **physical or mental labor** involved in selecting expressive units is the first parameter and ranges from the recognition that certain units are available as valid expressions for the intended meanings to the invention of novel units, given the inadequacy or nonexistence of available ones. The **associations users will have to do between form and meaning** is the second one and involves, for example, choosing forms that immediately evoke intended meanings instead of those that do it indirectly (e.g. by means of comparisons and implications), or choosing an expressive system that is an established way of conveying the intended meanings. The **segmentation of the expressive *continuum*** is the third one, and regards the distribution of content and form among a variety of communication systems, like the linguistic, the gestural, the pictorial, and many other ones among which — and very importantly — the computational one. Finally, the **level of articulation** is the fourth parameter and refers to existence or not of combinatorial rules applicable to components within the chosen communication setting; for example, natural language is highly articulated, whereas painted pictures are practically non-articulated.

The *semiotic engineering* [1] of user interface languages is a theoretical approach to designing communicative systems based on Umberto Eco's sign production parameters. Instantiated in the realm of computer power systems interfaces, *Semiotic Engineering* aims at providing a high-level theoretic background for choosing representations (i.e., means of expressing) that are adequate for the computer-mediated communication between users and (power) system interface designers. All the representations proposed in the previous section follow the four guidelines proposed in our approach:

Interface designers should produce signs they recognize as codified expressions of the intended contents. When developing representations of power system elements, the designer should prefer those that are more easily recognized. For example, most of the proposed representations have not been invented just for applications interfaces. They are easily recognized by electrical engineers. This increases the user's confidence and enables faster learning.

User Interface Language designers should try to select expressions that are recognized as a token of an established (i.e. easily associated) type of expression system which accounts for the intended contents. For example, our representation of the connectivity diagram is directly associated with the meaning of linked nodes, without need of further inference about the nature of the diagram meaning.

User Interface signs referring to domain objects and to computer-modeled solutions for existing problems should have forms directly or indirectly borrowed from the domain of the application system, whereas those referring to I/O devices and operation system actions should be directly borrowed from a computer-specific subset of signs. I/O elements, like windows and disks, have no meaning except inside the physical machine. Windows, for example, despite their names that refer to things found in buildings, are computer entities that may be sized, hidden, moved and so on. The use of computer-specific signs to represent computer windows is the basis for such rich manipulation: outside world windows are not manipulated in this way, and unless such signs are understood as computer objects they will probably be misused. Conversely, the representation of power system elements and processes should use power system domain signs, since the meaning users assign for them is selected from real world situations; otherwise the user may think that operations possible in the computer world are also applicable to power system entities. E.g., the user may think that it is possible to perform electrically impossible operations by just dragging and dropping icons. All our representations of domain elements have been inspired in diagrams, instrument displays, and similar layouts easily encountered in the power systems application domain.

User Interface Language designers should always resort to expressions belonging to a recognizably codified (i.e., rule-based) system. This is related to the fact that computation is symbolic manipulation. From the user interface level down to the hardware physical response, everything is layer upon layer of formal codes. It is in the very nature of computer systems that signs are articulated and rule-governed. Moreover, rule-based systems allow for generalizations made from perceived articulations between parts of the system. For example, if the selection of objects from the diagrams precedes that of the operation they must undergo, users can infer that this principle is general and also applies for objects and operations they select for the first time.

At a more experimental level, HF and HCI research offers us a wealth of guidelines to be followed in interface design. In the following, we summarize some generic principles compiled by Foley [6], that are to be applied to the whole interface.

At Design Level

Consistency: The model of task, the functionality of the application, the sequence of actions, and the representations adopted must be the uniform throughout the interface. Exceptions and special conditions must be avoided, thus allowing the user to generalize.

Feedback: As in person to person communication, feedback is essential in human-computer interaction. Users must be informed if their actions have been recognized or not. For instance, in an operation of the type *select object - select action* the user must be informed if each step of the operation was recognized and if the final result was achieved.

Minimize error possibilities: Interfaces must be context sensitive: if an action does not make sense in a certain context, it must not be available for selection.

Provide for error recovery: the interface must provide means for the user to recover from errors. Well implemented *Undo*, *Abort* and *Cancel* options are recommended; otherwise the user will not feel safe to do exploratory learning.

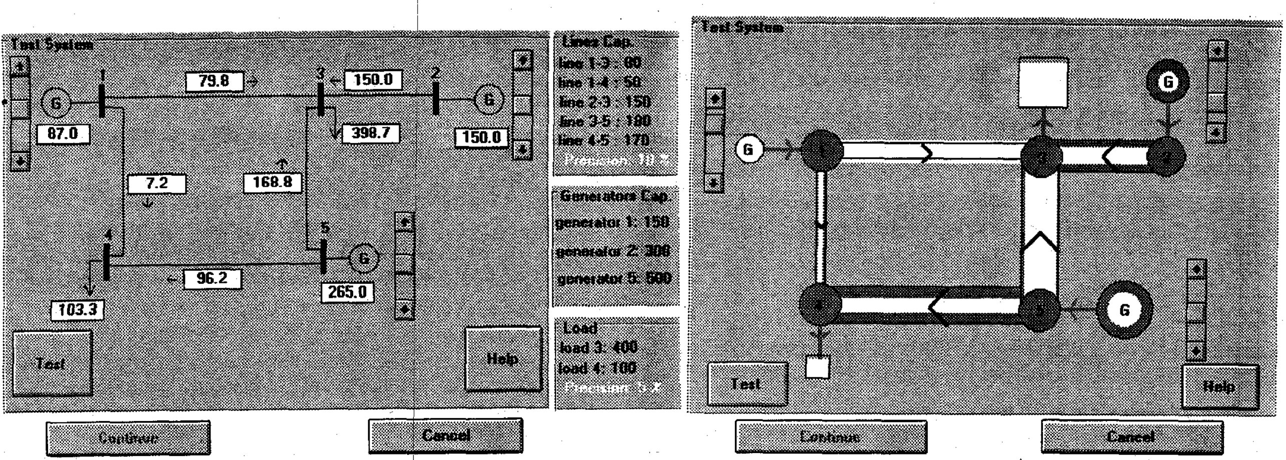
Accommodate multiple skill levels: Most interfaces will be used by people with very different skill levels. For new users, menus are very important, because they tell what to do and facilitate learning. However, skilled users are more interested in speed of use; for them, accelerators are essential.

Minimize memorization: interfaces must not require unnecessary memorization. For instance, if the user needs to open a file or select an element by name, the list of existing files or elements must be easily available.

At Layout Level [6]

Visual clarity: it is essential that the meaning of images is readily apparent to the viewer. Some visual-organization rules help accomplishing this task: *similarity* (visual stimuli that have a common property are seen as belonging together), *proximity* (visual stimuli that are close to each other are seen as belonging together), *closure* (states that if a set of stimuli could be interpreted as enclosing an area, the user sees the area) and *good-continuation* (given a juncture of lines, those that are smoothly connected are seen as continuous). The last three rules may explain the poorer results obtained by the classical representation of connectivity by vertical/horizontal bars and lines: the forced proximity of lines leaving a bar creates an illusion of association among their initial segments; the use of vertical and horizontal segments in the representation of transmission lines produces many almost closed rectangles, once more creating the illusion of association among segments of different lines; finally, the 90 degrees angles between consecutive segments of the lines are not an example of good-continuation. These three effects are considerably reduced by the alternative representation.

Visual coding: in this context, coding refers to the creation of visual distinctions among many types of interface objects. They are commonly implemented by the use of color, typeface, shape, size or length. These distinctions must be created only when they provide relevant information; otherwise they are more likely to be a source of confusion to the user. Visual coding can be classified as *nominative*, *ordinal* or *ratio*. Nominative information simply designates different types of elements (e.g., a menu of elements divided in



Lines Cap.
line 1-3 : 80
line 1-4 : 50
line 2-3 : 150
line 3-5 : 180
line 4-5 : 170
Precision: 10 %

Generators Cap.
generator 1: 150
generator 2: 300
generator 5: 500

Load
load 3: 400
load 4: 100
Precision: 5 %

a) b)

Fig. 5. Aspect of the representations in the test program.

loads, lines and generators); there is no notion of relative importance. Color is an efficient coding for nominative information. Ordinal information has a notion of greater than or less than, but no notion of varying distances between categories. Ratio information indicates those distances. If transmission lines are represented by lines of thickness directly proportional to their capability, we have an example of ratio information; if their thickness follow the voltage level but do not have any direct proportionality to it (e.g. 1 pixel for 69 kv, 2 pixels for 235 kv and 3 pixels for 500 kv) we are using ordinal information; if the different voltage levels are indicated by colors, we have nominative information.

Visual consistency: this is part of the overall consistency discussed above. It states that the rules and meanings of the visual elements must stay consistent in the different images of the interface. It includes the placement of information, that should keep the same relative position in different images.

IV. CONCLUSIONS

The quantity and quality of information produced by power system applications experiments a continuous increase. However, the use of this huge amount of data - and the exploitation of the potential of the applications - is restricted by the amateurish design of the computer representations of power system components, variables and processes, which did not accompany the progress achieved in similar fields. The related costs (training, sub-utilization, low productivity) can not be easily calculated, but are certainly high.

This paper has proposed alternative representations of elements involved in power systems applications, based on the fact that most of their existing interface representations do not fully explore the potential of computer graphics state-of-the-art. Proposed representations have drawn on current research work in such fields as human-factors, human-computer interaction, and computer semiotics. The potential of that approach is exemplified through the development of enhanced representations of one-line diagrams. Their effectiveness was shown experimentally.

This paper is intended to be a step towards the development of a generation of more efficient representations of power system components for graphical interfaces. This will allow a better use of the of the data and programs available to power system engineers.

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VII. BIOGRAPHIES

Gilberto Pires de Azevedo works with CEPEL (Rio de Janeiro) since 1982 and received his B.Sc. degree in Electrical Engineering from PUC-RIO in 1984 and the M.Sc. degree also in Electrical Engineering in 1989 from COPPE-UFRJ. He is currently developing a D.Sc. thesis in Computer Graphics at PUC-RIO. His interest areas include human-computer interaction, interface design and development, EMS/SCADA, sparsity and state estimation. E-mail: gpa@amazonas.acsi.cepel.br.

Clarisse Sieckenius de Souza is an Associate Professor at the Computer Science Department of Rio de Janeiro Catholic University (PUC-Rio). She has a Ph.D. in Computational Linguistics and has been doing research in Human-Computer Interaction for more than ten years. Her work intersects the fields of Artificial Intelligence (with natural language user interfaces) and Computer Graphics (with direct manipulation and iconic interfaces) along the lines of user interface language design. E-mail: clarisse@inf.puc-rio.br

Bruno Feijó received his B.Sc. degree in Aeronautical Engineering from Instituto Tecnológico da Aeronáutica in 1975, M.Sc. degree in Dynamic Analysis from PUC-RIO in 1980 and D.Sc. degree from Imperial College in Intelligent CAD in 1988. He is currently a Professor in the Computer Science Department of PUC-RIO and director of the Intelligent CAD Laboratory. His interest areas include CAD, Computer Graphics and Animation. E-mail: bruno@icad.puc-rio.br

Discussion

R. D. Christie and P. M. Mahadev (University of Washington, Seattle): The authors are to be congratulated on the advances in power system state visualization described in their paper, particularly for the representation of power system elements (generators, loads and transformers) and testing for display effectiveness.

The discussors feel that effective display techniques (encodings) for bus voltages are more difficult to obtain than power flows. We would appreciate the authors' comments/experiences on this issue. Could the authors also please comment on their experience with the ability to see voltage patterns in the system using the proposed encodings?

Do the authors have any thoughts on the ability to display real and reactive power simultaneously? Dr. Alvarado at the University of Wisconsin uses moving "bubbles" of different shapes to do so. This animation technique is perhaps more suitable for education than for power system control.

In the encoding of generators, the authors vary the radius of the generator symbol to indicate the maximum real power limits of the generator. Loads are similarly encoded. Tufte [1] points out that humans perceive area rather than radius as the encoded value. Thus, a circle of radius 1 is perceived as one quarter the size of a circle of radius 2. Do the authors think that this will present any problems in the interpretation of generator or load values?

In Figure 4, the buses appear to be represented with circles of different sizes. Does the size of circles have any specific meaning? There is no mention in the paper regarding encodings for overloaded lines or bus voltage violations. Would the authors wish to comment on it?

In Section III, the authors describe theories and guidelines for the development of a new generation of interfaces and summarize some generic principles to be applied to the whole interface. The discussors believe that one of them, **Accomodate multiple skill levels**, is not applicable to power system user interfaces. Power system operators generally have similar training and possess similar skill level. Given this, it appears that accommodating multiple skill levels in a EMS user interface is not necessary. Do the authors have a different view of this issue?

References:

[1] Edward R. Tufte, *The Visual Display of Quantitative Information*, Graphics Press, Cheshire, Connecticut, 1983.

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G. P. de Azevedo, C. S. de Souza and B. Feijó: The main objective of this paper is to propose a framework for better representations of power system diagrams based on concepts found in the areas of human-factors, human-computer interaction and computer semiotics. The effectiveness of this framework is shown by experiments with one-line diagrams. However there are several open issues to be investigated and a great number of new experiments to be carried out.

The discussers state that effective encoding for bus voltages is more difficult to obtain than for power flows. This is correct, because no effective metaphor has yet been developed. However, the discussers [10] present an interesting solution to this problem, which seems to be efficient in the recognition of voltage patterns even in systems with hundreds of buses. In our opinion their solution could be combined to the one we've proposed and we would then have both a viewing of global voltage patterns and the relative importance of buses.

The representation of power flows is easier, because there exists a metaphor that is not perfect but is certainly powerful, that is: water flowing in pipes. The visualization of the flows (including magnitude and direction) is essential to understand system's behavior. In Figure 4, in order to preserve the notion of flow continuity, when necessary, the bus diameters have been increased up to the dimension of the largest element connected to them. Considering that buses connected to the "largest" elements are often the most important ones, this approach increases the effectiveness of the representation of the relative importance of the buses. It is certainly possible to define the diameter of buses using other criteria selected by the system developer. However, the visibility of both power flow continuity and the relative importance of buses must be preserved if the main objective is the comprehension of the system's behavior rather than the analysis of some specific parameter of the system.

We fully agree with the discussers' observation on the use of area or radius to encode the power limits of generators. We indeed used areas to encode loads and generation limits in the experiments shown in Figure 5. Unfortunately the paragraph where the encoding rules are described actually leads to a misunderstanding. We appreciate the opportunity provided by the discussers to correct this imprecision.

Encoding of overloads and voltage violations is a problem of representing *state information*. Colors usually are an excellent encoding for state information and may be used to convey, simultaneously, magnitude information. In this case the boundaries that indicate the "normal" values should be displayed, allowing for the visualization of severity of the violation. This is done in the experiment of Figure 5 (see line 1-3 in Figure 5-b) and Table 2 presents the results. When using the "classical" diagram (Figure 5.a), the representation of overloads by colors produced an important improvement in users' productivity. However, in the alternative representation the difference was negligible. This is probably a consequence of the efficiency of the proposed representation, that is: the behavior of the system was so evident to the users that the indication of overloads was not necessary. We believe, however, that in larger systems the use of colors to encode state information may become necessary to improve the efficiency of the alternative representation, as well. Nevertheless, new experiments are required to demonstrate this latest assertion.

The question of displaying real and reactive power simultaneously is another important issue raised by the discussers. The simultaneous representation of real and reactive power is a problem to which no satisfactory solution seems to have been found. We do not think that animation techniques can solve this sort of problem, although we believe that computer animation is not yet fully explored in the representation of power system diagrams and many interesting proposals may arise in the future. An obvious alternative is to split in two parts the representations of generators, loads and transmission lines, perhaps using different colors. It would be necessary to develop experiments to verify if this alternative could produce useful results. However, we are not very optimistic about that. A simpler and possibly better solution is the implementation of straightforward dialogues to allow for fast switching among representations of real and reactive power in the same diagram, or (if screen space is not a problem) to show both views in two separate windows.

The discussers state that accommodating multiple skill levels in a EMS user interface is not necessary, because EMS operators generally have similar training and skill levels. Usually this is correct. However EMS operators are a small percentage of power system interface users. Furthermore, even well-trained operators have a period of adapting themselves to systems in real conditions, when they usually require more verbose dialogues and more intelligent support. Moreover, good interface design for power systems in general should account for varying user skill levels.

Finally, we would like to thank the discussers for their comments and for the opportunity to exchange different views on such important subjects.

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