2D AND 3D VISUALIZATION STRATEGIES FOR DISTRIBUTION MANAGEMENT

Sonja SANDER  
Siemens AG – Germany  
Sonja.Sander@siemens.com

Dr. Roland EICHLER  
Siemens AG – Germany  
Roland.Eichler@siemens.com

ABSTRACT
This paper demonstrates how effective visualization strategies and intuitive workflow guidance can support distribution grid operators in coping with tomorrow's challenges. Firstly, it will describe a methodology for understanding the requirements for Advanced Distribution Management Systems (ADMS) from an end-user perspective and illustrate an example outcome which has been evaluated with users. Secondly, it will introduce two new strategies for enhancing situational awareness.

INTRODUCTION
Distribution grid operators have to manage significant changes nowadays. Renewable energy sources increase the complexity in managing distribution grids while aging infrastructure and integration of renewable energy resources put the grid at risk. At the same time, there is a growing pressure to provide a reliable and efficient power supply to end-customers. The likelihood for errors thus invariably increases. To manage and mitigate these upcoming changes, the control center system should offer the operators the best possible support.

Two aspects are important for alleviating stress and improving operator performance. Firstly, the system needs to support the operator workflows for reducing reaction times. In particular, within the context of ADMS, operators have to manage multiple applications in parallel (SCADA, Network Analysis and Outage Management). The interplay between these applications must be as efficient as possible to enable the operator to react quickly and correctly upon any disturbances. As the described usage-centered design methodology was to date optimized for modeling a single application, it has been extended using a methodology for describing the interplay of multiple applications from an end-user perspective: workflow descriptions show the sequence of user tasks across multiple applications.

Figure 1 shows a sample workflow for managing an unplanned outage. The rows represent human actors (trouble call operator at the hotline, operator in the control room, crew working on-site), each box represents a task (e.g. enter new trouble call) while the arrows themselves, especially within a highly complex domain such as distribution management. Therefore, a proven methodology for building systems with a high degree of usability has been applied. This methodology concentrates on analyzing end user needs without getting lost in details in early development phases.

Usage Centered Design
Constantine & Lockwood [2] introduced a systematic approach for identifying user tasks and deriving models and requirements for the system under design. The method focuses strictly on what the user needs and for what purpose he/she needs it rather than concrete technical solutions. As a result, a model of the system users (actors) as well as their roles and tasks is built which provides a complete overview of the system scope. Each task describes the respective user intention and system responsibility. Based on this model, detailed user interface (UI) concepts (sketches) of the future system can be defined and built. The UI concepts will be refined and enriched iteratively by visual design and prototyping. Figure 1 illustrates the described process.

As above, in the context of ADMS, the user has to work with multiple applications in parallel (SCADA Network Analysis and Outage Management). The interplay between these applications must be as efficient as possible to enable the operator to react quickly and correctly upon any disturbances [3]. As the described usage-centered design methodology was to date optimized for modeling a single application, it has been extended using a methodology for describing the interplay of multiple applications from an end-user perspective: workflow descriptions show the sequence of user tasks across multiple applications.

Figure 2 shows a sample workflow for managing an unplanned outage. The rows represent human actors (trouble call operator at the hotline, operator in the control room, crew working on-site), each box represents a task (e.g. enter new trouble call) while the arrows themselves, especially within a highly complex domain such as distribution management. Therefore, a proven methodology for building systems with a high degree of usability has been applied. This methodology concentrates on analyzing end user needs without getting lost in details in early development phases.

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indicate the sequence in which tasks are performed. Based on the workflow description, it is possible to identify which applications (e.g., Outage Management, Trouble Call Management, SCADA) are involved and to derive how they are supposed to work together in order to support the end-user in the most efficient manner.

Each task contains descriptions on the user intention and system responsibility, which again follows the usage-centered design methodology by listing solution-free descriptions of the involved user intentions and system responsibilities (see Table 1).

In the initial analysis, ten major ADMS workflows and related task cases have been described in workshops with internal stakeholders and domain experts. Three customer sites in the US and Europe have been visited to verify the results and to make sure that the system is built using the correct assumptions. An important outcome of the customer visits was that although there are structural differences in distribution networks in Europe and the US, the overall workflows for managing unplanned outages and planning maintenance work are similar.

For each workflow, concepts have been created that visualize the future user interface as input for software development of the visualization strategy.

**Icons and Info Boxes**

A major outcome of the workflow analysis was that in order to ensure efficient usage, it is important that data from all relevant applications (SCADA, Network Analysis and Outage Management) are displayed in the same view without forcing the user to navigate between different application windows. The user’s workflow must be supported in the most efficient way to reduce navigation efforts.

For example, for the task “reviewing outage details and location” the operator needs to get a comprehensive overview on the network diagram regarding:

- The outage location (as determined by outage management prediction engine)
- Trouble calls from customers
- Crews and their availability
- Critical customers such as hospitals and police stations
- Indicators for fault locations (derived by network analysis)
- Planned maintenance work in the same area

Figure 3 shows how the ADMS was enhanced in conjunction with the visualization strategy in order to plot

![Figure 2: Workflow: Unplanned Outage](image)

![Figure 3 Icons and info boxes](image)
all these pieces of information as iconic symbols on the network diagram. This principle works on both schematic and geo-spatial network diagrams.

The user can access further details on the individual elements on demand. By clicking an icon, a small info box will pop-up showing the most relevant information as well as a link to further information such as the complete outage record. The operator can open multiple info boxes at the same time for comparing information.

As proof of concept, several users have been interviewed at two customer sessions in fall 2014. After a brief demo on the new ADMS functionality, customers were requested to fill out a questionnaire. For the questionnaire, the standardized Attrak Diff mini [4] was applied which measures four dimensions of quality of use:

- ATT: Attractiveness (product is perceived as valuable)
- HQI: Hedonic Quality – Identify (user identifies with the product)
- HQS: Hedonic Quality – Stimulation (product supports user in learning and moving forward)
- PQ: Pragmatic Quality (usability)

The questionnaire shows ten adjective pairs on a seven-point scale:

- easy vs. complex
- ugly vs. attractive
- useful vs. useless
- stylish vs. tacky
- predictable vs. unpredictable
- cheap vs. premium
- unimaginative vs. creative
- good vs. bad
- confusing vs. clearly structured
- dull vs. captivating

Figure 4 Attrak Diff Mini Questionnaire

In total, 13 persons were interviewed who were either distribution grid operators or employed in distribution utilities and hence familiar with the end-user needs. Figure 5 shows the results for the four dimensions of quality of use (arithmetic average and range of answers). Needless to say, these results only reflect the first impression customers get of the system, however deliver a general quality indication. For reliable results, a detailed usability test would be needed.

In summary, interviewees have perceived the improved system positively with the average values for all four scales being very good (7 = highest possible value). However, the range of answers indicates that there is still room for improvement, especially regarding hedonic quality – stimulation.

**SITUATION AWARENESS**

Control center systems must provide effective means for supporting operators’ situation awareness. On the one hand, operators must be able to perceive relevant elements in the environment and the respective information must be visualized in a meaningful way. In addition, operators must be able to understand the current situation and compare it to their goals. Based on what they see, they must be able to judge if the system is running into normal conditions or if they have to initiate any countermeasures for maintaining system stability. Finally, information must be visualized in a manner that allows operators to understand the dynamics of the system and to predict how the system will change in the next minutes or hours [1].

Therefore, the operator needs means for visualizing information depending on the needs of the current situation. To enable flexible display of relevant information, overlays were designed which can be superimposed on the network diagram. Such overlays contain combinations of pre-configured information and visualization means (e.g. voltages visualized as contours) and allow operators to switch between pre-configured overlays on-the-fly. The following sections of this paper will introduce two examples of how visualization strategies can be used to enhance situation awareness.

**Contour gradients**

Contour gradients are a well-known visualization means in the context of network monitoring. According to Overbye et al. [5], it is useful “for increased speed and accuracy in problem diagnosis” (p. 18), due to the fact that humans recognize visual patterns very easily. It is common practice to apply contour gradients to voltages in transmission grids for example for visualizing a single class of values (measured value). In order to support the distribution grid operator to comprehend the current situation and its impact on system stability, this concept has been extended in a way that contours not only represent the measured in-feed, but also significant deviations from forecast or schedule (i.e. focus on comparing two classes of values). As a result, the operator can identify significant deviations in the network at a single glance, as well as their location and severity. In the example shown below (Figure 6), generation infeed from renewables is visualized such that red and yellow spots represent a higher generation, while green and blue spots indicate a lower generation compared with the current (in the cited case, todays) schedule.
The reference point for the comparison needs to be specified very carefully in order to provide useful information. The operator typically wants to verify that the current operating conditions sufficiently match those conditions that were anticipated during operation planning - otherwise corrective measures would be necessary. The planning horizons of different operational planning tasks (e.g. maintenance planning, repair planning), however, might be different which in turns means different reference points for comparison. In any case, the user should be able to recognize in which network areas the boundary conditions for the current situation deviate from those originally expected (e.g. changes in PV generation forecast).

Additionally to contours, the user can activate the outage management overlay to get a comprehensive overview of the situation. As an example, Figure 6 shows contour gradients for renewable production together with icons representing planned works (construction worker), crews (truck) and unplanned outages (lightning). Red areas indicate significant deviations that might impact network stability. In two red areas, there is planned maintenance work scheduled that should be analyzed carefully before the works are commenced. One area can be seen to already be suffering from outages. By providing useful visualization means, data from three different systems (SCADA, forecasting & scheduling and outage management) becomes comprehensible in an intuitive way. The operator can understand the situation very quickly and even more significantly, identify dependencies between different lots of information and derive potential countermeasures.

2D bubbles and 3D cones

Another important topic for managing renewable generation in the distribution grid is voltage stability. Feeders with several renewable infeeds could suffer from voltage violations. Typically, this use case is visualized with contour gradients; however, contour gradients have several draw-backs. Firstly, contours also color areas that do not contribute measurements for the definition of the gradient. This could create a false impression of the situation [5]. Secondly, contours do not indicate violated limits. The user can identify different colors but he/she cannot identify the most severe violation in the network. A new visualization strategy focuses on highlighting significant deviations from normal state. The user should be able to recognize at one glance the location, type (upper/lower) and severity of a voltage deviation. The strategy uses interactive 2D and 3D voltage deviations. While the 2D view gives the operator a first impression on the problematic areas, the 3D view opens a new perspective on the network and conveys additional information in an intuitive manner.

In contrast to contours that melt into one another, the 2D view (Figure 7) only shows single-colored bubbles with a fixed radius around a bus. By only coloring the area around the bus, misunderstandings can be avoided. Another key principle is that bubbles are only shown when there is a deviation that needs the user’s attention; similar to putting the spotlight on. Two colors indicate the type of deviation (high voltage = yellow, low voltage = orange). The severity is shown by the color density with low density indicating upcoming problems and high density representing severe problems. Violated limits are coded additionally by showing a small black ring. With increasing excess of the limit value, the bubble grows beyond the initial radius, creating a halo effect around the black ring.

Feeders that are connected to a violated bus bar are highlighted in the same color as the bubble to indicate the impact of the deviation on the network. The operator receives a first level indication of a potential problem on a feeder, even if the feeder itself does not have real-time measurements. As a result, the user receives a clear picture on the voltage situation. He/she can immediately identify the most severe violation (orange bubble) and see which feeders might be suffering from the current situation.

To further support the user in understanding the voltage situation, the 2D view on voltage deviations is supplemented with a 3D visualization using cones to represent high and low voltage violations. 3D views are discussed very controversially in the literature. By tilting the network diagram, elements in the foreground are perceived to be more important than the ones in the background. Furthermore, 3D elements could
hide other elements. Most systems lack appropriate navigation means for 3D [6]. On the other hand, user tests showed that 3D can “facilitate a more accurate mental model of the system being manipulated, and allow for a better understanding of the interconnected nature and structure of a complex system such as an electrical power grid” [5, p.77]. While 3D provides a rough overview, detailed information for network analysis should be provided in 2D. In any case, the user must maintain control of his/her environment and be able to easily navigate between 2D and 3D views [7].

For the described use case, the 3D view (Figure 8) represents low voltage violations as cones pointing downwards with high voltage violations as cones pointing upwards. The height of the cone indicates the severity of the violation. Non-critical deviations (limit not yet violated) stay flat for indicating potentially upcoming but not yet critical problems. Each cone matches a bubble with a circle in the 2D view, supporting the user’s orientation in the system.

![Figure 8: 3D view on violations](image)

To remedy the described cited disadvantages of 3D, cones are slightly transparent in order that “hidden” elements remain visible. Furthermore, the user always stays in control on the visualization means. The operator can decide if he/she wants to view the information in 2D or 3D by switching from 2D to 3D mode in the toolbar. In 3D, the operator has appropriate means for navigating on the map. He/she can analyze the situation from a different perspective by changing the camera position, tilting or rotating the network diagram, similar to the interaction with 3D computer games. As a result, the user receives another perspective on the situation. High and low voltage violations are coded in an intuitive way that is immediately understandable.

The described principle can be applied to multiple other scenarios, for example for representing areas with very low versus very high demand, or outage indices such as customer average interruption duration index (CAIDI). 2D bubbles and 3D cones quickly guide the user’s attention to critical parts of the network and visually give the required overview at one glance: What kind of problematic situation is it? Where is it? What impact does it have on the power network?

OUTLOOK

The first results for workflow support and enhanced situation awareness are very promising. As workflows and processes for managing distribution grids further evolve and change, additional visualization strategies will be in focus for future development. Future work will focus on three aspects:

- Detailed user feedback on the described visualization means should be gathered to prove their benefits and identify possible drawbacks.
- The dynamic aspects of the system need a closer look: What changes are expected during the next hours? What dependencies exist in the system?
- The visualization strategies will be extrapolated to use cases outside of the control center e.g. to support proactive maintenance and planning of network extensions by easy visual identification of areas that frequently impact network stability.

REFERENCES


