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Virtual Reality for Monitoring and Control of Electrical Power

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Abstract: This project shows the results obtained from a new strategy based on Virtual Reality techniques, which intends to minimize the issues caused on the operation of electric power substations due to the lack of spatial and functional information on the traditional operation interfaces. For this purpose, a three-dimensional interactive virtual reality environment was built in a realistic and accurate way regarding a energy electric company of Minas Gerais – Brazil (CEMIG) substation and afterwards implanted it in its operation center for tasks related to its functioning. Lastly, tests were applied to the operators to obtain results aiming at the contextualized problems.

Keywords: Spatial and Functional Information, Substations Operation, Virtual Reality

1. INTRODUCTION

In electrical sector, the electric power providers have continuously employed efforts with the aim to improve the quality and continuity of their electric power supply to their customers. (Bernardon et al., 2016)

However, the interruptions in this supply are inevitable for various reasons, and among those stand out – the execution of system expansion works, preventive and/or corrective maintenance on the grid's components, or even mistakes associated to human aspects on the operation of the national interconnected system. (Porto et al., 2017)

In the context of human aspect failures, statistical analysis show that mistakes associated to human factors in a system correspond up to 90% of the total failures. (Peng-Cheng, 2012)

In Brazil, historically, major blackouts that occurred in national interconnected system are related to human mistakes in the operation. In this context, a situation that deserves the spotlight is a blackout occurred in 1996, which affected 9 states for 100 minutes due to a maneuver failure in a power. (Gomes, 2004)

In these circumstances, identifying the factors that influence the operators' performance is necessary to identify problematic aspects that raise the potential of human failures occurrence. (Embrey, 2000)

In this condition, methodologies related to the analysis of human trustworthiness on critical Engineering systems can help in the search of the national interconnected system operation process improvement. The objective of these methods is to analyze the factors that contribute to the occurrence of human mistakes and determine their probability. The model utilized in this study must be built and validated by empirical data, for instance, the operational experience and results based on simulators usage. (Podofilline & Dang, 2013).

In this aspect, the HEART (Human Error Assessment and Reduction Technique) methodology elaborated by Williams

(1986), and later consolidated by Bell and Williams (2016) assumes that any trustworthiness in a task's performance can be altered according to the presence of error-promoting conditions or performance factors. In this guideline, one of the main error-causing conditions related to the operation of Engineering systems is based in the absence of an interface to transmit spatial and functional information to the operator in a way that he/she can readily assimilate.

Contrasting this problematic, the application of Virtual Reality techniques aims to develop a more intuitive interface that maximizes the interactivity, usability and naturality aspects during the action process. (Kirner & Kirner, 2011)

Under this context, the Virtual Reality became the main technique to break the interaction barrier in the 2D space, allowing its user to manipulate information that are similar to the real space while being favored by the immersion feeling, which is the major characteristic in these environments, for it being the responsible of producing the feeling of presence in the virtual world. (Landberg, 2000)

This way, in front of the scenario of the difficulties faced in the electric system's operation process and the potential of the Virtual Reality area, this research has the objective to develop and evaluate a system based on Virtual Reality techniques that allows to transmit spatial and functional information in the process of electric power substations operation.

For this purpose, the premises of this research are: a) To investigate the art status of the operation process of electric power substations; b) To create methods and interface control tyles that reuse the mental model from the operator regarding the traditional operation process; c) To carry out usability analysis and apply evaluation and observation forms.

Lastly, having in mind that the main current systems for this practice do not bear the resources that promote the view of functional spatial information, a factor that is considered an error-promoting condition, the motivation behind this research is based in the search for improvements in the operation process of electric power substations, reduction of the error incidence possibility and greater safety and efficiency.

2. ART STATUS

2.1 Electric System Operation

The operation of the electric system has always been a very complex activity. Initially executed in a local level by station operators who, most of the times, does the operation directly on the machinery, generally, in a mechanical and manual way. The evolution of the machinery and, mainly, the increase on the systems' tension levels brought the possibility and the necessity to execute the commands remotely. Afterwards, the operation interfaces migrated, throughout this evolution, abandoning the objective of executing the operation directly on the electric system's machinery and sought to offer interfaces supported by computers and based on single-line diagrams. Nowadays, except for small-sized electric systems and simple substations which don't have machinery with electrical commands, the "natural" operation interface are systems based on computers with single-line 2D diagrams. (Prado et al., 2014)

For the operation system to reach its objectives, the information regarding the machinery's status need to be provided to the various interested sectors, simultaneously maintaining the data integrity and the access' safety. To allow the provision of the system's information, generally, the computer which executes the operation software will be connected to the company's network. (Alves, 2014)

2.2 Art Status of the Operation Interfaces of the Electric Power Substations

For all the operators of the operation centers, the natural operation environment is the 2D interface, the single-line diagrams. Most these operators, mainly the newer ones, barely know the stations they operate into. Normally, they are technicians who come directly from the technical courses to be trained directly in the control rooms. When they are taken to the stations, they will face an unfamiliar and strange environment, and may have difficulties in finding the correlation between the 2D operation interface and the actual station's environment, thus not promoting the association of the operation mechanisms with the real field scenario. (Prado et al., 2014)

The figure 01 shows an example of the current operation interface.

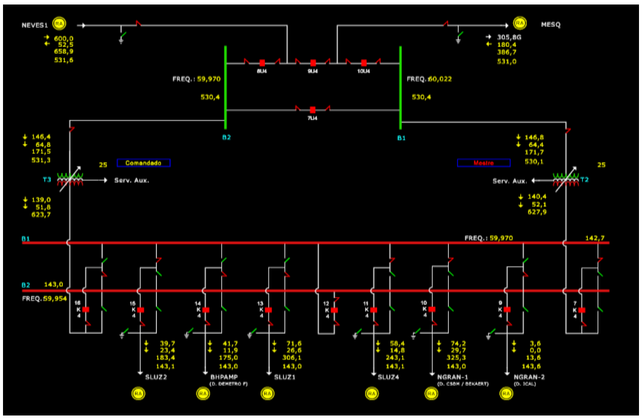

Fig. 1: Single-line diagram of the energy electric company of Minas Gerais (CEMIG).

2.3 Heart Methodology

The HEART method – Human Error Assessment and Reduction Technique, Bell and Williams (2016), assumes that any trustworthiness in the performance of a task can be modified according to the presence and the strength of error-promoting conditions.

The methodology identifies nine generic kinds of tasks and proposes nominal values of the corresponding human mistakes probability, and besides that, relates the main error-promoting conditions that have great influence on the tasks' performance.

Each error-promoting condition has a value associated to the impact it can cause. This value is based on an extensive analysis about the human performance literature.
It's worth highlighting, the error-promoting condition number 5 called "Lack of means to transmit spatial and functional information to the operator in a way that he/she can easily assimilate" has a value of 9, being considered high in a scale between 0 and 17 related to the impact that it could cause.
This error-promoting condition involves the problematic of this presented article.

2.4 Virtual Reality

The term Virtual Reality (VR) was released in the end of the 80s by Jaron Lanier, artist and computer scientist, who managed to blend two antagonistic concepts in a new and vibrant concept able to capture the essence of this technology: the search for the fusion of what's real with the virtual. (Tori et al., 2006)
There are many definitions to the term "Virtual Reality" which involve general and/or technologic aspects, to Byrne (2009), Virtual Reality is a computer technology that offers its user the illusion of being in a three-dimensional space, with the ability to interact with this 3D space.
Now for Kirner and Kirner (2011), Virtual Reality is an advanced interface for computer applications that allows its user the movement (navigation) and real-time interaction, in a three-dimensional environment, allowing the usage of multi-sensory devices for its acting or feedback.
Lastly, (Cardoso et al., 2016), Virtual Reality is a computer system used to create and artificial environment, where its user has the impression of not only being inside this given environment, but also being able to navigate on it, interacting with its objects in a natural and intuitive way.
In the definitions of the Virtual Reality term, it is possible to understand its formation in three basic principles.
Interactivity: It's related with the computer's capacity to detect its user's actions and react instantly, modifying the application's aspects.
Involvement: The idea of involvement is linked to its motivation grade to a person's commitment in a given activity. The involvement can be passive, like reading a book or watching television, or active, like participating of a game match with a partner.
Immersion: It's the sensation or feeling of being inside the environment.
This way, ratifying the basic principles of the Virtual Reality's idea, for it to be considered a VR system, more than the immersion, interactivity and the involvement, the environment also needs to provide a high-end interface.

3. DESCRIPTION OF THE VIRTUAL REALITY SYSTEM DEVELOPED TO THE OPERATION OF ELECTRIC POWER SUBSTATIONS

The proposed system consists of a realistic virtual environment that represents 44 electric power substations from Minas Gerais (CEMIG) equipped with interfaces for both monitoring and control.
Through an elaborate internal architecture, data regarding the machinery's status (on, off, electrical measurements) which compose an energy provider's substation are received and processed in real-time through WebService. Having this information, the virtual environment is updated representing accurately the status of the substation's devices, allowing commands to be sent and real field action.
In this context, it is possible to provide a new approach to control and operate devices from the electric power substation through the usage of VR techniques, granting a greater immersion and more intuitive interactions.
Another pertinent aspect is that the operators will be able to navigate through various ways, exploring and viewing the electrical components' conditions to control the substation with more safety.
Thanks to the virtual and accurate reconstruction of the environment, it emerges the possibility of using the system to carry out trainings. This way, the operators can explore and get to know physical details of the objects, besides simulating different operation possibilities of the circuit without compromising the system's safety and performance.
Figure 02 shows the system during an operation to consult the status of one of the substation's components.

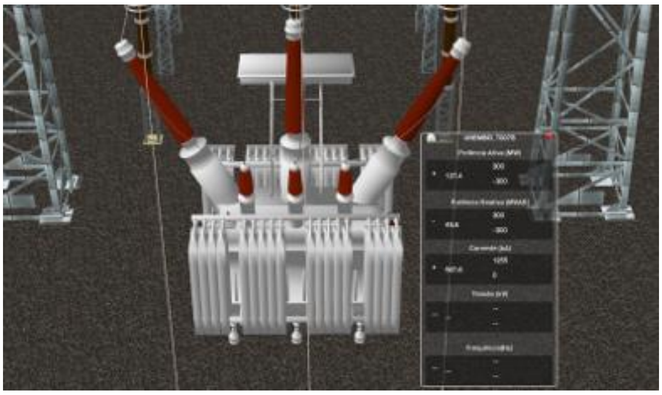

Fig. 2: Status information consult of a transformer through WebService

The proposed system needs to correctly represent the status of the referred operation, showing correct machinery's information. In this sense, it becomes viable the elaboration of an internal architecture that adapts itself to the engine. This engine was conceived using the object orientation paradigm. The equipment's data are collected and transmitted through WebService, which in turn, is provided by the electric power operator.
Through a data collecting and controlling system, the real equipment's status which compose the electric power substation are collected, processed and made available. Afterwards, the virtual environment consumes these data and updates the system, accurately corresponding itself to the actual substation. For it being a two-way architecture, it is possible to alter the machinery's state through the virtual environment, thus modifying the actual components' status.

4. ELABORATION OF INTERFACE STYLES AND METHODS THAT REUSE THE OPERATOR'S MENTAL MODEL REGARDING THE TRADITIONAL OPERATION PROCESS

For it being a complementary strategy to the electric power substations' operation context, it is important to elaborate screens to control the VR system that reuse the mental operation model acquired by the operators throughout the time by using the traditional operation interface based on a single-line diagram.

To elaborate these RV system's control screens, which have the purpose to operate the electrical components of the substation, some requirements related to the usability, design and layout aspects were defined. These are traditional in two-dimensional systems (2D widgets). They are: a) Every control screen must be integrated in the virtual environment. b) The control screens must promote mechanisms that allow a fast activation. c) The control components must be shown only when necessary to the interaction context or when activated by the user.

4.1 Selection Taskbar – Menu

The elaborated strategy contains a single taskbar to select the control options, situated to the left side of the environment. The space occupied by it, related to the vertical axis of the screen, is of a 100%. Regarding the horizontal axis, in inactivity moments, only 1,2% (just enough space to see its existence) of the area is occupied and doesn't show any item referring to the selection options in them. However, in moments of activity, its space is raised to 15% and the said items are shown. Figure 03 shows the item with the active selection taskbar. This activation is made by hovering the mouse over the taskbar. It can be noticed that the control interface is inserted in the 3D application context, with a 50% transparency.

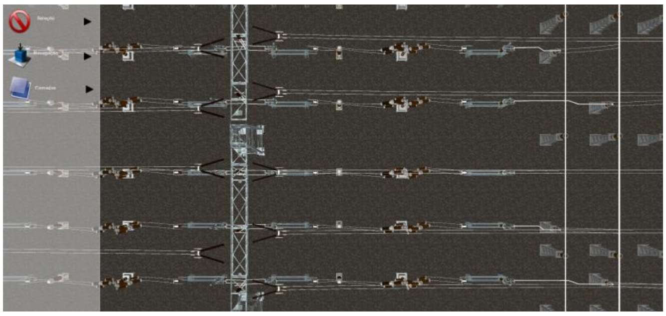

Fig. 3: Active Selection Taskbar. (Selection; Navigation; Layers)

4.2 Actions' Control Panels

Each item that composes the side taskbar has a panel with the options referring to determined actions. To show this panel, it is only necessary to hover the mouse over the unfolding icon (arrow). This way, the panel is only shown when the involved action is being solicited. When the mouse is pointed outside the control interface, the panel is hidden. From this point, the side taskbar returns to its inactive state.

Figure 04 shows a part of the lateral taskbar and the panel regarding a control action contained in the virtual environment.

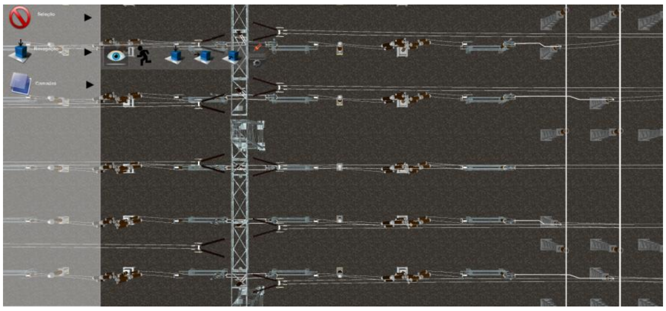

Fig. 4: Selection Panel of the Control Action. (Selection; Navigation; Layers)

4.3 Control Windows and Content Presentation

When the user needs to manipulate a virtual environment, windows and control elements are shown after their selection. These windows are also integrated in the virtual environment and their exhibition are automatically finished after executing or cancelling the action, thus making the virtual environment less overloaded and more intuitive. Figure 05 shows the said windows:

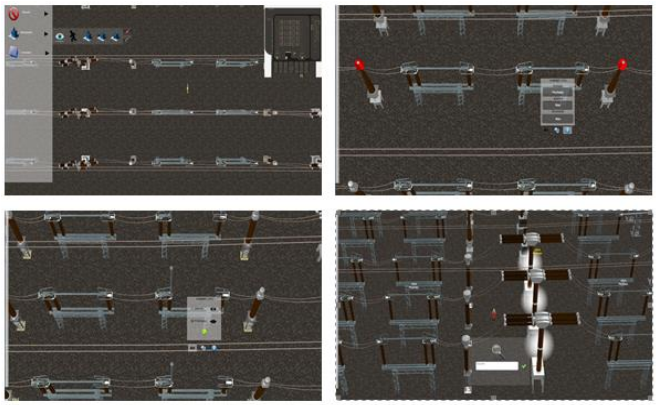

Fig. 5: Content Presentation and Control Windows.

4.4 Wrapper Layer

This function allows to control the content view in an independent way, allowing the activation or deactivation during the usage of the VR system. The user is free to manipulate this resource according to his/her necessity, at any time in the application, adding complementary information to the virtual environment.

An example of controlled content is the layer called "wrapper". Its aggregation value to the virtual environment is by applying a contour over the virtual equipment. If the equipment's status is "closed", the contour will be red, if it's the opposite, it will be green. By activating this layer, the user will obtain a faster interpretation about the machinery's status. Figure 06 shows this content layer in an active state.

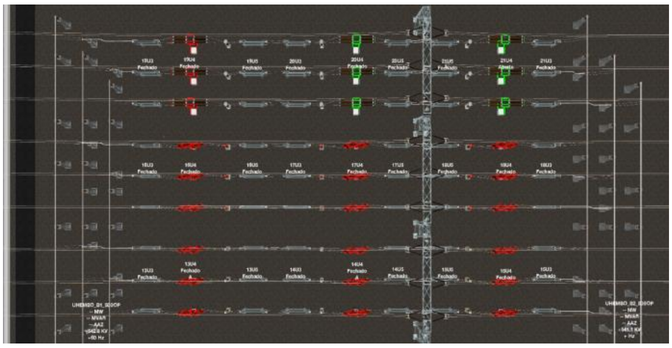

Fig. 6: Active "wrapper" layer.

The use of these colors is related to the mental model used by the substation's operator in the traditional interface (single-line), for it uses these attributions to represent these states (open and closed).

When the user wishes only to navigate through the virtual substation, he/she can turn off this layer, avoiding a visual overload in the virtual environment.

5. TEST PROCEDURES AND RESULTS

During all the development period and implantation of this strategy, the potential users of it were involved, besides a 6-hour training regarding the system's usability and functionality.

To analyze the strategy, various methods were applied, such as: moments to observe and monitor the usage of the Virtual Reality system, evaluation questionnaires and application forms to analyze the system's performance. These tests were applied to 12 operators from System Operation Center, and they correspond to 65% of its population.

The questionnaire's development was based on the QUIS (Questionnaire for User Interaction Satisfaction) methodology. The QUIS was projected to evaluate the overall satisfaction of the users with specific aspects of the man-to-computer interface. (QUIS, 2018)

This way, the users were able to properly talk about what's working and what's not. However, an efficient way to perceive the users' necessities is to observe them directly. (Lowdermilk, 2013)

To develop the application forms related to the operators' performance analysis, common failure recurring situations associated to substations operations were utilized.

5.1 Reaction to the VR System Usage

This criterion analyzes the user's satisfaction regarding the system's proposal: monitoring and controlling the substations. Aspects that were addressed: the degree of interest towards the application, utilization ease, suitability with the proposal and its overall pleasantness. Figure 07 shows the results obtained in these attributes.

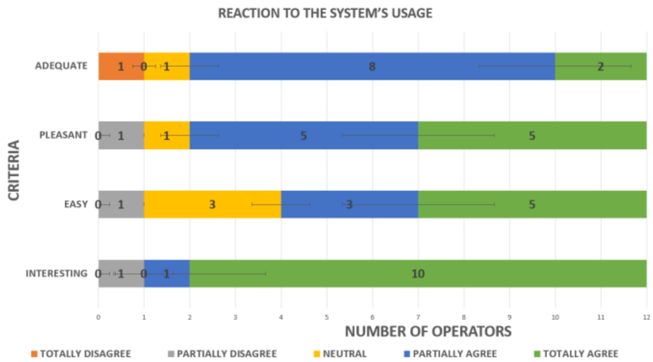

Fig. 7: Graph showing the analysis criteria about the system's usage.

By making a global average between the number of operators that utilized the system and the adopted criteria to analyze the proposal, it was measured that 76,5% of the users partially or totally agree that the VR techniques-based system has the necessary adherence to be used in the substations operation context.

5.2 Usage Control Screens – 2D Widgets

This criterion analyzes the menu, submenu, alternative interface, control and data presentation screens. Aspects analyzed: visualization, adequacy to the proposal, aesthetics, usage ease and the feeling of integration to the 3D environment. In Figure 08, it is possible to see the obtained results.

According to the shown graph, an ample satisfaction with the control mechanisms used in the VR system can be perceived, seeing that they were elaborated with the intuit to reuse the previous knowledge acquired through the conventional model, making the training and adaptability processes easier to the operator. This is one of the specific objectives of the research.

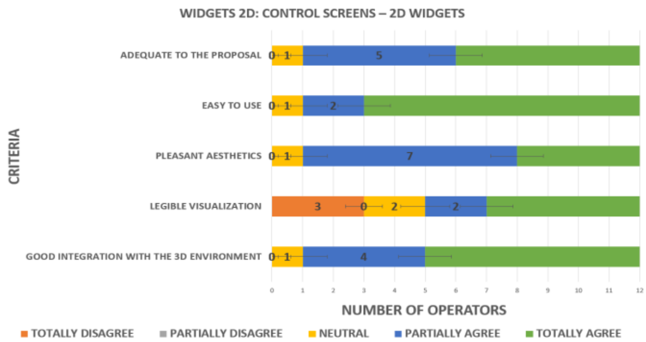

Fig. 8: Graph regarding the analysis criteria about the control screens.

It is important to point out that in the criterion "legible visualization", 41% of the operators didn't positively evaluate the attribute. Because of this, it was necessary to make a specific analysis of the situation and it was perceived that, in some moments, small visual confusions used to happen.

Figure 09 contextualizes the failure scenario.

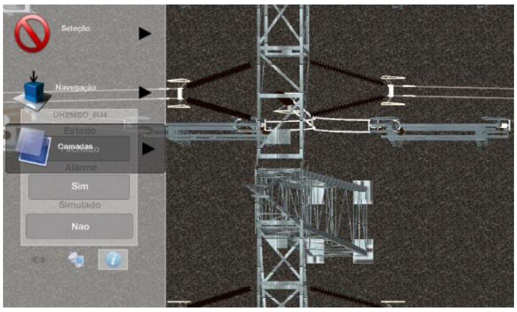

Fig. 9: Visual confusion between the menu and the data presentation window.

After identifying the failure, the presentation mechanism of the control interfaces was fixed, eliminating the occurrence of this kind of failures.

5.3 Navigation Ways and Spatial Visualization

This criterion analyzes the usability of the distinct navigation ways that the VR system has, highlighting the user's presence sensation, considering the control interfaces integration in the virtual environment and the paradigms confrontation (2D widgets and 3D virtual environment).

The evaluated parameters were: efficiency, interest, ease to learn how to execute the commands and the overall sensation of presence during the system's usage. Figure 10 shows the results raised in this criterion.

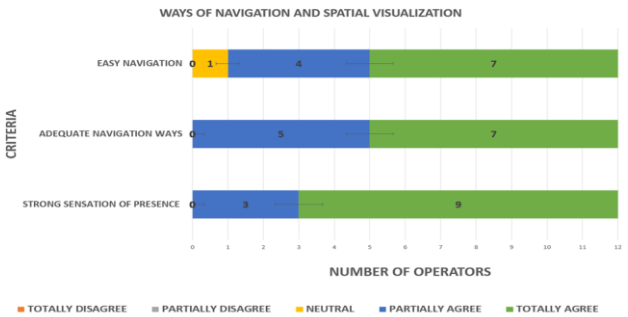

Fig. 10: Graph regarding the analysis criteria about the navigation in the 3D environment.

Based on the obtained data, it can be noticed that the available navigation manners and the way to fulfill this procedure were well received by part of the operators, easily allowing the access to his/her points of interest.

It is important to report that all the operators that took part in this research partially or totally agreed that the developed system transmits a strong feeling of presence with the approached context, an important attribute to reduce the absence of a way to transmit spatial and functional information to the operator in a way that he/she can readily assimilate.

Afterwards, a second stage was made to test the system, this stage being constituted in task execution and procedures associated to the operation domain of electric power substations.

For this purpose, the operators carried out two determined and simulated activities relevant in the operation process in the new proposed interface, with the objective to measure their success during the execution.

5.4 Activity 1: Locating the Equipment and Approaching the Field of View to it

In this activity, the operator needed to locate a designated transformer situated in a substation and, afterwards, approach the field of view through the "zoom in" resource, having a 30-second time limit. Figure 11 shows the results regarding this activity.

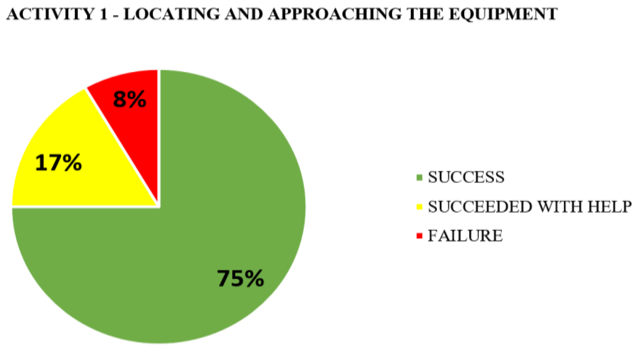

Fig. 11: Graph regarding the activity "Locating and Approaching the Equipment".

In this situation, it is possible to see that most of the operators successfully accomplished the proposed task without facing any difficulties, finding it easy to spatially locate the substation's components. On the other hand, 17% of them needed help to accomplish the task and 8% weren't successful, considering the 30-second time threshold. For it being a critical engineering system, it is highly important to estipulate a limit of time to execute a task.

5.4 Activity 2: Consulting information from an equipment and altering its operation state afterwards

In this task, the operator needed to consult the information about a designated circuit breaker (status, alarm, simulated mode) and alter its state (open to closed and vice-versa) afterwards, having a 45-second time threshold. Figure 12 shows the results regarding this activity.

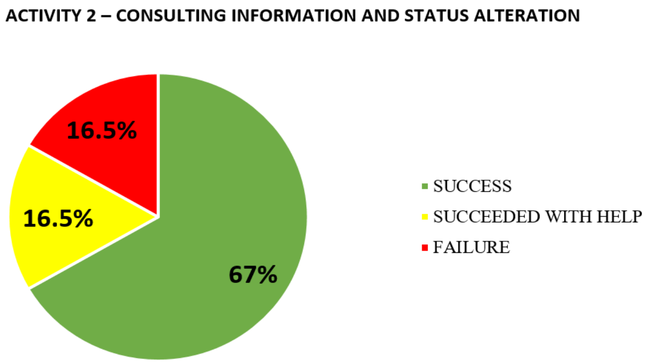

Fig. 12: Graph regarding the activity "Consulting Information and Status Alteration".

This performed task is considered routine and common in the substations' operation context, and as the presented result, most of the operators managed to accomplish it with total success, while only 16,5% needed help to accomplish and the same percentage of operators couldn't succeed in the given time.
Lastly, it is important to point out that approximately 83,3% of the operators that took part in these processes said that they've already had previous experience with a kind of three-dimensional virtual interactive environment.

6. Conclusion and Future Projects

As mentioned before, it is crucial that the operator can assimilate his/her operation interface in a way that there's no difference between it and the field reality, and for this purpose, it is important to develop strategies that transmit spatial and functional information.
Interaction concepts and techniques in a Virtual Reality can favor the intuitive and natural operation notion, which is strongly requested in engineering systems operation contexts. Thus, this project presented a new strategy and examples of representation and interaction of the user interfaces, that in turn, can act as a complementary method to the current operation ones.
Therefore, it is believed that the system proposed here contributes to a positive and more natural aspect in the substations operation process, consequently, an ally in the search to improve the quality and continuity in the electric power supply.
In this context, all operators will need to be exhaustively trained to use the VR system. An uncontested advantage is that this training will be potentialized since there is no need to dislocate to the field, saving time and accelerating the results. As it can be seen in the applied tests, the proposed system is satisfying and it's also easy to use.
However, it is necessary to be aware that Virtual Reality projects allow the virtualization of real and specific environments, representing routine paradigms breakage in the control and operation, creating a barrier in introducing these interfaces in Operation Centers, and needs to be thoroughly studied and planned.
Nowadays, this system is found implanted an energy electric company of Minas Gerais in operation center, and as future projects in this research, it is intended to analyze other error-promoting conditions faced in engineering systems and build new strategies to minimize their impacts of them in the electric power substations operation context.

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