Training in Virtual Environments for Hybrid Power Plant

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Abstract. This article describes a Virtual Environments application of a Hybrid Power Plant, for professionals in Electrical Power Systems training. The application is developed in the Game Engine Unity 3D and features three different modes as: immersion, interaction and failure modes, which enhance professional's skills through visualization of the plant components and different processes operation. Additionally, failure mode is proposed, it simulates wrong maneuvers consequences and effects. The Generation Environment is integrated by wind turbines and photovoltaic panels that interact through a mathematical model and enables manipulation of dependent variables bringing out a more realistic background.

Keywords: Virtual Reality Training, Hybrid Power Plant, Mathematical Model, Game Engine Unity 3D, Immersive and Interactive Environments

1   Introduction

In recent years, technology has shown great interest in improving methods and skills in training processes in different areas such as education, medicine and especially in industrial processes, thus allowing an increasement in operators and instrumentalist's experience at work [1]. The industrial technology has incorporated simulators and programming languages to represent and emulate the operation of different processes in real time, due to the fact that operation maintenance and maneuvers require meaningful resources, it is important to mention that by associating these technological tools with the different engineering branches, great advantages are obtained, *e.g.,* in Electromechanical Engineering, it allows to have a constant calibrations maintenance and electrical and mechanical components adjustments, where the main responsible is the operator at performing these procedures [2, 3]. On the other hand, Electric Power Systems are permanently delivering energy and require constant monitoring of the Generation and Transmission System, *i.e.,* their maintenance is essential and the maneuvers performed are dangerous [4, 5]. Although computational technologies are found in all engineering branches, lately it has grown significantly in renewable energies field, the main objective of it, is helping the designer in planning and impact assessment processes of wind and solar power plants. [6, 7].

One of the computer technologies developed in recent years is virtual environments training, this tool leads the future of learning processes in education and professional fields, making a turn into traditional classroom-based method with exclusively theorical learning and the limited availability of laboratories for practices and training due to different factors such as time, infrastructure, costs and other resources. Simulation software used in information technology and computing allow students and professionals to infer the problem in any experiment performed on a computer [8]. These immersive technologies are being used to undergo into new methods of training in engineering subjects, allowing the identification, analysis and diagnosis of failures that take place among man-machine interaction [9]. It is important to mention that Virtual Reality as a learning tool has two key concepts, immersion and interaction. There are several immersion software's, which help motivating learning and encourage interest in this type of teaching tool where visualization equipment and graphic software converge; while in the field of virtual interaction there is a certain difficulty, due to the complexity of developing them, in having complete dynamic control of all the components that intervene in their environment [10,11].

The contribution generated by Virtual Reality in teaching and learning in all of engineering fields and especially in Electrical Power Systems, has allowed a strengthening in practice, due to the complexity and danger of real electrical equipment, Therefore, the performance of all these virtual maneuver tests represents a great advantage, allowing professionals to improve the operation protocols and constant maintenance of the electrical and mechanical installations [12]. Studies related above have proposed several applications of Virtual Immersion in EPS, such is the case, Barreto *et al.* Implements a methodology to create virtual scenes of electrical substations, which allows the acquisition of 3D models to improve communication between the operating room and the field [5]. Galván *et al.* Poses an application for the training of operators in underground electrical distribution lines, this system incorporates different maintenance and operation maneuvers for medium and low voltage underground distribution networks [13]. Barata *et al.* Incorporates a transformer testing system using a virtual reality application for maintenance and operations procedure for optimum performance [13]. The virtual applications mentioned above provide great advantages, however, there are some cons, because the user only has the feeling of being inside this environment, but not of being able to interact with it. Virtual reality has the advantage of being safe, controllable, less expensive and improves learning and training outcomes [15, 16].

This paper features the development of a VR application where students and professionals can be trained in Hybrid Generation Systems, ensuring a correct analysis and diagnosis of it, *i.e.,* can be trained not only in an immersive environment but can also interact with the different components of the application. In order to have a better dynamic interaction with the energy variables involved in the Hybrid Power Plant, a mathematical model of a wind turbine and a photovoltaic panel is determined. In addition, a substation is interlinked to the Generation Plant, which raises the voltage level for subsequent transmission systems, where it is possible to observe and interact with all the major components of the application, *e.g;* instrument transformer, bus bars, circuit breakers, break switches, relays and the power transformer as a fundamental

element of a substation. Additionally, it is possible to carry out all the operation protocols, observe the failures and destruction effects that the whole system can present due to bad maneuvers.

2   Problem Formulation

Nowadays, the teaching methods implemented in professional training in the area of Electrical Power Systems have certain limitations, because they do not provide adequate techniques to improve the skills of the operator. Many of these methods have been innovated by means of graphic simulators, notably replacing traditional and classical teaching such as 2D diagrams and plans. Therefore, in order to reduce risks, prevent damage to equipment and specially to involved personnel, the aim is to improve training through an application of a 3D virtual immersion and interaction environment, providing the professional the ability to analyze and make correct decisions in operation and maintenance procedures.

As described above, this work poses the development of a virtual reality application for the training of a Hybrid Generation Plant interlinked to an Elevation Substation. The application presents three training modalities: *i) Presentation*, in this scene you will be able to visualize and monitor all the components of this application, such as, electrical substation, wind turbines, solar panels and control rooms; *ii) Interaction*, in this mode, the operator will be trained by performing guided maneuvers through operating instructions within an electrical substation; *iii) Failure Modes*, in this space there are failures shown in different stages of the generation process, where the damages that can be caused can be observed. To achieve immersion and interaction, a virtual reality helmet and haptic input controls are used to interact with the environment; In addition, a control system for the generation stage is developed using a mathematical model of a wind turbine and a photovoltaic panel. The link between these input devices and the control system will respond to the actions performed by the user through the virtual environment developed in the Game Engine Unity 3D.

The Fig.1 presents the component interrelation diagram, the first phase contains the *Game Objects* required for the virtual appliance, where the interaction methods are linked to the *Grab Object Controller* to manipulate and verify the behavior of all 3D models in the virtual environment. In this phase, energy variables are used to simulate a generation process identical to a real one.

In the *Input* and *Output* phase many devices that allow immersion and interaction are considered with the virtual environment, e.g. virtual reality helmet types (*HTC VIVE* and *Gear VR*) and haptic input controls. This application has a universal code with different inputs and outputs, which allow to automatically detect the devices and their compatibility with various platforms, avoiding errors and project reconstructions.

The *Scripts Module* is responsible for managing communication between input, output and control block devices through the *APP Manager*, providing an efficient functionality of the virtual environment. The user will be able to select the virtual training mode through the user interface providing a dive (technical observation of the system) or interaction (operation and failure modes), where the *Grab Object Controller*

will allow manipulation of the virtual environment components and the location within the Power Generation System. In addition, this application has a Multiuser Support allowing the interaction of several users in the application at the same time.
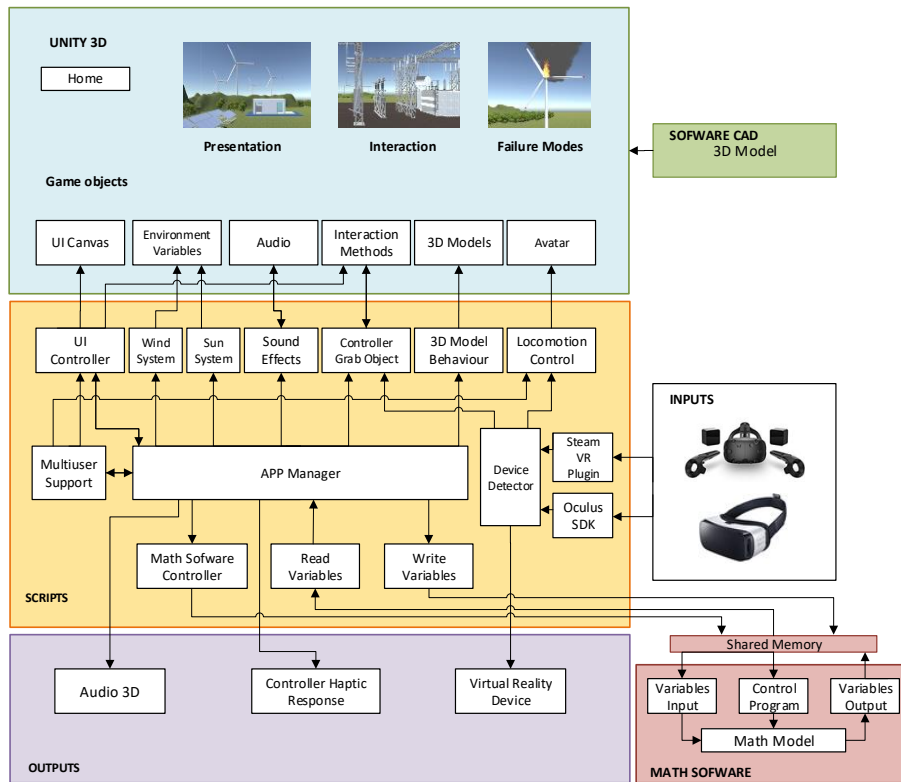
Fig 1. Component Interrelation Diagram

The *Mathematical Software Module* poses a modeling system for a wind turbine and a photovoltaic panel, in this process the input variables of wind and solar irradiation originated in the Game Engine Unity 3D are directly linked to the modeling process through mathematical formulations and relationships between operating variables. Output energy variables such as power, voltage, current, rotor speed return to the virtual application through a shared memory, with the aim of visualizing and monitoring the generation system for better immersion and interaction.

Finally, the *Output Module* provides the user a real feeling through total immersive audio, a haptic response system to the inputs to increase the level of interaction and tracking of user movements within the virtual environment.

3 Virtual Interaction and Immersion

A Virtual Reality application must integrate aspects that, mixed together, allow users a complete immersion and interaction in a virtual environment. The virtual application is developed in Fig. 2.

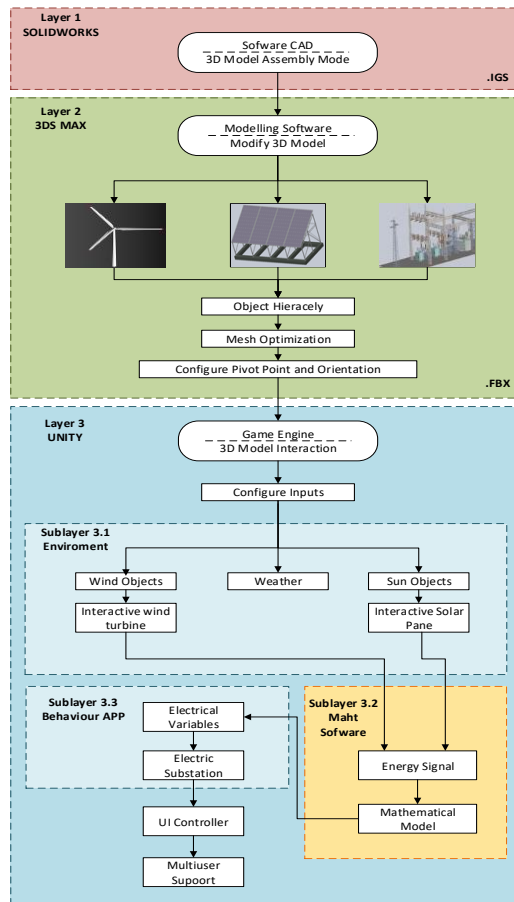**Fig 2**. VR. Application developed in the Game Engine Unity 3D

Fig 3. Virtualization Model

To develop and perform this work, a multi-layer scheme that considers different types of blocks is proposed in Fig. 3.

Layer 1 is the first phase of the virtualization model, here a CAD software; SOLIDWORKS is being used, these design tool allows an integrated work flow that evolves creation steps, importing of parts, assembly and validation of all 3D parts that conform this virtual application, e.g., mechanical parts of the wind turbines, photovoltaic panels, electromechanical components of the substation, control room, and the entire hybrid generation plant, within others, as shown in Fig. 4. At the end of this phase every part needs to be saved or exported with a *.IGS extension which is compatible with 3DS MAX, software required for next phase of virtualization.
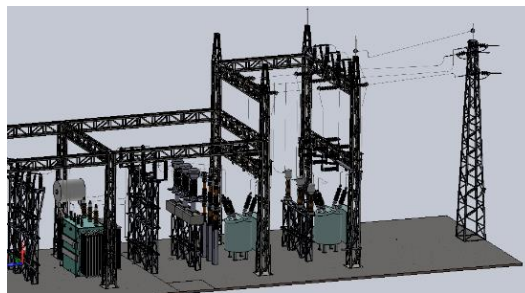
Fig 4. Electrical Substation developed in SolidWorks

Layer 2 In this phase 3D models are imported and developed in the CAD software 3DS MAX, model parts hierarchy is defined, these are arranged according to the assembly, the number of elements, and positioning and movement restrictions of every single part. It also allows orientating and location of the parts of the model through reference parts (Pivot Points). Finally, a *.FBX file is obtained which is totally compatible with the Game Engine Unity 3D where de application will be developed.

Layer 3 In the third phase a platform will be developed where the simulation of virtual 3D will be performed being this Game Engine Unity 3D. In this application the scenes of different virtualization and training are built. The configuration of entries for interaction of mobile items which build the 3D model and input devices such as HTC VIVE and Gear VR that allow an interface between the user and the virtual application, it is developed using the OnTriggerEnter, OnTriggerStay, OnTriggerExit functions. For manipulation of mobile device and the Trigger or Grop, emphasizing the collider for object movements. The user in the virtual environment can transfer to a desired point in the surface, by pointing towards the reference point where it wants to locate, this by the implementation of teleportation.

Sublayer 3.1 This scene proposes a virtual interaction with photovoltaic panels and wind turbine environments with GamesObjects (Wind and Solar Zone).
Wind Zone, allows having a wind zone to interact directly with the blades of the wind turbine movements in a realistic mode, simulating primary wind generation conditions.
Solar Zone, the created environment for photovoltaic panels, has the solar light intensity, generating variables with irradiance characteristics and direction, causing a better sense of realism in the environment, as well as having the possibility to simulate world places with weather conditions and interpret generation data according to geographic location.

Sublayer 3.2 The mathematic modeling is essential in the application, this allows having a better interaction with the electric generating objects which are wind turbines and photovoltaic panels, improving its operation performance, based on an interactive variable from Game Engine Unity 3D, MATLAB and Simulink.
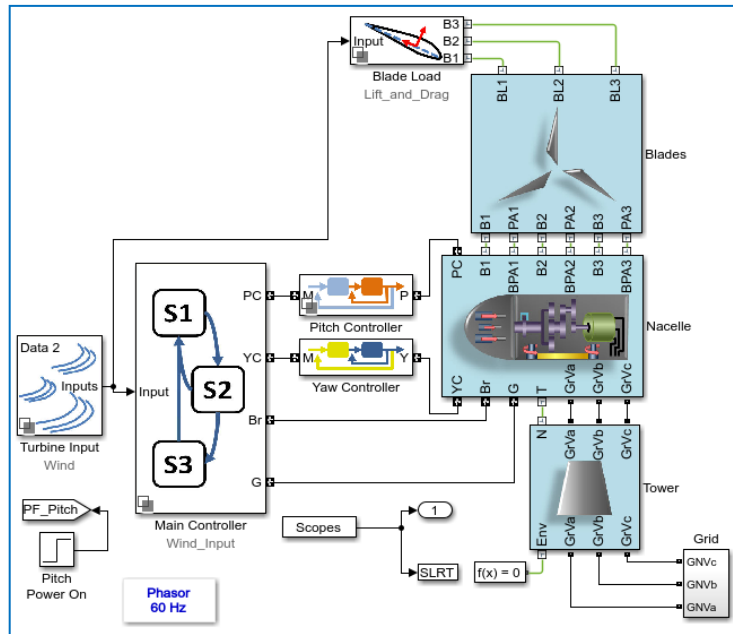
Fig 5. Mathematical Model of the Wind Turbine

The wind turbine modeling as shown in Fig. 5 is provided directly from *MathWorks Simulink*. This is a high-level visual programing method tool, that works under MATLAB software, due to it, simulates physics, mathematic, hydraulic, and other systems in real time.

Sublayer 3.3 This layer represents the electrical dependent variables obtained from the mathematical models and the independent variables involved in each of them. The data is obtained in the control room for its operation, monitoring and verifying its variation according to weather conditions for electric generation. Once this process is accomplished, transmission of electric energy is required through an elevation single bus bar substation. The training process in these electrical transformation centers is important because there is a lack of accessibility and several safety protocols, so the user can interact and activate the elements that are part of the substation, assuming safety and operation parameters, as well as maneuvering the control room.

Finally, the virtual environment has a multi-user interface, which allows several people to be connected at the same time for training, with an application with three modes: presentation, interaction and failure modes.

4   Results and Discussion

In this section, the virtual simulation environment of a Power Plant System is displayed (wind turbine, photovoltaic panels and electrical substation). The user can interact in a dynamic mode with the different elements and devices of the system as shown in Fig. 6.

**Fig 6.** Virtual Environment System and Experimental tests developed

Immersion Mode, this application displays a virtual environment where the professional is involved in the area of Electrical Power Systems, the user is able to visualize the power wind plant get inside the wind turbine tower to identify interior elements, such as bearings, power shaft, gear box, electric generator, control panel, anemometer and other (See Fig. 7). In addition, it consists of an electrical substation, control and maneuvers stations where all the electromechanical components can be inspected and the plant generation stage supervised as shown in Fig. 8.
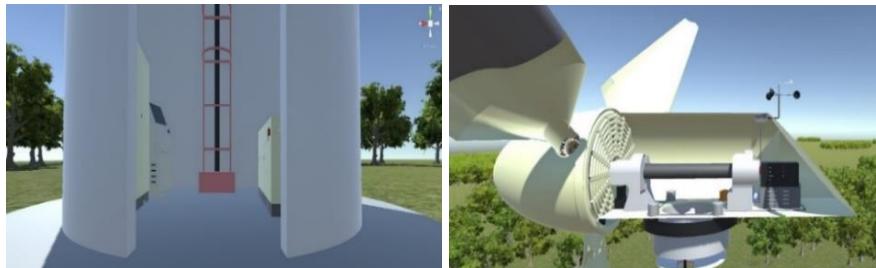
(a) Inside the wind turbine **(b)** Electrical and mechanical parts
**Fig 7.** Immersion in the wind turbine
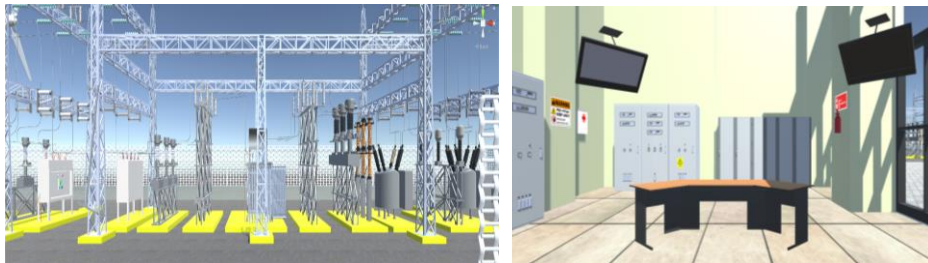
(a) Virtual Electrical Substation **(b)** Control Station
Fig 8. Supervision and maneuvering of the Power Plant

Interactive Mode, this method is important in the development of the application, the user will be able to interact directly with the parts and components of the virtual environment. It will be able to carry out maneuvering protocols in the entire substation under the respective safety standards. A comparison is made between the classical method and our virtual application in the Fig 9. It can be appreciated that the training methodology surpasses the traditional method, because the professional will be able to observe and interact with each of the elements involved in the process of maneuvers, leaving obsolete the classical method consisting of plans and electrical symbols.
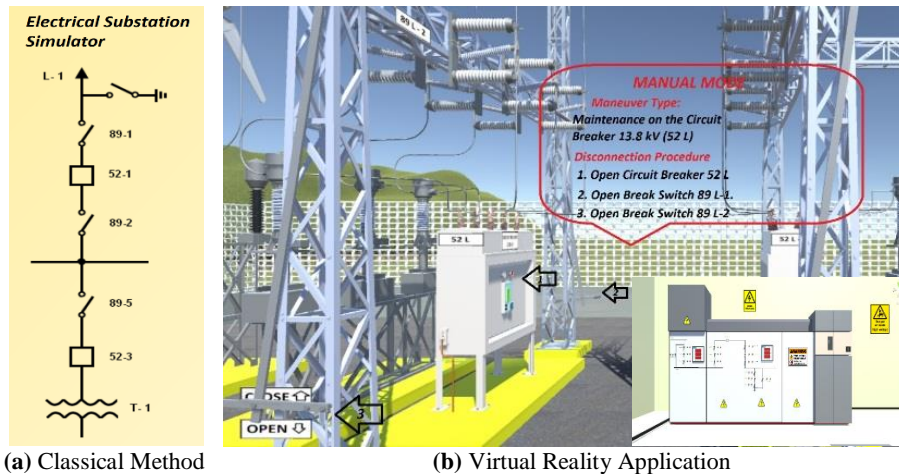

(a) Classical Method   **(b)** Virtual Reality Application
Fig 9. Training Methods

Failure Mode, In Fig. 10 a). It shows a wind turbine that suffered an overload of energy in the system, this originated the combustion of the lubrication system and fire the nacelle. This disturbance was implemented in the mathematical model of the wind turbine, specifically in the regulator, forcing it not to control the energy in the accumulators, which later led to an inevitable fire, thus losing economic resources and human lives. Fig. 10 b) shows a fire of a break switch in an electrical substation caused by a bad maneuver of the operator, this is done by virtual programming to give the corresponding graphic and sound realism at the time of causing a fire and explosion.
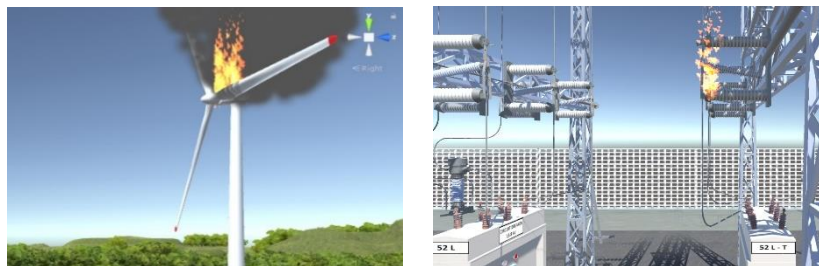

(a) Fire in the wind turbine   **(b)** Fire in the Break Switch
Fig 10. Simulation of failure modes in the Power Plant

Finally, to determine the efficiency of the application a test is proposed to the technical participants in this area; each of them received an induction on the operation of the two training methods, with the objective of carrying out an operations protocol to connect and disconnect the electrical substation. Fig 11 shows the results obtained.
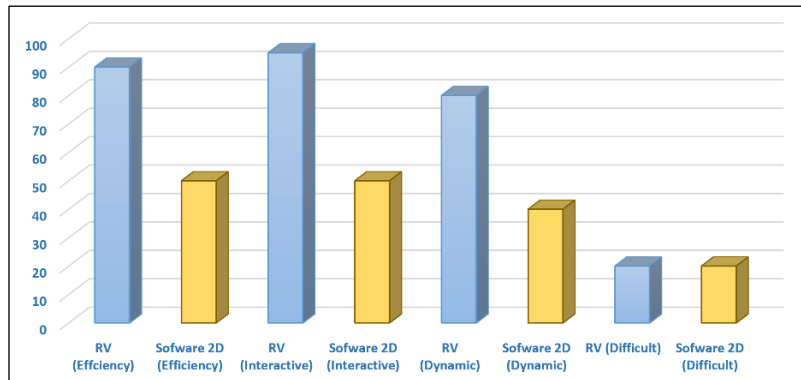
Fig 11. Training System Evaluation Results

The results obtained indicate that our Virtual Application contributes with the learning and development of skills of the professional in this area, because it allows to identify and interact with all the electromechanical components of a Power Plant.

5   Conclusions

In this article, an application of virtual training in a Hybrid Power Plant is being proposed for Electrical Power Systems professionals. This virtual simulation environment is being developed in the Game Engine Unity 3D, where the user is able to have a better immersion and interaction with all the devices implemented during the learning process, optimizing economic resources, as well as infrastructure and time. The experimental results obtained show a greater efficiency of the application, developing a friendly human-machine interaction with the development of skills and strengths in the Electrical Power Systems.

6   Acknowledgements

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