Development of 3-D virtual electric safety training by applying National Electric Safety Code (NESC)

Sayli Bhide, Bibi Ibrahim, Luis Rabelo
Department of Industrial Engineering and Management Systems
University of Central Florida
4000 Central Florida Blvd, Orlando, Florida – 32816, USA.

Abstract*—Personnel work in close proximity of high electric voltages and are often exposed to electric equipment. Hence, their training on electrical safety is considered crucial. Conventional safety training is provided through lectures, power point slides or newsletters. However, conventional training practices are found to be less engaging. Practical training is difficult to conduct due to safety risks involved in exposing trainees to high voltages. Considering these problems in existing training methods, a virtual simulation based safety training is developed which can act as an aid in conventional training. Simulation based training can provide 3-D visualization of work environment, customizable avatar, real time feedback, capability of interaction and immersion in a risk free manner. Also it helps to overcome language barrier and provides environment for practicing skills. This research project focused on developing a 3-D virtual constructive simulation environment based on rules explained in National Electric Safety Code (NESC) part 1, section 11: protective arrangements in electric supply stations.

***Index Terms*— NESC, electric safety, virtual environment, safety training.**

I. INTRODUCTION

This section describes importance of electric safety and role of simulation based games in training. The development of simulation based training for electric safety that utilizes rules from National Electric Safety Code (NESC) is also described.

A. Electric safety

We live in the era of machines and they are mainly driven by electricity. As a result, almost every human being is exposed to electricity in one way or the other. From 1992 to 2013, on an average 254 fatal injuries were reported every year due to electric hazards in United States [1]. Personnel work in close proximity of high voltages to perform various operations. Professionals like electricians, engineers, power line workers and technicians come in direct contact of electrical equipment utilizing high voltages while office workers and staff come in indirect contact of electric equipment. Workers and operators are exposed to electric hazards during operations like welding, cutting, etc. along with installations and maintenance of equipment. Utility workers work in close proximity of electric supply and transmission. Electric safety is of utmost importance as even momentary contact with high voltage and passage of small current through human body can result in health hazards ranging from temporary tingling to death. Electricity is a serious workplace hazard that could cause electric shock, electrocution, burns, fires and explosions.

B. Simulation Based Training

Virtual reality based simulation training is proving increasingly effective for training personnel on safety. For example, Tulane University used OpenSimulator based virtual activities in their online courses and it was observed that student participation rate increased from 10% to 33% in courses offering virtual activities. Virtual activities based learning was rated higher than conventional online course learning activities and classroom based activities. In terms of engagement, interactivity and understanding content students ranked virtual world activities higher than conventional activities [2]. Virtual simulation based training development has been identified in various industries such as construction, healthcare, machining and defense [3, 4, 5, 6].

A virtual simulation provides environment for practice, interaction and immediate application of knowledge. Virtual environment based activities can complement traditional classroom based teaching approach and support information exchange [7] as well as bridge gap between learning about subject and learning by doing.

C. Virtual environment for electric safety training

Businesses spent about 170 billion dollars every year on occupational injuries and illnesses [8]. Proactive measures are required in industries to avoid injuries that occur at the workplace. Part 1 of National Electric Safety Code (NESC) deals with practical safeguarding of persons during installations, operations and maintenance of equipment in electric supply stations [9]. Conventional safety training in classroom environment is known to be less engaging while real life training in the presence of high voltages has limited scope due to safety risks and costs involved. In order to create an interactive, efficient, safe and cost-effective electric safety training module for personnel, this research implemented various aspects of NESC part 1, section 11 into a 3-D virtual constructive simulation environment.

In this research project, an electric supply substation along with avatars of participants is modeled in OpenSimulator using Linden Scripting Language (LSL). Various NESC requirements and risks in workplace are modeled that personnel working at a substation could face in real life during installations, operations and maintenance activities such as firefighting or enclosing electric equipment. Participants will be able to interact in this virtual substation environment and they will encounter virtual scenarios aimed at challenging their understanding of NESC. Responses will be logged in a database and utilized to provide participants with real time feedback depending on their actions. This project is an effort to create a novel 3-D virtual constructive simulation environment to disseminate the electric safety principles provided in NESC into the masses in an engaging, effective, simplistic and risk-free manner.

II. STANDARDS APPLIED

There are specific standards, guidelines and regulations in place to help eliminate injuries caused due to electricity. They address qualification, tools, protective equipment, and approval level as well as provide cautionary information. National Electric Safety Code (NESC) is concerned with safeguarding of persons, utility facilities and property that is affected during installations, maintenance and operation of electric supply and communication facilities.

Generally, electricity is generated at large power plants located away from heavily populated areas by electromechanical generators typically using fossil based or nuclear fuel. Then the generated electricity is stepped up to a higher voltage and is transmitted over long distances to power substations. After arriving at substation, voltage is stepped down again to a distribution level voltage. Finally the power is again stepped down from distribution voltage to service voltage which is then utilized by customers at homes, offices or factories [10]. Hence, electricity is not only present in closed places like office or house to operate machines but it can also be observed outdoors in overhead wires, transformers, etc. which allow to transmit and distribute electricity from one point to other.

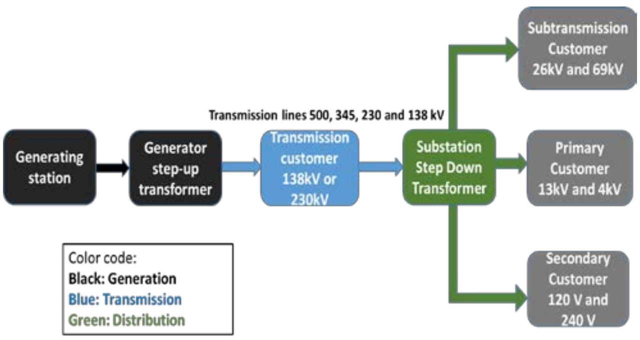

Figure 1 Basic electric system structure [11]

National Electric Safety Code (NESC) covers line side electrical safety while NEC and NFPA 70 are concerned for load side electric safety as shown in figure 2. Section IV elaborates on various NESC rules applied in the proposed research.

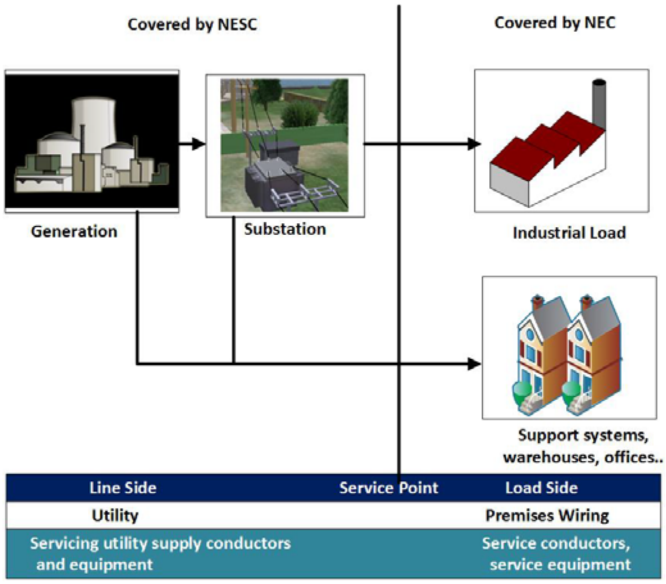

Figure 2 Scope of NESC and NEC [9, 12]

III. THE FRAMEWORK

This section explains dimensions to the development of safety training that educate personnel on risks involved in surroundings and train on mitigating those risks. The framework is shown in figure 3.

A. Content development

NESC part 1, section 11 focuses on protective requirements in electric supply rooms. Content for electrical simulation development is based on requirements explained in this section.

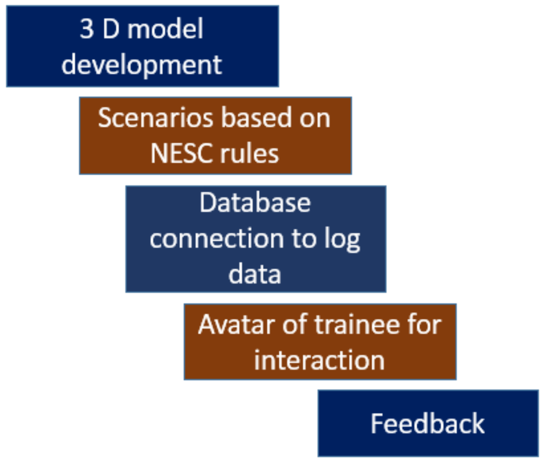

Figure 3 The framework for development of virtual electric safety training

B. 3- D Environment

OpenSimulator platform was used to develop 3D environment for virtual electric safety training. OpenSimulator is an open source platform which supports persistent simulation, stable virtual environment and content portability

[13]. Players can customize their avatar by choosing avatar's clothes, shoes, etc. Also, OpenSimulator allows user avatars to communicate with each other using voice calling, instant messaging and chat options.

OpenSimulator was selected for development of constructive virtual simulation training for electric safety considering advantages such as high performance, lower cost and ease of programming. OpenSimulator, utilizes Linden Scripting Language (LSL) which follows structure similar to widely used programming languages C and Java. LSL is a simple and powerful scripting language that is used to create interactive content and to control and manipulate objects in the simulated environment. Primitive objects are the basic building blocks in OpenSimulator that are used to develop 3D objects ranging from large buildings to furniture and clothing. Primitive objects can be provided with behavior using scripts written in LSL. Participants will be able to see a three-dimensional model of the environment on a computer screen and interact with it by simply using a keyboard and mouse through an avatar.

C. Development of 3D models

The next step was the development of 3D models. Various real world electrical equipment such as electric poles, transformer, bus bars, fire extinguishing equipment, etc. were modeled by utilizing primitive objects in OpenSimulator. Model of electrical equipment were developed based on real world measurements. For example, while developing model of electric poles it was taken into consideration that real utility electric pole's height is 40 feet (12 meter) in general, while 2 meter is buried in ground in the United States [14].

(a) (b)

Figure 4 (a) Avatar of a trainee, (b) electric substation in virtual world

Avatar of a trainee is a 3D representation of a person who can walk, run, touch and interact with other objects in virtual world as shown in figure 4(a). Figure 4(b) shows modeling of substation with transformer, electric poles and electric wires.

D. Scenario Development

Development of virtual electric safety training was divided into 2 parts. In part one, basic electrical safety related knowledge was tested while part two focused on scenarios based on NESC part 1, section 11. Scenario development is explained in detail in next section. In order to make trainee aware of the interaction and controlling avatar in virtual environment, at the beginning of the virtual training, a small introduction was provided.

E. Feedback

Feedback is an important aspect offered in simulation based training that enhances experiential learning process. Feedback can be delayed or immediate; where immediate feedback is provided depending on trainee's actions in an environment which results in temporary interruption of task. On the other hand delayed feedback is either provided after every task/scenario (known as formative feedback) or after completing entire training session (also called summative feedback) [15, 16].

In virtual electrical safety training, both- formative and summative feedback are utilized. For example, while avatar is walking in the simulated environment, a scenario based on NESC code is simulated and avatar is asked questions or to take specific actions. A dialog box opens up on the screen asking question along with options from which a correct answer needs to be selected. Depending on the selection of option, feedback is provided to trainee. Also, at the end of the exercise i.e. when participant has successfully completed all the tasks, summative feedback is provided to participant about various actions taken during the exercise.

Developers can program most of the desired functionality using LSL. However, in the default state, the actions performed by participants in virtual environment are not available later for data analysis. In order to achieve persistent data storage functionality, MySQL database is used in this research. Response of trainee will be saved in a database which can be utilized for further analysis and providing feedback to the trainee.

PHP is a widely used open source general purpose scripting language [17]. Virtual world based on OpenSimulator is running on one web server while MySQL database is working on another web server. Hence, there is a need of a mediating tool that can capture data from virtual world and save it to database. To serve the purpose of communicating between virtual environment and database, PHP scripting was used. When trainee touched an object, she was displayed with a task and her response to the task was sent over internet and written in database table using PHP script. Also, PHP script was used to retrieve information such as final scores from database which were displayed to the trainee at the end of the simulation game.

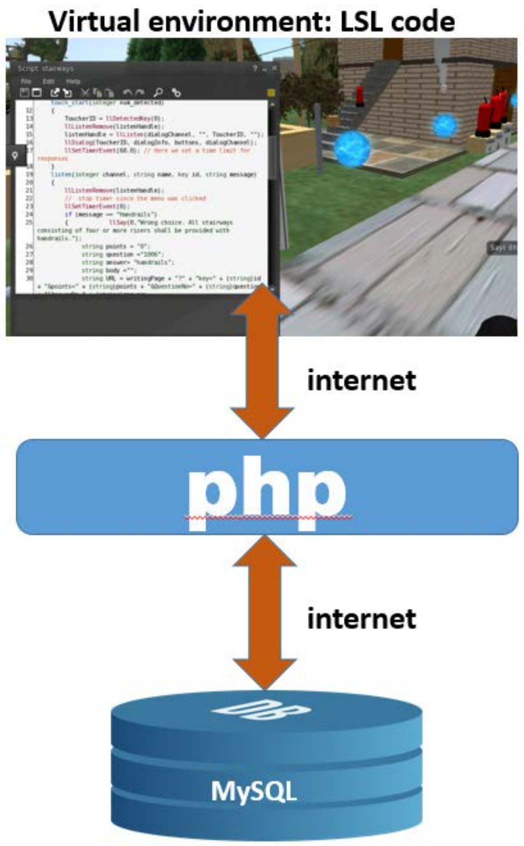

Figure 5 OpenSim and database

IV. VIRTUAL SIMULATION BASED ELECTRICAL SAFETY TRAINING

Virtual training module for electrical safety begins with basic electric safety related knowledge. Scenarios are briefly explained in this section.

A. Scenario 1: Electric shock

Electric Shock is a phenomenon in which human body becomes part of an electric/ electronic circuit. When a person comes in contact with both conductors in a circuit, a person provides a path between ground and ungrounded conductor or conducting material that is in contact with ungrounded conductor [18].

To test basic understanding of trainee on electric shock concept, a scenario was displayed where an electric wire has fallen over a parked car as shown in figure 6. Trainee was asked question to identify safest action to take in such situation and different answer options were provided.

Figure 6 Electric shock scenario

B. Scenario 2: Electricity and Environmental factors

The most common reasons behind electric accidents are unsafe actions of humans around electric machines. However, environmental causes such as lightning, presence of conducting materials and impurities in the environment can also result in electric hazards. Pure water is a bad conductor of electricity, however, small amounts of impurities like salts can turn water into a good conductor of electricity. Anyone working in a damp, wet environment needs to be extra cautious to avoid electric hazards [18]. Hence, a scenario was developed to test knowledge of environmental causes where three ladders made of different materials and placed in different environment were displayed and trainee was asked to identify most appropriate ladder to operate near electricity as shown in figure 7.

Figure 7 Electricity and environmental factors scenario in the training

C. Scenario 3: PPE near electric hazards

Personal protective equipment (PPE) such as hard hat and safety glasses are some of the important control measures against electric hazards. Employees should be trained on when to use PPE, how to wear PPE, remove PPE and limitations on PPE. Also, employers should enforce the use of PPE [19]. Insulating gloves provide insulation against electric current. They come in different types and voltage ratings. If an explosion occurs or an employee receives electric shock there is a possibility of getting thrown away or struck by objects. In such circumstances, use of hard hat can protect one from head injury. Employees who might get exposed to electric hazards should wear protective footwear with non-conductive electrical shock resistant soles and heals. Flame Clothing made from self-extinguishing fabrics, designed to limit burn injury is necessary in case there is possibility of exposure to high voltage and energized circuits. A scenario was modeled to emphasize on importance of PPE as shown in figure below:

Figure 8 Scenario with PPE in virtual electric training

After basic electric safety scenarios trainees faced scenarios based on National Electric Safety Code (NESC), part 1, section 11.

D. Scenario 4: Enclosure of equipment

NESC section 11, 110 general requirements explain that, “Rooms and spaces in which electric supply conductors or equipment are installed shall be so arranged with fences, screens, partitions, or walls to form an enclosure.” Two scenarios were developed based on fencing related requirements.

In first scenario, three fence fabrics with different heights were displayed and trainee was asked to choose fence fabric that is in accordance with NESC requirements as shown in figure 9. Once trainee selected one of the three fences, he/she was shown with feedback.

Figure 9 Fence height scenario in virtual electric training

In the next scenario, four fence fabrics were shown to trainee and he/she were asked to select the one that did not follow NSEC requirement for fencing as shown in figure 10.

First option was based on requirements for fence fabric as explained in section 11, 110. 1. Types of enclosures. Trainee was showed a fence with 6 feet fence fabric and 3 barbed wires in accordance with NESC requirements for fence fabric, “A combination of 1.80 m (6 ft) or more of fence fabric and an extension utilizing three or more strands of barbed wire to achieve an overall height of the fence of not less than2.13 m (7 ft).”

Second and third options were based on section 11, 110 which states: “A safety sign shall be displayed at each entrance. For fenced electric supply stations, a safetysign shall be displayed on each side of the fenced enclosure.” Second option showed 7.5 feet fence fabric with safety sign on both sides of fabric while third option displayed 3D model of fence fabric with safety sign displayed from inside out. Last option showed 3D model of 7.5 feet fence fabric provided with grounding.

Figure 10 Fence requirement rule in virtual electric safety

E. Scenario 5: Fire extinguishing

Rule 114 explains that fire-extinguishing equipment approved for the intended use shall be conveniently located and conspicuously marked. NESC section 42, Rule 420 L states that “In fighting fires or in the vicinity of exposed energized parts of electric supply systems, employees shall use fire extinguishers or materials that are suitable for the purpose.”

Based on these fire extinguishing related rules two scenarios were developed. In first scenario trainees would face a question that asks them about placement of fire extinguisher based on rule 114.

Second scenario was developed where trainee can see smoke coming out of electric equipment stored in electrical room and trainee was asked to identify which fire extinguishing equipment can be utilized to fight the fire. Class A (fires due to wood, plastic, trash etc.), class B (fires involving flammable liquids) and class C (fires involving electrical equipment) fire extinguishers were displayed as options [20].

F. Scenario 6: Exits

Figure 11 shows a scenario that was developed to emphasize on exits related requirements explained in section 11, rule 112 and section 11, rule113.

In this scenario, trainee saw an exit for equipment room with a stairway that did not follow Rule 112 D, Rule 113 A and B. Rule 112 D explains that stairways with four or more risers should be provided with handrails. Rule 113 A explains that all the exits should be kept clear of obstruction, while Rule 113 B clarifies that double exits should be provided for the rooms consisting of equipment such that if an accident closes one exit, another exit should be available.

Figure 11 EXIT related scenario in virtual training

G. Scenario 7: Rooms and spaces

Rule 110 B describes requirements for rooms and spaces in which electric supply equipment is installed. A scenario was developed in virtual electric safety training that focused on rooms consisting of electric installations that should be as much noncombustible as possible and shall not be used for manufacturing and storage. An electrical room with electric switchboard, transformer and furniture was modeled in OpenSimulator and trainee was asked to identify which of the pieces of furniture can be present inside an electric room. Wooden poles that are used to support electrical equipment or conductors are exception to noncombustible material rule.

Figure 12 Electric room storage in virtual environment

After completing all the tasks, trainee will see a final score board which will show summary of performance of trainee.

V. CONCLUSION

This paper explains development of virtual 3D simulation based training based on NESC codes. After receiving IRB approval, authors plan on conducting a research where qualified electrical personal can walk through this virtual training and respond to questionnaire. This study will help us to understand aspects that need to be improved in the training.

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