International Journal for Housing Science and Its Applications
Publish August 6, 2025. Volume 46, Issue 3 Pages 4930-4940

https://doi.org/10.70517/ijhsa463422

Development and Application of Virtual Training Platform for Intelligent Substation Integrating Augmented Reality and Virtual Reality

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Abstract Training of substation trainees using virtual platforms is one of the priorities to realize cost reduction and efficiency. This paper designs an intelligent substation virtual training system containing six modules such as instructor machine to enhance the visualization level of intelligent virtual training. The use of VR technology and other collection of substation power equipment related information, complete the substation actual layout scene modeling, and incorporate a sense of reality in the fault judgment link. Combine with virtual reality engine technology to complete the resource control management of the virtual training platform, and improve the development and design of the platform's practical training scenes. After completing the validity verification, the platform is applied to the training of substation trainees, and its value of use is analyzed in the light of the training results. The results show that the error between the simulation value of relay protection current/voltage and the sampling value of the platform is only 0.7%, 0.5%, 0.2%, 0.9%, which is relatively small. 22-36 years old training trainees, the younger female trainees are more active in the problem feedback. Female trainees had a maximum of 2.4% over male trainees in homework completion and a maximum of 0.47 over O&M theory exam scores.

Index Terms intelligent substation, virtual training platform, VR technology, scene modeling

I. Introduction

In today's rapidly developing information age, augmented reality and virtual reality are gradually penetrating into various fields [1], [2]. At the same time, as the scale of the power grid is getting bigger and bigger, the structure is getting more and more complex, and the number of substations is getting bigger and bigger, the workload of the power grid for substation maintenance and daily operation is getting bigger and bigger [3]-[5]. The existing substation simulation training platform is difficult to make the maintenance personnel quickly master the skills, so the construction of intelligent substation virtual training platform integrating augmented reality and virtual reality technology has become one of the urgent problems to be solved [6]-[8].

Based on augmented reality and virtual reality technology, the intelligent substation virtual training platform can create a virtual learning environment for the trainees to simulate the real scene and provide an immersive experience of the training method, which mainly includes two parts: hardware equipment and software system [9]-[12]. In terms of hardware equipment, virtual reality devices such as head-mounted displays are required for realizing the sense of immersion of learners [13]. As for the software system, corresponding virtual reality applications need to be developed to provide content-rich learning modules [14]. The platform through the simulation of substation simulation operation, to achieve a variety of substation operating conditions display and daily maintenance operations, simulation of substation fault location and accident handling, training students through the helmet display and operating handle and other interactive equipment, to achieve the operation of the 3D virtual reality substation scene equipment interaction function, to improve the training effect, which is conducive to the faster enhancement of the skills of substation equipment maintenance personnel [15]-[18].

In this paper, VR augmented reality technology and virtual reality engine technology are introduced into the development of intelligent substation virtual training platform to enhance the sense of reality in the training process. A multi-module virtual training system is designed by combining the instructor machine, panoramic simulation trainee operator machine, simulation computing device, backstage monitoring equipment, simulation simulation equipment, and substation regulation and control equipment to realize the construction and application of the panoramic view of the simulated power grid. Analyze the differentiated characteristics of electrical equipment, enhance the authenticity of VR technology modeling, and enhance the sense of fault diagnosis proximity. Optimize the scene of the virtual training platform for intelligent substations using virtual reality engine technology drive. Judge whether the designed platform has practicality according to the actual training results.

II. Technical support for the virtual training platform for intelligent substations

This part systematically analyzes the specific application of the relevant technologies of the platform from the overall design of the intelligent substation virtual training platform, the application of VR technology, and the application of virtual reality technology in 3 dimensions.

II. A.System design

Figure 1 shows the framework of the intelligent substation virtual training system. This training system includes an instructor machine, a panoramic simulation trainee operator machine, a simulation computing device, a background monitoring device, a simulation simulation device, and a substation regulation and control device. Among them, the panoramic simulation trainee operator contains a graphics editing module, a simulation control module and a result output module.

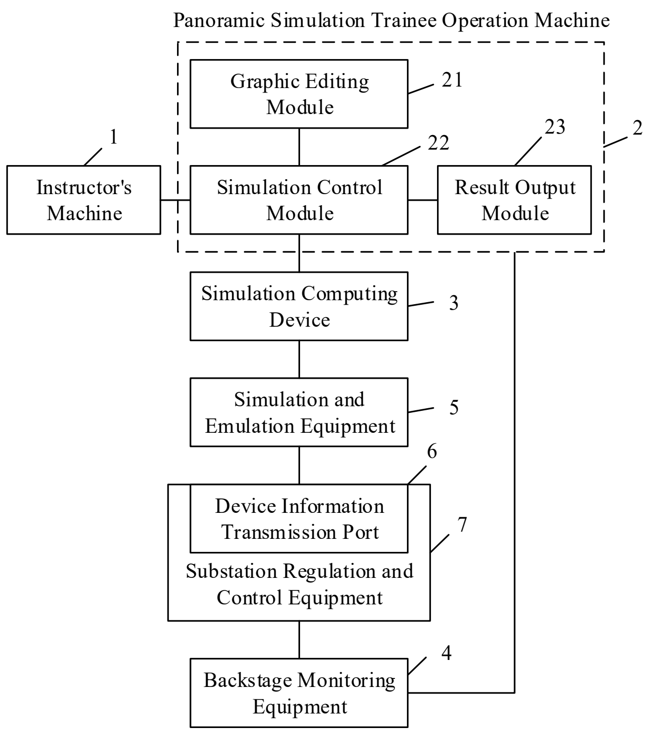

Figure 1: Framework of Virtual Training System for Intelligent Substations

Instructor machine and panoramic simulation trainee operator wired connection, panoramic simulation trainee operator, simulation computing device, simulation simulation equipment successively connected in turn. Substation control equipment and background monitoring equipment wireless connection, background monitoring equipment and panoramic simulation student operator and simulation simulation equipment wired connection. Panoramic simulation trainee operator is connected to the simulation equipment through the I/O interface, and the simulation equipment is used to simulate the transient behavior of the power grid under normal operation and fault operation.

The graphic editing module on the panoramic simulation trainee operator can support the creation and editing of user-defined components UDM (unified data management), and the construction of a panoramic view of the simulated power grid can be completed through simple operation to simulate the operation of the primary system of the intelligent substation, and the simulation process can be controlled through the simulation control module, and the simulation results can be displayed by using the result output module.

II. B.Application of VR technology

II. B. 1) Equipment Modeling

In order to better apply virtual reality technology in the intelligent substation hybrid inspection training system, the characteristics of each electrical device need to be effectively analyzed, mainly including electrical characteristics, action characteristics and physical characteristics. Among them, the static characteristics of the equipment is the physical characteristics, including color and shape, etc.; the electrical characteristics of the equipment refers to the description of the parameters of the electrical equipment, such as resistance, current-carrying capacity, withstand voltage, etc.; the action characteristics of the equipment include the equipment switching/closing speed, action adjustable value and other content.

The information acquisition process of substation power equipment is as follows:

(1) Abstract decomposition of substation power equipment physical characteristics information, according to the DSFO-7-4 standard will be equipment shape abstracted into a number of relatively independent reference points, the physical parameters of each reference point is integrated, the process is as follows:

$$A = \frac{J \times m}{\partial} \quad (1)$$

where J represents the shape data collection of substation power equipment information collected using VR technology; ∂ represents the number of reference points; and m represents the actual measurement value of equipment information obtained using VR technology.

Through the above fusion result, the corresponding shape data object of each reference point is obtained.

(2) Identify the electrical characteristic information of the equipment, and complete the decomposition and categorization of the electrical characteristic information according to the actual function of the equipment. Since the electrical nodes and functions of the equipment in the substation are different, the electrical node data of different functions are processed as follows:

$$W = \beta \times \sum_{e} i \times \frac{H}{l_e} \quad (2)$$

Among them, β represents the weight factor, indicating the relative importance of the type electrical function, with a value range between 0.1 and 1.1; H represents the electrical collection data of different electrical equipment; $\sum_{e} i$ represents the electrical information of electrical equipment i; and l_e represents the type of electrical information.

3) Combine the above processes to construct the 3D solid model of electrical equipment according to the characteristics of substation equipment action. The process of 3D modeling of each electrical equipment is realized by the 3D design function of Solid Works. At the same time, 3DMax technology is used to implement texture mapping rendering of the equipment material pictures taken on site to better show the material characteristics of the electrical equipment. Taking the main transformer pressure gauge as an example, the main transformer pressure gauge inspection scene constructed under the joint action of Solid Works and 3DMax shows that the proposed system is able to visualize the data of the inspected transformer pressure gauge, and discover abnormalities of the electrical transformer in time by collecting and digging out the pressure data of the transformer in different time periods.

II. B. 2) Scene modeling

Taking the actual layout and characteristics of the substation as a reference, VR and 3DMax technologies are used to simulate the scene for the system and create a 3D virtual substation scene. Firstly, the scene information fusion is carried out, and its affiliation degree is analyzed by combining the principle of discriminant analysis to establish the substation scene information association domain. On this basis, the scene state determination index value is established, and the process is as follows:

$$Z = \delta \times \frac{c}{V} \quad (3)$$

where V represents the substation scenario state rectification value, the value range is between 0.1 and 1.1; c represents the scenario safety index measurement value; and δ represents the ratio of the scenario safety index measurement value of the operation process to the rated state standard.

Substation virtual scene includes roaming scene, space scene and operation scene. Among them, the roaming scene can show the appearance information of the field primary electrical equipment, protection screen and control room and other units; the spatial scene refers to the overall environment of the substation, such as sunny days and rainy days and other different natural environmental factors under the substation environment information; the operation scene refers to the manipulation of each electrical equipment, such as inspection and maintenance of the main transformer process scene, and so on.

The inspection process of the substation can be accomplished with the help of joystick, mouse and keyboard. Such as circuit breakers and other electrical equipment action characteristics can be seen through the inspection process, greatly enhancing the realism of the substation scene.

Due to the substation equipment in the operation process is very susceptible to the influence of the external environment, therefore, the need to determine the state of the scene information whether there is equipment failure information. Assuming that the rationing alert value is 1.1, the process of calculating the safety level of power equipment status in the virtual scene of the substation is as follows:

$$Y = Z \times \frac{\gamma\mu}{V} \tag{4}$$

Among them, γ represents the fault discrimination parameter, when there is a clear fault, γ takes the value of 0.1, when there is no clear fault, γ takes the value of 1.1, and μ represents the rated power of power equipment. When $Y>1.1$, it means that there is a serious fault problem in the scene; when $Y=1.1$, it means that there is a hidden fault in the scene, which needs to be checked and corrected by professionals in time, and when checking, VR technology can be used to identify the identifiers of the power equipment, and fault judgment and diagnosis can be realized through the intelligent information system of the substation; when $Y<1.1$, it means that the scene is in a safe state.

II. C. Virtual Reality

II. C. 1) Technical principles

The secondary device objects in the virtual reality scene are combined by basic geometrical shapes, the geometrical model of the 3D object is described by mathematical methods, firstly, the transformation matrix is established for each model in the system, the geometrical transformation matrix T_{3D} of the 3D shapes can be expressed by formula (5).

$$T_{3D} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \tag{5}$$

In a virtual reality scene, the translation, rotation, and scaling operations of the model are actually transformations of the matrix T_{3D}, which splits T_{3D} into four submatrices. Table 1 shows the manifestation of the specific transformations acting on the submatrices.

Table 1: The influence of submatrix parameter transformation on the model

Submatrix	Influence of matrix transformation	Submatrix	Influence of matrix transformation
$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$	Geometric transformations such as the scale and rotation of the model	$\begin{bmatrix} a_{14} \\ a_{24} \\ a_{34} \end{bmatrix}$	Projection transformation of the model
$\begin{bmatrix} a_{41} & a_{42} & a_{43} \end{bmatrix}$	Translation transformation of the model	$\begin{bmatrix} a_{44} \end{bmatrix}$	Overall scale transformation of the model

According to Table 1, it can be seen that if the model with coordinates at $P(x,y,z)$ is translated to the position (t_x,t_y,t_z), there are new coordinates after translation transformation as shown in Equation (6):

$$\begin{aligned}[x',y',z',1] &= [x,y,z,1]\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ t_x & t_y & t_z & 1 \end{bmatrix} \\ &= [x+t_x, y+t_y, z+t_z, 1]\end{aligned} \tag{6}$$

If the model is scaled with a scale of (S_x,S_y,S_z), there are new position coordinates after the scaling transformation as shown in equation (7):

$$[x',y',z',1]=[x,y,z,1]\begin{bmatrix} S_x & 0 & 0 & 0 \\ 0 & S_y & 0 & 0 \\ 0 & 0 & S_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{7}$$

If the model is rotated on the coordinate axes, the coordinate transformation formula for rotating the θ angle clockwise relative to the origin of the coordinate system about the x axis is (8):

$$[x',y',z',1]=[x,y,z,1]\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & \sin\theta & 0 \\ 0 & -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{8}$$

The coordinate transformation formula for rotating the θ angle clockwise relative to the origin of the coordinate system about the coordinate axis y-axis is (9):

$$[x',y',z',1]=[x,y,z,1]\begin{bmatrix} \cos\theta & 0 & -\sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ \sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{9}$$

The coordinate transformation formula for rotating the θ angle clockwise relative to the origin of the coordinate system about the coordinate axis z-axis is (10):

$$[x',y',z',1]=[x,y,z,1]\begin{bmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{10}$$

In addition, in the virtual reality scene, the movement of the model needs to be restricted to avoid the phenomenon of two models penetrating each other, so it is necessary to do collision detection on the movement of the object. Hierarchical enclosing box method is currently a more mature method used to detect collision, the use of more regular simple geometric shapes will be complex model objects surrounded by them, according to the enclosing sphere whether the collision occurs to determine whether the collision occurs between the models.

Collision detection firstly constructs the enclosing sphere for the model, let the coordinate transformation range of the object in x-axis is $x_{\min} \sim x_{\max}$, in y-axis is $y_{\min} \sim y_{\max}$, and in z-axis is $z_{\min} \sim z_{\max}$. The radius of the enclosing sphere sphere is r, and the coordinates of the center of the sphere are (x_c, y_c, z_c), then the center of the enclosing sphere sphere and the radius can be calculated according to Eq. (11).

$$\begin{cases} x_c = \frac{1}{2}(x_{\min}+x_{\max}) \\ y_c = \frac{1}{2}(y_{\min}+y_{\max}) \Rightarrow r \\ = \frac{1}{2}\sqrt{(x_{\max}-x_{\min})^2+(y_{\max}-y_{\min})^2+(z_{\max}-z_{\min})^2} \\ z_c = \frac{1}{2}(z_{\min}+z_{\max}) \end{cases} \tag{11}$$

To determine whether the model has collided with coordinate (x, y, z), it can be determined whether the coordinate is located inside the enclosing sphere, and the judgment formula is (12).

$$l=\left\{(x,y,z)^T \mid (x-x_c)^2+(y-y_c)^2+(z-z_c)^2<r^2\right\} \tag{12}$$

Collision detection techniques are used not only to detect whether a collision occurs between models and where the collision occurs, but also to calculate the dynamic response produced by each model after a collision occurs, based on the model type.

II. C. 2) Virtual Reality Engine Architecture

Virtual reality technology is a complex integrated system based on computer graphics, and its realization needs to rely on the virtual reality engine as a driver. In essence, it is a universal development platform based on the underlying programming language, which not only contains model drawing, retrieval, simplification, complementation and reconstruction, but also contains a variety of hardware interaction interfaces, graphic data, functional design, message response mechanism and communication interfaces, etc. At the same time, the virtual engine also controls and manages the data, peripheral devices and other resources in the whole system. Figure 2 shows the engine driver function.

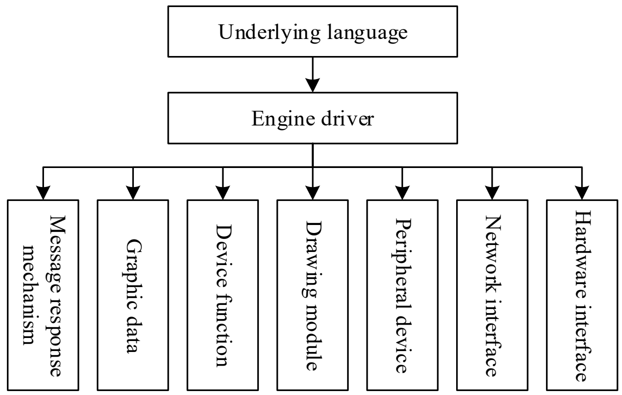

Figure 2: Engine drive function

The Unreal Engine4 selected by the training simulation platform is used as the virtual scene engine for the development and design of intelligent substation simulation training scenes. As a perfect virtual reality engine, it has the following features:

1) Visualized management interface: the visualized management interface allows the trainer to design and adjust the model in the scene and modify the simulation data and training content.

2) Secondary development capability: using Unreal Engine4 as the virtual reality engine, the application oriented mainly to intelligent substation training simulation system, the engine itself does not meet all the needs for substation training simulation, which requires secondary development of the driver engine. By building a program interface that can communicate with all models of the intelligent substation training simulation platform in real time, the data interface is used to complete the routine training tasks of the substation.

3) Data compatibility: data compatibility in this training simulation platform means that the data of the power grid simulation platform and the data of the substation secondary equipment simulation platform can be received by the virtual reality scene and transformed into the specific action behavior of the models in the scene.

Through the above characteristics of Unreal Engine4, the virtual reality scene design of the intelligent substation training simulation platform can be completed, and according to the actual training needs of the specific simulation scenarios for the design planning and secondary development.

III. Validation of the effectiveness of the platform and analysis of the results of its application

In this chapter, the usability of the designed virtual training platform for intelligent substations is first verified through simulation experiments, and then it is applied to the training of substation trainees to analyze the training effect of trainees.

III. A. Intelligent virtual training device power network design

III. A. 1) Simulation of board power supply design

The rationality and stability of the device power supply network play a key role in the working performance of the board. In this section, the system power consumption of the simulation circuit board and the communication circuit board are examined and analyzed respectively, and the power supply design process of the two circuit boards is introduced. Finally, the power consumption and design requirements of the whole device are synthesized to select a suitable power supply battery for the intelligent virtual training device. The power supply voltage required for the emulation circuit board has five voltage levels: 3.5V, 2.5V, 2.0V, 1.5V, 1.3V. After referring to the datasheets of each device and chip, Table 2 organizes the power of the main devices and chips of the handheld training device in accordance with each voltage level. The total power of the five voltages is 2.7818W, 0.0924W, 0.5500W, 0.0300W, 0.2420W, respectively, which can meet the needs of the simulation experiment.

Table 2: Simulated circuit board network power consumption

<table>
<tr><th>Voltage level</th><th>Chip/module</th><th>Current (mA)</th><th>Quantity</th><th>Voltage fluctuation (mV)</th><th>Power (W)</th><th>Total (W)</th></tr>
<tr><td rowspan="3">3.5V</td><td>EP4CGX FPGA</td><td>421</td><td>1</td><td>±160</td><td>1.3870</td><td rowspan="3">2.7818</td></tr>
<tr><td>EP2C FPGA</td><td>47</td><td>5</td><td>±160</td><td>0.6338</td></tr>
<tr><td>Mini-PCIE</td><td>205</td><td>1</td><td>±160</td><td>0.7610</td></tr>
<tr><td rowspan="2">2.5V</td><td>EP4CGX FPGA</td><td>18</td><td>1</td><td>±120</td><td>0.0424</td><td rowspan="2">0.0924</td></tr>
<tr><td>EP2C FPGA</td><td>6</td><td>5</td><td>±120</td><td>0.0500</td></tr>
<tr><td rowspan="2">2.0V</td><td>EP4CGX FPGA_IO</td><td>123</td><td>1</td><td>±95</td><td>0.2150</td><td rowspan="2">0.5500</td></tr>
<tr><td>DDR2</td><td>185</td><td>1</td><td>±105</td><td>0.3350</td></tr>
<tr><td>1.5V</td><td>Mini-PCIE</td><td>205</td><td>1</td><td>±170</td><td>0.0300</td><td>0.0300</td></tr>
<tr><td rowspan="2">1.3V</td><td>EP4CGX
FPGA_CORE</td><td>75</td><td>1</td><td>±55</td><td>0.0885</td><td rowspan="2">0.2420</td></tr>
<tr><td>EP2C
FPGA_CORE</td><td>30</td><td>5</td><td>±55</td><td>0.1535</td></tr>
<tr><td colspan="6">-</td><td>3.6962</td></tr>
</table>

III. A. 2) Analysis of simulation results

After the power supply voltage design is completed, the function of the TPS5430 voltage regulator used in the system is further designed. In order to ensure the normal operation of the regulator, the peripheral circuit parameters are configured accordingly, the parameters include the boost capacitor, input capacitance, output filter circuit, output voltage set point. After the design was completed, this paper used the PSPICE discharge software to simulate the circuit function of the system, in which the model of the regulator was obtained from the TI official website. Figure 3 shows the final simulation results of the 3.5V voltage conversion circuit. The simulation is built exactly according to the design results, and since the maximum output current is 3.5A, the size of the load resistor that can make it reach the maximum current is selected as 1.5Ohm to simulate its operation in the maximum current steady state.VOUT and I(RLOD) finally reach the steady state before the 13V voltage input for 6.5ms, which is exactly the same as the calculated results of the output voltage of 3.7V and the output current of 3.4A, which verifies the TPS circuit function. A, which is in perfect agreement with the calculated output voltage of 3.7V and output current of 3.4A, verifying the correct implementation of the function of the TPS5430 regulator.

In addition, the design of the other power supply chip peripheral circuits in the simulation circuit board power supply network is roughly the same as that of the TPS5430, and this paper also uses the PSPICE simulation software to simulate the simulation power supply board power supply system as a whole. In the model diagram, VIN is 13VDC power input, through the TPS5430 regulator circuit described above, the output is VOUT. Subsequently, VOUT is divided into three ways as the input of TPS73625, TPS73618 and TPS73613 voltage regulator chip, respectively, the circuit construction of these three circuits are configured in accordance with the design requirements, and at the same time carry a suitable decoupling capacitor, the circuit loads were RL1, RL2, RL3, whose values are taken to be 35hm.

The three output voltages are VOUT1, VOUT2, and VOUT3. Figure 4 shows the simulation results of the 3.5V simulation board power supply system. As can be seen from the final simulation results graph, VOUT, VOUT1, VOUT2, VOUT3 output voltages of 12V, 3.3V, 2.0V, 1.5V, respectively. due to the TPS73625, TPS73618 and TPS73613 regulator chip's input is the output voltage of the TPS5430 regulator, when the time to about 6ms, VOUT reaches about 3.5V, the last three regulator chips can reach the trigger voltage to start level conversion, and finally VOUT1, VOUT2, VOUT3 three output voltages reach steady state before and after 10ms, the simulation results support the design of the power distribution circuit to meet the power supply level requirements of the simulation circuit board.

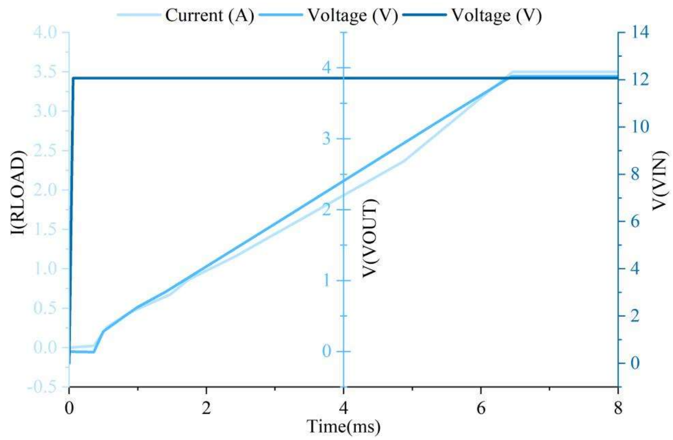

Figure 3: Simulation results of 3.5V voltage conversion circuit

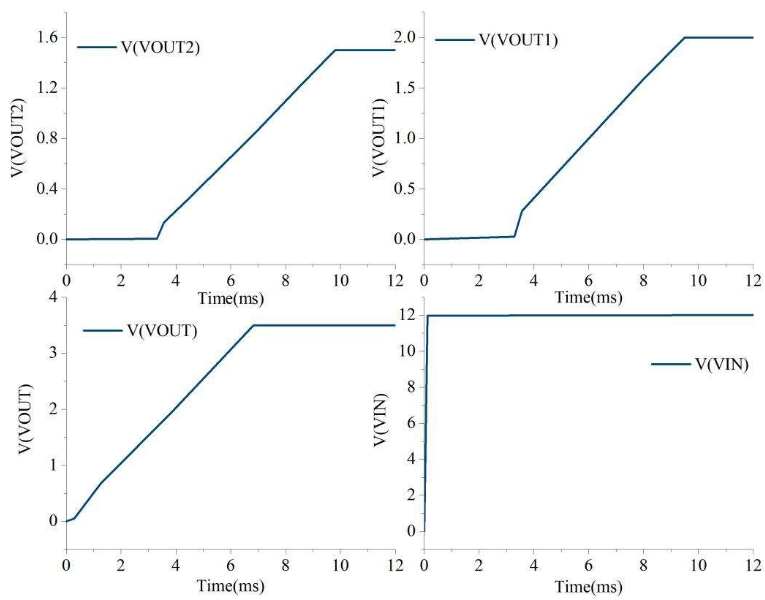

Figure 4: Simulation of 3.5V Simulation Circuit Board Power Supply System

III. B. Virtual Training Platform Application Analysis

III. B. 1) Platform error analysis

In order to verify the performance of the virtual training platform designed in this paper, a large-scale power supply station as the research object, using the designed platform for training. In order to test the training application effect of the simulation platform, the simulation system will be designed with a typical 220kV intelligent substation in this large substation, whose primary system is configured with two main transformers, two outgoing lines for each of 220 and 110kV, and the voltage levels of 220 and 110kV use double busbar connection, and the system is constructed through visualization components, and combined with the simulation training needs of the real world, the system is completed with accurate modeling of the functions of each of the IED devices. The system is constructed by visualization components, combined with the real-life simulation training needs, and the accurate modeling of the functions of the IED equipment is completed. In the experiment, the application performance of the system is tested through the error between the simulated value Tv of the simulation training and the actual sampling value Mv of the secondary equipment, and the error is calculated by the formula:

$$E_r = \frac{T_v - M_v}{T_v} \tag{13}$$

During the simulation training process of the platform, the simulated value of the primary voltage or current of the relay protection equipment and the sampled value of the reagent are observed, and the error between them is calculated by equation (1). Table 3 shows the error between the current simulation value and sampling value of relay protection. Table 4 shows the error between the voltage simulation value and the sampling value of the relay protection. From the results of 0.7%, 0.5%, 0.2%, 0.9% error, the error between the current/voltage simulation value and the sampling value of relay protection is less than 1%, which belongs to the lower level of error, indicating that the simulation training platform is close to the field and has the feasibility of application.

Table 3: Error between the current simulation value and the sampling value

Line	Simulation value /A	Sampling value /A	Error /%	Simulation accuracy requirements
Phase A current of 220 kV line	125.1	124.2	0.7	Suitable
Phase B current of 220 kV line	125.1	124.2	0.7	Suitable
Phase C current of 220 kV line	125.1	124.2	0.7	Suitable
Phase A current of 110 kV line	249.8	251.0	0.5	Suitable
Phase B current of 110 kV line	249.8	251.0	0.5	Suitable
Phase C current of 110 kV line	249.8	251.0	0.5	Suitable

Table 4: Error between the voltage simulation value and the sampling value

Line	Simulation value /V	Sampling value /V	Error /%	Simulation accuracy requirements
220 kV Ⅰ Mother A-phase voltage	127.2	127.5	0.2	Suitable
220 kV Ⅰ Mother B phase voltage	127.2	127.5	0.2	Suitable
220 kV Ⅰ -Mother C-phase voltage	127.2	127.5	0.2	Suitable
220 kV Ⅰ Mother A-phase voltage	127.2	127.5	0.2	Suitable
220 kV Ⅰ Mother B phase voltage	127.2	127.5	0.2	Suitable
220 kV Ⅰ Mother C-phase voltage	127.2	127.5	0.2	Suitable
110 kV Ⅰ Mother A-phase voltage	63.7	64.3	0.9	Suitable
110 kV Ⅰ -Mother phase B voltage	63.7	64.3	0.9	Suitable
110 kV Ⅰ -Mother C-phase voltage	63.7	64.3	0.9	Suitable
110 kV Ⅰ -Mother phase A voltage	63.7	64.3	0.9	Suitable
110 kV Ⅰ Mother B-phase voltage	63.7	64.3	0.9	Suitable
110 kV Ⅰ -Mother C-phase voltage	63.7	64.3	0.9	Suitable

III. B. 2) Analysis of training evaluation results

After verifying through simulation experiments that the error situation of the virtual training platform in this paper meets the training requirements, the virtual training platform is applied to actual training. Taking the number of trainees' problem feedback as a measurement index, the training effect is tested from the perspective of the age group of the trainees who receive the substation operation and maintenance simulation training in a certain training stage, and the test results are shown in Fig. 5. The younger the age of the trainees in the substation operation and maintenance simulation training, the higher the number of question feedbacks in their training phase. At the age of 22 to 24 years, the number of question feedbacks of male trainees during the training phase was slightly lower (14) than that of female trainees (16), and the number of question feedbacks of male trainees gradually decreased with the increase of the age group. Female trainees, on the other hand, consistently had 16 and 14 problem feedbacks between the age groups of 22 and 28 years, with a greater decrease in the number of problem feedbacks with increasing age groups than male trainees. In the age group between 32 and 36 years, the number of question feedbacks was lower for both male and female participants. The above results indicate that the younger age groups had more questions during their participation in the substation operation and maintenance simulation training, were more active in the classroom, and the female trainees were more active than the male trainees [19]-[21].\

Table 5 shows the training effectiveness of male and female trainees in different age groups. In terms of assignment completion and O&M theory test scores, the training effect of female trainees in different age groups is higher than that of male trainees, and the assignment completion and O&M theory test scores of younger male and female trainees are lower than those of the trainees in higher age groups. In the analysis of the perspective of assignment completion, there is not much difference in the value of assignment completion between male and female trainees, and the maximum difference is 2.4%. As for the O&M theory examination scores, the training effect of female trainees is better than that of male trainees, and the maximum difference between the two examination scores is 0.47 points. The above results show that female trainees have better training effect than male trainees in theory learning in different age groups participating in substation operation and maintenance simulation training.

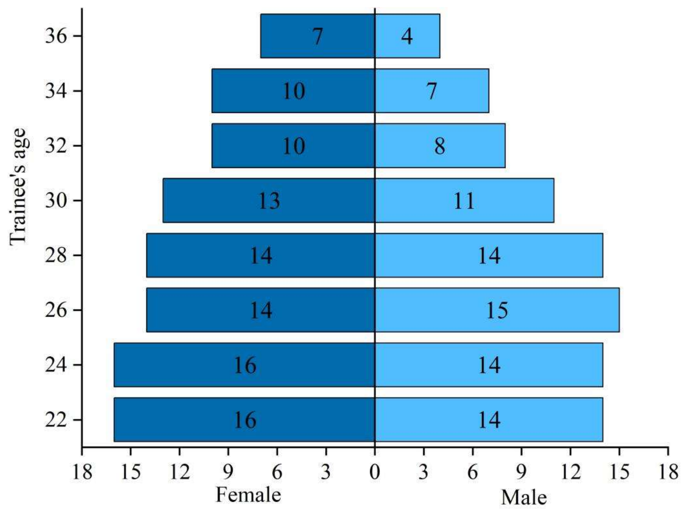

Figure 5: Number of feedbacks on trainees' training issues

Table 5: Training effects of male and female students of different age groups

Age group	Job completion degree (%)		Operation and maintenance theory examination score	
	Male student	Female student	Male student	Female student
22-24	93.0	95.4	9.22	9.69
25-26	93.4	95.6	9.35	9.72
27-28	94.1	96.3	9.43	9.76
29-30	95.4	97.4	9.51	9.78
31-32	96.2	98.6	9.55	9.85
33-34	97.1	98.7	9.63	9.87
35-36	97.6	98.9	9.62	9.89

IV. Conclusion

This paper designs a virtual training platform for intelligent substations, combining VR technology and virtual reality engine technology to realize on-site training for trainees. Combined with the current and voltage simulation error calculation results, it is found that the error between the current simulation value and the sampling value of relay protection is 0.7% and 0.5%, and the error between the voltage simulation value and the sampling value of relay protection is 0.2% and 0.9%. The error is less than 1%. The virtual training platform designed in this paper has good data calculation performance and can realize effective simulation. 22-36 year old trainees in the process of participating in the training process, with the growth of age appears the law of the number of problem feedback decreases, and female trainees are more active than male trainees. Comparing the completion degree of assignments and the scores of the operation and maintenance theory exam, it is found that female trainees have better training effects than male trainees by 2.4% and 0.47 points. In the future, the training data of male trainees can be combined with research to find the reasons for the differences and optimize the training system to improve its training effect.

Funding

This work was supported by State Grid Corporation science s technology project: Research and application of intelligent training system based on configuration algorithm and digital twin technology (project number: 521944240001).

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