Research on Simulation Training System for Substation Equipment Maintenance

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Abstract. Substation equipment is the core component of substation. The occupational skill level of the operation and maintenance personnel is directly related to the safe and stable operation of power grid. Obviously the training for substation equipment maintenance is essential. Virtual simulation training platform for substation equipment maintenance is an effective tool to improve the practical skills of maintenance personnel. Therefore, a realization scheme of the substation equipment maintenance simulation training system is mainly researched in this paper. By configuring maintenance tasks and equipment defects, the automatic generation of equipment maintenance virtual operation scenes and three-dimensional equipment models can be realized in the training system, thereby accomplishing flexible configuration of training tasks. Besides, trainees can be evaluated via the establishment of the maintenance evaluation model. In the actual training application, the equipment patrol and inspection as well as the maintenance process are simulated in the virtual substation scene, which can effectively improve the maintenance skill training effect.

1. Introduction
The operation and maintenance of substation equipment plays a critical role in the safe operation of power grid, which requires the higher skills of substation operation and maintenance personnel. Therefore, it becomes critical to train the personnel engaged in substation operation and maintenance.

At present, the training for substation operation and maintenance personnel is basically carried out by means of theoretical studying, training in manufacturers, on-site probation training during equipment maintenance¹⁻², etc. The methods mentioned above have certain effects, however they have disadvantages. For example, there’s lack of intuitive understanding of actual equipment and operation process in theoretical studying, training in manufacturers is with few opportunities and high costs³, and on-site probation training for equipment maintenance is easily restricted by time, climate and space. Consequently, it is necessary to develop a substation primary equipment maintenance simulation training system pertinently. Then trainees can simulate operation training in the simulation training system to improve their skills in operation, equipment faults handling and defects discernment.

Recently, the equipment maintenance simulation training system has developed rapidly. The overall composition and characteristics of the software system, the functions as well as modules of the software system, and the virtual reality technology as well as the 3D development platform have been introduced and analyzed in many references⁴⁻⁸. Nevertheless, there’s little research on the realization of simulation training system scheme. Herein, this paper studies the substation equipment maintenance
simulation training system and its realization steps, which realizes the automatic generation of equipment maintenance virtual operation scenes and three-dimensional equipment models by configuring maintenance tasks and equipment defects, establishes the maintenance evaluation model to evaluate the trainees’ skills so as to improve the training effectiveness, and introduces the network cache mechanism to reduce the running delay of the simulation training system and improve the working efficiency of the training system. In the actual training application, the simulation training system provides the trainees with the operation scene in the virtual substation. The trainees master the maintenance process in the virtual scene, which improves the skill level of personnel.

2. Overall architecture of the system
The simulation training system of substation equipment maintenance which adopts modular and dynamic software technology is designed according to a multi-layer application system. The overall software architecture is shown in Figure 1, which indicates that three sub-modules are respectively distributed among system servers, network servers and trainee computers.

3. Key steps of the realization of simulation training scheme
3.1. Implementation process
The goal of substation equipment maintenance simulation training system is to carry out simulation training on substation equipment maintenance for the trainees. In the implementation process, the simulation training scheme is the key part which mainly includes three key segments, namely training project generation, virtual operation scene generation, trainees’ practical operation and evaluation.

3.2. Generation of the training project
3.2.1. Generation of the process. The training project generation of this simulation training method mainly includes five steps, which is shown in Figure 2.
3.2.2. **Import of the substation wiring diagram description file.** Instructors import the transformer substation wiring diagram description file from the outside through the configuration task module of the system server. Based on the State Grid Corporation's enterprise standard Q/GDW 624-2011 “Power System Graphics Description Specification”, the file applies Document Object Model technology to traverse and read the graphic elements and their attribute information, and then converts and stores them. Besides, the primitive related to the equipment and the attribute information related to the location are the filtering conditions. Elements related to the equipment include Bus (representing the bus bar), CBreaker (representing the circuit breaker), Disconnector (representing the isolation breaker), GroundDisconnector (representing the grounding breaker), Generator (representing the generator), Transformer2 (representing the two-coil transformer), Transformer3 (representing the three-coil transformer), CT (representing the current transformer), PT (representing the voltage transformer), Arrester (representing the lightning arrester), etc. Location-related attribute information include W (representing width), H (representing height), x1 (representing abscissa of starting point), y1 (representing ordinate of starting point), tfr (representing coordinate transformation). The storage format applies a table structure which is defined as follows:

**Table 1. Storage format table about substation wiring diagram description file.**

| Field name | EID | equipment | SID | x   | y   | width  | height | rotate |
|------------|-----|-----------|-----|-----|-----|-------|--------|--------|
| Explanation| Device graphic ID | Device name | Substation ID | Starting point abscissa | Starting point ordinate | Width | Height | Direction of rotation |

Apart from the substation ID which is automatically generated by the system, the other data are extracted from the substation wiring diagram description file. For example, the graphic description of a circuit breaker in the substation wiring diagram description file is as follows:

**Table 2. Substation wiring diagram description file of a circuit breaker.**

```
<Layer id="0" type="0" w="1000" h="1200" name="kv500" bgc="0" bgi="1.jpg" show="1">
  <CBreaker fm="0" p_PlanePlane="0" id="100000000" x="50" y="56" keyidKeyId="114560487319940993" p_AssFlagAssPlag="128" lc="0, 0, 255" p_AutoChangeAppFlagSwitchApp="0" p_ShowModeMaskShowMode="3" p_RoundBoxRoundBox="46, 52, 26, 44" p_DyColorFlagDyColorFlag="0" appApp="100000" p_LevelEndLevelEnd="16" p_NameStringNameString="" voltypeVolType="112871465660973058" index="1" p_LevelStartLevelStart="0" afAF="2147483647" p_ReportTypeReportType="1" fc="0, 255, 0" tfr="rotate(0) scale(1, 1)" ls="1" devrefDevRef="#sgdslg_kg1.dlq.icn.g:sgdslg_kg1" lw="1" />
</Layer>
```

Converted results are stored as follows:

**Table 3. Converted results of substation wiring diagram description file.**

| EID       | equipment | SID | x   | y   | width  | height | rotate |
|-----------|-----------|-----|-----|-----|-------|--------|--------|
| 1000000000| CBreaker  | 1   | 50  | 56  | 1000  | 1200   | 0      |

3.2.3. **Configuration of training tasks.** As to the substation which is imported with the wiring diagram description file, the instructor utilizes the configuration task module of the system server to configure specific training tasks including equipment regular patrol routes and specific overhaul operation contents. The storage format of the configured training task utilizes a table structure shown as follows:
Table 4. Storage format of training tasks configuration.

| Field name  | TID | SID  | inspection | maintenance | weather                |
|-------------|-----|------|------------|-------------|------------------------|
| Explanation |     | Training task ID | Substation ID | Patrol route | Maintenance task | Weather conditions |

In the table, the training task ID is automatically generated by the system; the substation ID is selected from the substation ID in the substation wiring diagram description file. Besides, the patrol routes, maintenance tasks and weather conditions are all from the preset data list in the system. For example, configuration of training tasks for closing resistance maintenance are stored as follows:

Table 5. Storage format of training tasks for closing resistance maintenance.

| TID | SID | inspection          | maintenance                  | weather        |
|-----|-----|---------------------|-------------------------------|----------------|
| 1   | 1   | Regular route inspection | Maintenance of closing resistor | Sunny          |

3.2.4. Configuration of substation equipment defects. The instructors set up the defects of substation equipment in specific training tasks through the configuration defect module of the system server, such as oil infiltration, oil leakage, loose clamp, clamp breakage or cracking. And the step-by-step configuration of maintenance tasks and equipment defects enables flexible configuration of training. The storage format of the configured defects applies a table structure which is defined as follows:

Table 6. Storage format of defect configuration.

| Field name  | TID | ID  | equipment | part        | defect        |
|-------------|-----|-----|-----------|-------------|---------------|
| Explanation |     | Training task ID | Device graphic ID | Device name | Defect location | Defect content |

In the table, the equipment graphic ID (shown as ID) and equipment name are both derived from the substation wiring description file, which are also selected and designated by the instructor. The defect location and defect content are all from the preset data list in the system. For example, configuration of the defect for closing resistor damage are stored as follows:

Table 7. Storage format of defect configuration for closing resistor damage.

| TID | ID           | equipment | part     | defect   |
|-----|--------------|-----------|----------|----------|
| 1   | 100000000    | CBreaker  | Closing resistor | Damaged   |

3.2.5. Generation of the virtual operation scene. The equipment information stored in a substation wiring description file and the training task information and equipment defect information stored in the configured training task is loaded to generate the virtual operation scene through a scene generation module. The generation of a virtual operation scene comprises of the following steps.

First of all, a model node named N is created. According to the equipment name stored in the substation wiring diagram description file, a corresponding three-dimensional equipment model which is invoked from a preset three-dimensional model library is added to the model node named N.

Secondly, the model node named N is modified with the configuration of the defect model. The model node to be configured with defects is located based on the equipment graphic ID stored in the substation equipment defect storage file in the training task. And then the three-dimensional equipment model of the model node is modified to realize defect configuration according to the corresponding the preset three-dimensional defect model based on the defect part and defect content.

Thirdly, the model location node named P is created. The location node is set according to the equipment location information stored in the substation wiring diagram description file.

What’s more, the environment node named E is created. The corresponding three-dimensional environment model invoked from the preset three-dimensional model library is added to the environment node according to the weather conditions stored in the configured specific training task.

Finally, the model node named N is added to the corresponding model location node named P as a child node, and then the location node named P and the environment node named E are added to the scene root node as its own child nodes. Accordingly, the construction of the virtual operation scene is accomplished.
For instance, the equipment stored in the substation wiring diagram description file is ‘CBreaker’, namely the equipment type corresponds to circuit breaker. The circuit breaker model is loaded from the preset three-dimensional model library to the model node named N. Then the information of ‘x, y, width and height’ is added to the position node named P of circuit breaker to set up the position of the circuit breaker in the three-dimensional scene, and the information of ‘rotate’ is added to position node P to set up the rotation angle of circuit breaker on the plane. If there’s the same equipment information stored in substation equipment defect storage file, the defect model is loaded from the preset three-dimensional model library via the information of ‘part’ and ‘defect’, accordingly, the model node named N is modified. For the subordinate substation, if the ‘weather’ stored in the configured training task is sunny, the sunny environment model is loaded from the preset three-dimensional model library to the environment node E. The construction of the virtual operation scene is completed by adding the model location node P and the environment node E to the scene root node. Then the three-dimensional virtual operation scene information is transferred to the training file module to form a complete training program. The storage format of the operation scene information is defined as follows:

Table 8. Storage format of three-dimensional virtual operation scene information.

| Field name | DID | TID | VID | UID |
|------------|-----|-----|-----|-----|
| Explanation| Training file ID | Training task ID | Virtual job scenario ID | Trainee ID |

In the table, the training file ID is automatically generated from the system. In addition, the virtual operation scene ID is derived from the corresponding three-dimensional scene ID that has been generated; and the trainee ID is from the user ID which is logged into the system.

3.3. Presentation of virtual operation scene

3.3.1. Process of the scene presentation. The process is shown in Figure 3.

3.3.2. Virtual operation scene configuration information transfer. The information of the training project is transmitted to the trainee computer by the data transmission module of the network connection equipment. Then the virtual operation scene file is acquired through the virtual operation scene ID stored in the whole training project, and then the information such as the model node, the location node, the environment node is traversed and read. Afterwards, the three-dimensional equipment model pointed in the information mentioned above is downloaded, and the state of the data cache module of the network connection equipment aiming at the models is simultaneously identified and stored. A table structure is applied as the storage format, which is defined as follows.

Table 9. Storage format of virtual operation scene file.

| Field name | DID | TID | EID | part | defect | weather |
|------------|-----|-----|-----|------|--------|---------|
| Explanation| Training file ID | Training task ID | Device graphic ID | Defect location | Defect content | Weather conditions |
For the same training task, the data cache module judges whether the information in data cache table is consistent with the node information in the file such as the defect position, defect content, weather conditions. If information consistency occurs, the downloaded three-dimensional model will be used still for rendering. Otherwise, the three-dimensional equipment model or the environment model which is changed is downloaded only, consequently the pressure on the system server and trainee computer is relieved. Therefore, the network cache mechanism is established, which can reduce the operation delay of the simulation training system and improve the working efficiency and simulation immersion degree of the training system.

3.3.3. Virtual operation scene presentation of trainee computers. The three-dimensional model of trainee computer is downloaded and transmitted to the rendering processing module according to the position information in a virtual operation scene file, presenting the virtual operation scene to trainees by means of display devices. Meanwhile other information is used to form training task flow and judgment constraint rules through the flow processing module.

3.4. Practical exercises and evaluation of trainees
In the virtual operation scene of the trainee computer, the trainee can carry out the operation simulation, including equipment patrol operation, switching operation, equipment maintenance, etc.

Trainees patrol the equipment on the trainee's machine according to the training task flow and record the defects found during the patrol. Then the flow processing module judges whether the defects record is correct. If it is correct, the trainees will perform the equipment switching operation according to the training task flow and record the operation process. Similarly, the flow processing module judges whether the operation record is correct. If it is correct, the trainees will carry out the simulation operations of safety arrangement via the input equipment in accordance with the training task flow, and record the process. Afterwards, the flow processing module judges whether the record about safety measures is correct. If the record meets the process requirements, the trainees will carry out the equipment maintenance operation based on the training task flow, and record the operation process. If all the maintenance steps are completed, the operation records are saved by the data processing module and then transmitted to the examination management module of the system server through the network connection equipment for evaluation. The evaluation module establishes an evaluation standard for the maintenance training simulation system according to the number of errors, the completion degree, the completion quality and the completion time of each operation step, which can realize the comprehensive and objective evaluation of the equipment maintenance operation.

4. Application
The substation equipment maintenance simulation training system has been applied in the actual power grid enterprise training center, providing the trainees with the operation scene in the virtual substation, realizing equipment patrol inspection as well as equipment structure analysis. The operation simulation training is carried out in accordance with the maintenance process so that the trainees can experience a real maintenance operation process in the virtual scene. Besides, the training effect of the trainees can be detected via the operation assessment module. As a result, the closed-loop management of training, including learning, practice and examination is formed.

Taking switch maintenance training for example, the trainees can simulate the whole process of actual on-site switch maintenance in a three-dimensional virtual scene, and independently complete the specified related maintenance tasks assigned by the trainer, as shown in Figure 4. A keyboard and a mouse are utilized to control the virtual person to complete the equipment maintenance task and practice the maintenance process in the virtual scene. In addition, the system can automatically record the maintenance operation process, so that trainees can correct errors and improve their levels. Trainees can watch and learn the maintenance process and key points through video, then simulate the
operation training in a virtual scene, and finally take part in the skill assessment to promote them mastering the maintenance process and technology of substation equipment as soon as possible.

Figure 4. Virtual operation scene

5. Conclusion
The substation equipment maintenance simulation training system can realize automatic generation of equipment maintenance virtual operation scenes and flexible configuration of training schemes by configuring maintenance tasks and equipment defects. The assessment of trainees can be realized by means of the maintenance evaluation model, improving the effectiveness of training. In practical application, the simulation training and skill assessment of substation equipment maintenance in the virtual substation operation scene can be realized, which can promote the training effect and effectively improve the skill level of operation and maintenance personnel.

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References
[1] Bai Yongxiang, Gao Yan and Fu Weichuan 2012 J. Innovation of Skills Training Mode for Substation Maintenance Teams China Electric Power Education p 45-6.
[2] Wu Guoqiang, Wang Xinwei and Chen Meirong 2015 J. Application of On-site Maintenance and Training 1+1 Management Mode in Power Transformation Zhejiang Electric Power p 60-2.
[3] Zhong Ming 2005 J. Multimedia remote training system and its application Guangdong Electric Power vol 18 p 35-7.
[4] Zhu Jinhua, Zhao Kaifeng and Liang bin 2013 J. Research on Implementation of Three-dimensional Simulation Training Integration System for Power Equipment Maintenance China Electric Power Education p 155-6.
[5] Zhu Yuanda and Yin Yongfei 2009 J. Research and Development of Multimedia Teaching Software for HV Disconnector Electric Power Information Technology vol 7 p 88-90.
[6] Tang Xiaohui and Yang Tao 2011 J. Research and Design of Substation Maintenance System Based on Virtual Reality Technology Agricultural Science & Technology and Equipment p 40-2.
[7] Tao Songmei 2017 J. Application of 3D Visualization Technology in Maintenance Training of Substation Equipment Guangxi Electric Power vol 40 p 34-42.
[8] Li Wei, GU Jianming and Yang Hongxia 2017 J. Research on Substation Equipment Failure Analysis System Based on Virtual Reality Technology Electrical Engineering Materials p 39-41.
[9] Wu Yichun, Zhou Lei and Fang Xuelei 2018 J. Development and Application of Simulation Training System for Maintenance of Switchgear in Substation Electric Engineering p 49-51.