Design and Application of Multiple Adaptability Evaluation Algorithms Based on UHVDC Digital Simulation Operating System

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Abstract—The digitally simulated UHVDC system provides an all-round, full-process, and full-scenario high-fidelity training and teaching platform for the switching operation of the UHVDC system, which can fully meet the training requirements of the operation and maintenance personnel of the converter station. In order to solve the problem of inaccurate evaluation due to the existence of multiple operation procedures for an operation target, an improved digital simulation system based on multiple adaptive evaluation algorithms was designed: the teacher uses a modular combination method to generate a standard operating procedure as the main line, and then uses the trainee's simulated operating procedure as a supplement to jointly form a standard answer to adapt to the different operating procedures of the same operating task for the trainees. Based on this system, it can solve the problem of inaccurate evaluation caused by millions of answers in the simulation operation evaluation process. It provides fast, efficient and accurate evaluation results for the digital simulated UHVDC system switching operation procedure.

1. Introduction
With the continuously increasing number of UHVDC projects of State Grid Corporation of China, by the end of 2020, the number of UHVDC projects in operation under the jurisdiction of the State Grid Corporation of China has reached 12 items\textsuperscript{[1]}. As UHVDC projects have the characteristics of various types of equipment, high technical content\textsuperscript{[2]}, high technical requirements for operation and maintenance, and a large range of equipment failures, higher requirements are placed on the technical level of UHVDC converter station operation and maintenance personnel\textsuperscript{[3]}.

The digital simulation UHVDC System is low cost and convenient operation\textsuperscript{[4]}, which is widely used in the operation skill training and skill improvement training for operation and maintenance personnel of converter station. Accurately evaluate the operation of simulation operators (hereinafter referred to as trainees), timely find out the irregular, arbitrary and misoperation of trainee's operation, and put forward corrective opinions and suggestions, which will play an important role in helping trainee's operation training, skill training and improvement. At the same time, the accurate evaluation system of simulation operation will provide automated evaluation tools for operation process evaluation, skill appraisal, skill evaluation, etc.

However, in practice, there are often a variety of operation processes for the same operation task, which is easy to lead to the problem of inaccurate evaluation. On this question, an improved digital simulation system based on multi adaptability evaluation algorithm is designed, the teacher uses a modular combination method to generate a standard operating procedure as the main line, and then uses...
the trainee's simulated operating procedure as a supplement to jointly form a standard answer to adapt to the different operating procedures of the same operating task for the trainees. Based on the system, the problem of inaccurate evaluation in response to millions of standard answers in the process of simulation operation evaluation can be solved, and the fast, efficient and accurate evaluation results can be provided for the switching operation of digital simulation UHVDC System.

2. Problems in the operation evaluation method

The simulation operation record is shown in Fig. 1, which includes many types of signals such as trainees operation record, SCADA information and system message information. The trainees operation information is filtered out according to the information characteristics for analysis and evaluation.

The basic method of evaluation is to compare the operation records with the standard operation records, obtain the correct operation quantity of the trainees and record the wrong operation of the trainees.

In order to accurately evaluate the trainee's operation, an operation record of the standard operation process is necessary to manually be made. The trainee's operation record is compared with the operation record of the standard operation process to obtain the comparison results. When the simulation operation has multiple processes, it will be necessary to make multiple standard operation processes, otherwise misjudgment will occur.

The with H-type main steel beams and steel channels, lightweight precast panels set upon the steel skeleton, shear keys connected to the main steel beams and post-pouring concrete layer.

For example, the operation title is "converter station pole I changes from operation to maintenance under UHVDC bipolar full load". The simplified operation process is shown in Table 1 and shown in Fig.2 by flow chart.

In order to achieve accurate evaluation, the characteristics of switching operation are analyzed as follows: each operation includes checking the status and characteristics of the system or equipment to see whether they meet the operating conditions, change the status of the operating system or equipment,
and then check whether the status of the system or equipment has been changed, which can be simplified as "pre inspection" - "operation" - "post inspection".

According to this feature, an operation topic is divided into multiple modules. Each module completes a simple operation task, including complete "pre inspection" - "operation" - "post inspection". Thus, the above application example is divided into 33 modules, as shown in Table 1. Each module contains multiple items of "pre inspection", "operation" and "post inspection", as shown in Table 1, which is the module of "pole 1 single pole power reduced from 1600MW to 320MW".

Table 1 "UHVDC bipolar full-load condition of converter station pole 1 from operation to overhaul" operation module list

| Module name                                            | No. | Next module |
|--------------------------------------------------------|-----|-------------|
| Reduce bipolar power to 3200MW                        | A1  | A2          |
| ...                                                    |     |             |
| Pole 1 shutdown                                       | A4  | A5          |
| DC field of Pole 1 changes from pole connection to pole isolation | A5  | D6,D7,D8,D9,D10, D711,D811 |
| Pole 2 changes from unipolar earth loop to unipolar metal loop | D6  |             |
| ...                                                    |     |             |
| Converter of high-end pole 1 changes from charging to hot standby | D711 | D712 |
| Converter of high-end pole 1 changes from hot standby to cold standby | D712 | D713 |
| Converter of pole 1 high-end transfers from cold standby to overhaul | D713 | |
| Converter of low-end pole 1 converter changes from charging to hot standby | D811 | D812 |
| Converter of low-end pole 1 switches from hot standby to cold standby | D812 | D813 |
| Converter of low-end pole 1 transfer from cold standby to overhaul | D813 | |
| DC field of pole 1 changes from maintenance to isolation | A11 | C12,C13,C14,C15, C711, C811 |
| ...                                                    |     |             |
Each yellow background box in Fig.2 represents an operation module, which is represented by a number. The modules beginning with the number A contain a link to the next module. The link is ordered and one-way. The modules beginning with D and C are none Order multi-directional links, that is, unordered operation items. Among them, D71 and D81 contain multiple ordered one-way links.

The flow chart is mainly divided into four parts. Unordered operation item 1 includes 7 operation modules. There is no order requirement in the operation process, but all operations need to be completed. Different combinations can form a factorial of 7, which is 5040 operation processes. Different combinations of unordered operation items 2 can form a factorial of 6, which is 720 kinds of operation processes. The both have a total of 3628800 different operation processes. No matter which order is adopted, it is correct.

In the process of evaluation, it is impossible to manually make so many correct standard operation processes to compare with the trainee's. If the trainee's simulation operation has no standard process corresponding to it, its operation will be evaluated wrong.

| No. | Typical ticket operation item                                                                 | Simulation operation record                                                                 |
|-----|---------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| 1   | Check that the active power of pole 1 is 1600MW and operates normally                       | Check the extremely active power (Fulong converter station, P11)                            |
| 7   | Check that the reactive power control mode on the sequence control flow chart interface is constant reactive power control | Check Q/U control (Fulong converter station, reactive power control): Q control               |
| 8   | Click the "unipolar power control" icon of pole 1 on the sequence control process interface |                                                                                             |
| 9   | Set the power change rate to 60MW / min on the pop-up interface                             | Change the power rate of Fulong converter station P11                                        |
| 10  | On the pop-up interface, set the transmission power to 320MW                                 | Change the power reference value of Fulong converter station P11                             |
| 11  | Click the "execute" icon on the pop-up interface                                             |                                                                                             |
| 12  | Check pole 1 DC system power 320MW                                                           | Check extreme active power (Fulong converter station, P11): [320.00]                        |

Table 2 "Pole I unipolar power reduced from 1600MW to 320MW" module
3. The design of multi adaptive simulation operation evaluation algorithm

A reasonable algorithm should have a variety of adaptability. No matter what kind of process is adopted, it can automatically evaluate whether the trainee's operation process is correct.

There are two steps to evaluate the trainee's operation records. The first step is to evaluate the operation process; The second step is to evaluate the complete operation. The operation process is used to evaluate whether the operation process is correct. If it is correct, evaluate the complete operation. If the operation process is wrong, it is not necessary to evaluate the complete operation. The complete operation is composed of several operation modules, and each module includes multiple equipment status checks and equipment operations. As shown in Table 2, the complete contents of the operation of the module "pole I single pole power is reduced from 1600MW to 320MW".

Each module in Table 1 sets the number and the next module. Lower module refers to the module connected with this module. When there are multiple connected modules, there is no connection sequence between multiple modules.

The algorithm flow is shown in Fig.3.

The first step is to establish a standard operation module library and determine which modules are in fixed order or disorder in the library. Modules in fixed order need to be marked with the name of the module below them, and multiple modules without order need to be marked together. Take this as the comparison standard.

The second step is to process the trainee's simulation operation records. After the operation records are filtered, two files will be generated, one is the operation outline, that is, only the core operation process of simulation operation, which is used to evaluate the operation process, and the other is the detailed operation record, that is, the record file containing all the operation behaviors of trainees, which is used to evaluate the complete operation.

The third step is to prepare standard operating procedures. According to the operation requirements, the teacher shall prepare the outline of standard operation process to form the standard operation process.

The fourth step is to compare the operation outline generated in step 2 with the standard operation process in step 3. If the comparison results are the same, extract the complete module from the standard operation module library according to the outline number and compare it with the detailed operation records generated in step 2. If the comparison results are different, you need to check whether it is a one-way process module. If so, it is an error operation. If not, it is a multi-way module, Check whether the outline number is in the "next module" of the upper module. If yes, extract the complete module according to the outline number. If not, it is an error.

The fifth step is to compare the detailed operation record with the extracted complete module. If the comparison result is correct will score, otherwise, record the wrong operation.
During the execution of the algorithm, the "Next Module" will be listed. When the comparison is correct, the correct modules will be deleted. According to the assumption that the operation of the trainee trainee's is correct, the remaining modules in the list will be reduced in turn. After 7 comparisons, the list will be no elements, as shown in Table 3, which minimizes the workload of circular comparison and improves calculation efficiency.

Table 3 "Next module" comparison cycle perspective table

| Order | Item | D6 | D7 | D8 | D9 | D10 | D71 | D81 |
|-------|------|----|----|----|----|-----|-----|-----|
| 1     |      | 1  | 1  | 1  | 1  | 1   | 1   | 1   |
| 2     |      | 0  | 1  | 1  | 1  | 1   | 1   | 1   |
| 3     |      | 0  | 0  | 1  | 1  | 1   | 1   | 1   |
| 4     |      | 0  | 0  | 0  | 1  | 1   | 1   | 1   |
| 5     |      | 0  | 0  | 0  | 0  | 1   | 1   | 1   |
| 6     |      | 0  | 0  | 0  | 0  | 0   | 1   | 1   |
| 7     |      | 0  | 0  | 0  | 0  | 0   | 0   | 1   |

Note: 1 in the table indicates that the module is not used, and 0 indicates that the module has been used.

4. Algorithm test and problem processing of intelligent evaluation

After processing 121 simulation operation records, some problems are found. If the trainee's simulation operation is "very" standard and operates in full accordance with the process guided by the teacher, there is no misoperation or missing operation, and the evaluation is very accurate. Fig.4 shows one of the operation results; If the trainees "play freely" and "do whatever they want", the evaluation results are very inaccurate. After analysis, the following problems are found.
1) The simulation operation process of the trainee's cannot be used as the main line, because there are many simulation operation errors of the trainee's, resulting in standard process errors.

2) There are operation errors in the simulation operation of the trainee's, such as, one or several misoperations, irrelevant operations, or one missed operation. After finding the operation error, correct and continue the operation, resulting in abnormal evaluation results.

3) There is no obvious characteristic information between different modules. Each module is composed of "pre-inspection", "operation" and "post-inspection", but there is no clear order for system or equipment status inspection, which makes it difficult to accurately isolate the modules in the trainee's simulation operation records, resulting in incorrect evaluation.

4) Multiple "random" modules are randomly sorted, but D71, d81, C71 and c81 in Fig.2 respectively contain three ordered sub module groups, that is, the "random" module contains multiple "ordered" sub modules, and the "ordered" sub modules are easy to be disordered, resulting in evaluation errors.

The corresponding treatment measures are:

1) The main evaluation process is based on the standard process which is made by teachers, supplemented by the operation process of trainees. When the trainee's simulation process is inconsistent with the teacher's standard process, identify and evaluate whether it is legal, that is, the teacher makes a standard process, and the trainee's operation process is compared with it. When the both are different, check whether the module is a "disordered" module. If it is a "disordered" module, check whether the trainee's module is in the lower module group of the upper module, If it is in the group, the operation is correct and included in the standard process. If it is not in the group, this module belongs to the trainee's wrong operation.

2) According to the relevant operation regulations on the production site, for misoperation, the algorithm program shall record the misoperation items, stop the evaluation, and give the evaluation according to the prior agreement.
3) There is no obvious characteristic information between modules to be corrected. Since the system or equipment operation of each module is clear, the trainee's records are divided at intervals based on the clear system or equipment operation of adjacent modules. For example, module A includes "A pre-inspection", "A operation" and "A post-inspection", and the adjacent module is module B, including "B pre-inspection", "B operation" and "B post-inspection", module A and module B will be divided into three parts, "A pre-inspection" + "A operation", "A post-inspection" + "B pre-inspection" + "B operation" and "B post-inspection".

4) The "Random" module contains multiple "ordered" sub-modules. The solution is that each module defines which module can be connected later. The random modules need not define the connected module. For the sub-modules contained in D71, D81, C71 and C81 in Fig.2, only the first sub-module code participate in disorderly arrangement, as D711 and D811 are connected to the code A5 in Table 1, C711 and C811 are connected to the code A11.

5. Conclusion
The operation of UHVDC System is very rigorous. In order to ensure the accuracy of operation, detailed descriptions are made in the power safety work regulations of State Grid Corporation of China (power transformation part), regulation and operation regulations of national dispatching center and operation regulations of converter station. In order to ensure accurate switching operation, the operation and maintenance personnel shall conduct simulation rehearsal operation in advance. During the operation, the guardianship operation, ticket Voting and recitation must be implemented[5-7]. The operation of digital simulation UHVDC System is a training and teaching system for operation and maintenance personnel. The rigorous learning process helps to improve the stability of on-site operation and prevent habitual illegal operation. Therefore, the incorrect operations in the process of simulation operations should be discovered and corrected in time, which is of great practical significance. Accurately acquiring incorrect operations in simulation operations through multiple adaptive evaluation algorithms can significantly improve the training effect of digital simulation of UHVDC system operation training.

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