Architecture Design of Digital Twin Platform for AC&DC Hybrid Transmission System with MMC-HVDC

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Abstract. With the development of power electronic devices, more and more high-power power electronic devices were used in high-voltage DC transmission. The purpose is to improve the stability of grid and the acceptance ability of new energy. The Yu-E flexible DC back-to-back interconnection project is a typical example of this technology. However, due to the large number of power electronic devices and sub modules, it brings many difficulties to the analysis of AC&DC hybrid power system. Especially when there is a lot of new energy penetration. This paper is based on the concept of digital twin, equivalent to the MMC sub-module as a series connection of the power supply and its on-resistance, then based on actual operating parameters and grid planning, a set of digital twin platforms for AC&DC transmission systems with large-scale new energy integration has been established. Comparing the running results of the digital twin model with the actual running state, the method and architecture described in this paper have certain practicability and effectiveness.

1. Introduction
In order to strengthen the transmission capacity of the power grid and improve the safe and stable operation of the power grid, the State Grid Corporation of China built the Yu-E back-to-back ±420kV DC project[1]. The project has been put into operation at present, and the converter station capacity is 2×1250MW.

Based on the digital twin technology[2], this paper describes wind farm output, some important 500kV substation off-grid load and back-to-back MMC-HVDC system in the form of digital models, and establishes a complete set of grid event preview and analysis digital twin platform [3], with better practicality.

2. Digital Twin
Aiming at the shortcomings of the traditional power system analysis method, the power grid "digital twin" platform can reproduce the operation condition through simulation under the support of the actual data in the past, observe the unmeasured signal, and find out the cause of the fault. More importantly[4], the platform can analyze the effects of changing operation control strategies or appropriately strengthening the power grid, such as reducing wind abandon or light abandon, ensuring power quality, reducing loss, reducing power failure loss, and adjusting short-circuit level. The technology leverages the power of current computer data access and model computing to map the real
power grid to a virtual digital world in a Monte Carlo manner. However, it is very convenient to verify the accuracy of the model due to the historical data of the actual power grid. In addition, the "digital Twins" platform can also be used to conveniently change the power grid operation data and predict the impact of data changes on the future power grid operation[5].

3. MMC-HVDC structure and twinning method

3.1. MMC-HVDC

The modularized multilevel bridge arm is composed of a number of switching devices and capacitors, but the structure is not simply in series, but in the way of cascading submodules. In addition, the working principle of MMC is different from that of two-level and three-level converters. Instead of pulse width modulation, MMC adopts step wave to approximate ac sinusoidal wave.

MMC is adopted as the bridge arm connection mode in the DC back-to-back project of Chongqing and Hubei. Each bridge arm is composed of a bridge arm reactor and a cascade of half-bridge submodules [6].

According to the principle of MMC, the calculation formula of rated voltage on the DC side is as follows:

\[ U_{dc} = 1.35 \times \sqrt{2} \times U_{Ac rms} \]  

Where, \( U_{dc} \) is DC side voltage; \( U_{Ac rms} \) is the effective value of AC side voltage.

3.2. MMC control system

The control system can be divided into inner loop control and outer loop control, of which the inner loop control is mainly current control and the outer loop control is mainly power control [7~9]. The detailed diagram of inner and outer loop control of the control system is shown in Figure 1 below.

![Figure 1. MMC control system diagram](image)

Control strategy of MMC in essence is a kind of VSC, but the complex structure and numerous MMC of power electronic devices, to execute hundreds or thousands of triggering control of switching devices, we have to control a great amount of MMC control level, process complex characteristics, compared with the VSC control system needs to implement more features [10].

3.3. Half bridge sub-module twin model

Based on the concept of digital twin, the half bridge sub module of MMC system is transformed to improve its model mapping speed. The main method is to equivalent the switch devices T1 and T2 in the classic structure of MMC sub module into a variable resistor. The resistance can be adjusted to the on or off resistance of the device according to the control system, as shown in Fig. 2, so as to realize the control of the on and off of the sub module.
4. New energy digital twin model

4.1. Wind farm
The wind power output in Northeast Chongqing is larger from April to June and from September to November, and smaller from December to February of the next year. Based on this, medium and long-term forecast of other wind power output in this region can be made.

In this paper, the output characteristics are modeled in the form of multiple function fitting, including two Gaussian functions and a linear function of one variable.

\[
y = \begin{cases} 
17.3 \cdot e^{-\left(\frac{x+4.62}{4.15}\right)^2} + 0.68x + 11, & x \in (1,8) \\
20.6 \cdot e^{-\left(\frac{x+9.71}{1.57}\right)^2} + 0.68x + 11, & x \in (9,12)
\end{cases}
\]  

4.2. Solar power
The output fluctuations of photovoltaic power plants in northeast Chongqing change in a day-to-day cycle. The output is relatively large at noon, and the output is small at night, almost zero. Among them, the negative power appears at night. Mainnet acquisition.

According to the trend of output curve of photovoltaic power station, normal distribution can be used to describe the daily characteristics of photovoltaic output, as shown in Figure 4 below.

According to the fitting results of the solar power characteristics of the photovoltaic power station, the following formula 3 can be used to describe the solar power characteristics.

\[
\hat{P}_s = P_{\text{total}} \times 0.86e^{-0.31 \left(\frac{x-153}{35.8}\right)^2}
\]  

Among them, \(\hat{P}_s\) is the photovoltaic power generation at sampling time \(x\); is the total installed capacity of the photovoltaic power station.

5. Digital twin system architecture
Based on the above analysis of DC back-to-back, load forecasting, and wind power output forecasting, this paper establishes a grid digital twin system as shown in Figure 5. It mainly includes four stages as follows:
Step 1: Raw data collection and preprocessing stage
- Collecting the original data of the power grid, the data to be collected include weather data, wind power output, line flow, holidays/working days, electrical quantities of each node, and network topology, etc.;
- Grid data preprocessing, including data cleaning and normalization;

Step 2: Establish volatility characteristics and prediction models
- Use Gaussian function to establish multi-stage wind energy fluctuation model and corresponding prediction model;
- Use normal distribution to simulate photovoltaic output fluctuation characteristics;

Step 3: Establishing the twin model of AC/DC hybrid power grid
- DC part: establish an efficient mathematical twin model of MMC-HVDC with equivalent sub-modules
- AC part: establish virtual models of substations and line towers

Step 4: Function realization stage
- Real-time monitoring of power grid status;
- Data collection at key locations,
- Assistant decision-making for power grid construction
- Power grid event rehearsal, data feedback and model revision stage.

Figure 5. Architecture of power grid digital twin system

6. Verification of the digital twin platform of AC&DC hybrid power grid

6.1. Basic network parameters
The main AC parameters and back-to-back converter valve parameters used in this twin model are shown in Tables 1 and 2 below. Among them, the AC bus outlet of the Hubei converter station adopts Thevenin equivalent treatment, and the Chongqing AC system builds two 500kV substation coverage areas. The network topology is as shown in Figure 6.
Equivalent point 1
Wanxian station
Jiupan station
Wanxian station
Equivalent point 2
Figure 6. Network topology

Table 1. AC parameters

| Parameter Type            | Chongqing side converter | Hubei side converter |
|---------------------------|--------------------------|----------------------|
| Normal voltage            | 525kV                    | 525kV                |
| Normal voltage range      | 500-550kV                | 500-550kV            |
| Rated frequency           | 50Hz                     | 50Hz                 |

Table 2. DC parameters

| Parameter Type         | Chongqing side converter | Hubei side converter |
|------------------------|--------------------------|----------------------|
| Number of submodules   | 367                      | 367                  |
| Capacitor              | 8000uf                   | 8000uf               |
| Start resistance       | 6000Ω                    | 6000Ω                |
| Arm reactance          | 140mh                    | 140mh                |

6.2. Result
Based on the above parameters and the grid structure in Northeast Chongqing, an AC/DC hybrid simulation model in Northeast Chongqing was established, and the electrical parameters under heavy load during high water period were input into the model. Among them, the back-to-back DC transmission capacity is set to 2×500MW, and the positive and negative poles of the converter unit each transmit 250MW of electricity; the DC voltage is set to ±420kV, and the specific results are shown in Figures 7 ~10.

Figure 7. Equivalent point 1 voltage
Figure 8. Equivalent point 2 voltage
According to the results of the twin model DC steady-state voltage and DC line transmission power flow, it can be seen that the twin model established in this paper can stabilize the voltage at the rated voltage ±420kV, and the DC line transmission power can be maintained at the preset 250MW, which is consistent with theoretical analysis and actual operation.

In addition, in order to verify the validity of the twinning model for the instantaneous grid failure, when a three-phase instantaneous fault occurs on the AC 220kV line sent from the AC-side grid-connected wind turbine (150MW), the DC line voltage and power fluctuations in the converter valve are shown in Figure 11&12.

From the calculation results of the twin model, it can be known that at the moment of the fault, the DC line voltage fluctuates little, and it can quickly recover to the rated voltage ±420kV after the fault ends. The DC transmission power is instantly weakened due to the active power provided by the AC side, and there is a power fluctuation of about 50MW, but under the adjustment of the control system, it can also be restored to a stable level and maintain the preset 250MW. Meanwhile, in terms of the time required for calculation, digital twin models only need 3.6 minutes to complete (Hour level when the length of a conventional AC-DC transient simulation with 367 submodules).

7. Conclusion
Digital twin is a new type of power system analysis method. With the development and progress of information communication and computer technology, the generation of digital twin in power grid is possible. The establishment of a power grid twin model is conducive to real-time analysis of the current health status of the power grid, and combined with power output and load forecasting, it can realize a preview of possible grid events in the future, even if measures are taken to ensure the stable operation of the power system. This article combines real power grid data and parameters to build an
AC&DC hybrid model in Northeast Chongqing as much as possible. Using a combination of digital and physical models, the simulation efficiency of the AC&DC hybrid system is improved, and it is verified under normal operation and fault conditions. The built twin model can more accurately simulate the operating status of the AC&DC hybrid power grid, and the twin analysis framework can provide assistance for the normal operation of the power grid.

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