Analysis and Simulation of Typical Faults in 500kV UPFC Station based on PSCAD/EMTDC

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Abstract. The 500kV UPFC demonstration project of Jiangsu Suzhou south grid was put into operation in December 19, 2017. Depending on the State Grid science and technology project "Study on control and protect coordination of 500kV UPFC" and according to the system operation mode and equipment parameters provided by the relevant institutes, the authors had researched on electromagnetic transient modelling and simulation of 500kV Suzhou south grid and 500kV UPFC in earlier period. In this paper, the theoretical analysis and simulation verification of several typical faults in 500kV UPFC station are carried out by using the above model, which is an important part of the project.

1. Introduction

Reference [1] introduced the application of 500kV UPFC in Suzhou south grid, connection of the system and the capacity of UPFC. Compared with traditional AC power system, because of its DC part, UPFC has more complex system structure and various devices. Therefore, there may be more fault locations and types. According to the location of the fault point, UPFC fault can be divided into the fault in UPFC station and the external AC system fault. The fault in the UPFC station includes the series/shunt transformer fault, the DC side fault and valve fault, which was also mentioned in [2]-[4]. When the fault occurs in different regions, the different types of fault will have different effects on the UPFC system, and the severity of overvoltage is different. Especially for the 500kV UPFC system, the voltage level is higher and the insulation requirement of the equipment is higher, so the overvoltage problem caused by the fault is also more serious. Figure 1 shows the common fault locations in the UPFC system. Among them, F1~F6 is a fault in the UPFC station.

Figure 1. Locations of faults in the UPFC system
2. Analysis of typical faults in UPFC station

2.1. Single-phase fault on the valve side of the shunt transformer
A single-phase fault of the valve side of the parallel transformer occurs at F1 point in Figure 1. In engineering, the shunt transformer is usually placed in the open air, and the valve side is connected with the 110kV bus bar in the station. The AC bus is connected with the arm reactor through the wall tube insulator. Normally, the UPFC station has a good environment, and the probability of single-phase fault is lower than that of the AC system. However, once this fault occurs, it is usually caused by the breakdown of the insulation or the fault of the GIS bus, and most of them are permanent faults.

Figure 2. Winding circuit diagram and voltage phasor diagram during the fault
Assuming that phase A was in fault (also in follow sections), as shown in Figure 2(a), the fault point voltage to ground dropped to 0. Because the neutral point of the valve side of the shunt transformer and the series transformer are each grounded through a high resistor (2000Ω), through which the fault current needed to flow, the fault current was very low. The fault current circuit is shown in Figure 3.

Figure 3. Fault current circuit during the fault F1
Therefore, the bridge arm current and capacitor voltage of the sub-modules was almost unchanged. The non-fault phase voltage at the valve side of the shunt transformer is shown in equation (1).

\[
\begin{align*}
\hat{U}_b &= \hat{U}_v - \hat{U}_a \\
\hat{U}_c &= \hat{U}_w - \hat{U}_a
\end{align*}
\]  

(1)

At the same time, there was no other direct grounding locations in the devices of the UPFC due to the neutral grounding high resistor, that caused AC voltage fluctuation occurred on the devices and increased the insulation pressure, especially at the valve side of the series transformer. Single-phase
fault on the valve side of the series transformer (F2) is similar with this kind fault and won’t be carried out here.

2.2. DC bus single pole fault
A DC bus single pole fault occurs at F1 point in Figure 1. Taking a positive pole fault as an example, the fault current mainly consists of two parts. One is provided by 500kV AC bus, through shunt transformer to the arm reactors and valves of the parallel side converter and then into the fault point, while the other is provided by the AC transmission line, through the series transformer into the fault point, as shown in Figure 4.

![Figure 4. Fault current circuit during the fault F3](image)

When the fault occurred, the two neutral grounding high resistor could effectively limit the fault current. Similarly, because of the existence of high resistor, the UPFC system had no other direct grounding points, voltage of every device of UPFC to ground reduced by $U_{dc}/2$, that causes the voltage of negative pole reduced to $-U_{dc}$. Meanwhile, the AC voltage of the parallel transformer and the series transformer had a $-U_{dc}/2$ DC offset, which also increased the insulation pressure.

2.3. DC bus inter-pole short circuit fault
A DC bus inter-pole short circuit fault occurs at the F5 point in Figure 1. During the fault, the submodule capacitors between the upper and lower bridge arms of the two sides converter formed a discharge circuit through the fault point. For the AC side, as shown in Figure 5, the characteristics of this fault was similar to those of a three-phase short circuit fault of the AC system. Therefore, the characteristics of this fault are mainly in the following aspects:

![Figure 5. Fault current circuit during the fault F5](image)

- The capacitors of the submodules discharged instantaneously, causing the capacitor voltage drop to 0, and the positive and negative pole of DC bus voltage drop to 0.
The AC side voltage of the parallel converter was high during normal operation, so the AC current of the shunt converter increases rapidly when the fault occurred.

Because the discharging circuit contains the arm reactors, the current of arms had a decaying DC component, and the huge discharging current through bridge arm would cause induced overvoltage on bridge arm reactors.

Zero DC voltage caused the UPFC to lose the function of reactive power compensation for the AC bus and the active power and reactive power compensation for the transmission line. At the same time, as the capacitor discharging would produce reactive power fluctuation, which would affect the AC system bus voltage and reactive power on the transmission line, even lead to serious instability in AC system.

3. Fault simulation results

3.1. Operation mode of simulation system

The electromagnetic transient simulation model of 500kV UPFC based on PSCAD/EMTDC had been built, and all kinds of fault types in Section 2 can be simulated to verify theoretical analysis above. The model parameters of the AC system and the UPFC, as well as the steady-state operation mode before the fault, which was given in [5], are shown in Table 1 and Table 2.

| Devices          | Items                | Parameters               |
|------------------|----------------------|--------------------------|
| MMC Converter    | $U_{dc}$             | 180kV (±90kV)            |
|                  | $N_{SM}$             | 20                       |
|                  | $C_{SM}$             | 2000μF                   |
|                  | $L_{arm}$            | 36mH                     |
| Shunt transformer| Connection           | YN0/YN/d11               |
|                  | Voltage ratio        | 505kV/94kV/36kV          |
|                  | Rated capacity       | 300MVA                   |
|                  | Neutral grounding    | Through a 2000Ω resistor |
|                  | Short circuit impedance | 10%                      |
| Series transformer| Connection           | III/YN                   |
|                  | Voltage ratio        | 43.5kV/105kV             |
|                  | Rated capacity       | 300MVA                   |
|                  | Neutral grounding    | Through a 2000Ω resistor |
|                  | Short circuit impedance | 20%                      |

| Values | Table 2. System steady state operation before faults |
|--------|-------------------------------------------------------|
| AC Bus voltage (RMS) | 506.90 ± 81.00 kV |
| Offside AC Bus voltage (RMS) | 508.07 ± 83.13 kV |
| Line power flow | (-650.2 ± j200.1) MVA |
| Parallel side operation mode | Injecting AC bus $Q_{sh}=200$ MVar |
| Series side operation mode | $P_{ref}=-650$ MW, $Q_{ref}=200$ MVar |

3.2. Simulation results of single-phase fault on the valve side of the shunt transformer

The fault began at simulation time of 1.5s, and the duration is 0.1s. Through calculation, the fault waveforms of each electrical amount could be obtained as shown in Figure 6. This paper focused on the overvoltage level at the moment of fault, and does not consider the protection action, such as the converter blocking, the bypass switches action, etc.
As seen from the figure, the voltage to ground of the whole UPFC system rises, that causes overvoltage on DC bus and transformers. However, the voltage between the equipment and the bridge arm current are basically unchanged, and the function of the UPFC is not affected.

3.3. Simulation results of DC bus single pole fault

Because the fault current didn’t cross zero, without considering the protection action, such as the converter blocking, the bypass switches action, etc., the fault would continue to the end of the simulation, while the simulation time is 2.0s. Waveforms are shown in Figure 7.

The whole UPFC system voltage had a DC offset to the ground, the voltage between devices and the arm current are basically unchanged. However, voltage fluctuation of upper arms submodule capacitors decreased while that on lower arms increases. The overvoltage position was mainly in the shunt transformer valve side, the series transformer valve side, the valves bottom and the non-fault pole of DC bus.
3.4. Simulation results of DC bus inter-pole short circuit fault

The fault began at the simulation time 1.5s, continued to the end of the simulation, and the simulation time was 2.0s. Waveforms are shown in Figure 8.

As seen from the waveforms, after the fault, the capacitors discharged instantaneously, and induced overvoltage occurred on bridge arm reactors (-103.7kV peak voltage). The current of the bridge arm had a large attenuation DC component and the zero sequence current of the AC side of the converter was very large.

Meanwhile, the voltage of the AC bus seriously reduced (from 508.1kV to 497.9kV) and the power flow of the line oscillated. Therefore, the type of fault is very serious, which could cause the instability of the AC system.

![Waveforms of DC bus inter-pole short circuit fault](image)

**Figure 8.** Waveforms of DC bus inter-pole short circuit fault (a) fault current; (b) DC voltage; (c) AC current of the series converter; (d) arm current of the series converter; (e) voltage on an arm reactor; (f) AC bus voltage

4. Conclusion

In this paper, the theoretical qualitative analysis and simulation calculation of three typical UPFC station faults were carried out. Among them, single-phase fault on the valve side of the shunt transformer would cause overvoltage on DC bus and transformers. but function of UPFC was unaffected. DC bus single pole fault would cause a $U_{d0}/2$ DC voltage offset on transformers and DC bus, and the function of UPFC was also unaffected. Notably, DC bus inter-pole short circuit fault would cause large current in converter arms which led to overvoltage on arm reactors. This type of fault also seriously impacted on the AC system, including voltage of AC bus dropping and power oscillation.

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Reference

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