The Anomaly Power Transmission and Analysis at a 500kV GIS Substation

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Abstract. In view of the extension which steps up from 220kV to 500kV at the switching station, induced the flashover of insulation spacer in gas chamber from 500kV line side, the voltage fault of 500kV bus, the discharge of junction which between oil-gas casing of 500kV main transformer from 220kV bus side and GIS branch bus, due to improper installation. The paper analyzes connection diagram, graph of fault recorder and repair with disassembly point for point. It also suggests the recommendations for improvement, to avoid the appearance.

1. Introduction

The newly-built or expanded substation and overhead line, have finished overall acceptance of correlation specialty. The operating crews will execute power transmission according to the scheme plan beforehand. The power transmission order is: checking the new line→ checking the line interval devices→ checking the bus and the devices belong to bus( such as potential transformer, arrester, etc.) → checking the main transformer, etc. After the assessment of charged and the correct of phase position, the system would be on-load operation. The paper has analyzed anomaly power transmission that extension steps up from 220kV to 500kV at the switching station. It also has suggested the recommendations for improvement, how to handle such commissioning test.

2. The power transmission situation of substation

The set-up transform of 220kV Yanshui substation would be showed by one-line graph under 500kV.

2.1. The first power transmission situation

The first power transmission was on December 6\textsuperscript{th}, 2010. At 11:43, the dispatcher gave an order that charging 500kV Jinyan line, 500kV I and II bus in Yanshui substation. All of their voltages were normal. The phasing of PT secondary side in 500kV I and II bus was accurate.

At 13:32, the dispatcher gave an order that disconnecting the 5012 switch of 500kV I and II bus in Yanshui substation. After that, finding the three phase voltages of 500kV II bus were unusual. Such as: \(U_a=60kV\), \(U_b=60kV\), \(U_c=126 kV\), but the voltages of Jinyan line and 500kV I were regular. Then the dispatcher gave an order that disconnecting the 5051 switch of Jinyan line in Yanshui substation. The line voltage was regular. The three phase voltages of 500kV I were 10kV or so. The operator executed the order next, disconnecting the Jinyan line. The background displayed the voltages of 500kV Jinyan line, 500kV I and II bus PT were 0kV.

In consideration of above conditions, provincial dispatcher commanded to check on site. The result showed no exception. So the operation went on. When charging the 500kV Jinyan line and the
500kV I bus, current differential protection operated, both sides of the switch tripped. The fault
differential current was 7100A, the fault phase was C, fault distance was 0km from the Yanshui
substation. The fault distance of opposite terminal was 56.2~57.7 km (The line was 65.2 km). The
fault distances matched each other.

After the failure, power supplier and operator checked the 500kV Jinyan line and related devices. The
visual position indicated normally. So it said that the GIS had a fault in a preliminary estimate. To aim
at finding the fault position, tester tested all analysis on SF$_6$ of the Jinyan line GIS of C phase in
Yanshui substation. The analysis showed the abnormality in Jinyan C phase outlet chamber
(SO$_2$+SOF$_2$:87.2 μL/L, H$_2$S:10.1 μL/L, CO:90.4 μL/L). Hereby, the insulation of Jinyan C phase
outlet chamber had broken down.

At 19:20, both sides of Yanshui and Jinjia substation switches were disconnected, also the Jinyan line.

2.2. The second power transmission situation
On December 6$^{th}$, after replacing the disc insulator of C phase. On December 18$^{th}$, power supplied.
The same order induced the same fault like before. When #2 transform got power, finding that A and
B phase voltage of 220kV IV bus were unusual (The 220kV side connected to the 220kV IV bus).

Hearing ‘flat-flat’ following the electric spark at the connection of GIS case flange, that A and B phase
casing connected to the GIS. The voltage waveform record of 220kV side bus is shown below.

3. The checking on site after twice power transmissions

3.1. The checking the chamber C phase of GIS line on 500kV Jinyan line
The installer checked the C phase chamber, which had an insulation breakdown on December 6$^{th}$. The
disc insulator of outlet casing bottom discharged breakdown. See figure 3.
The figure 3 shows a penetrating discharge trail of the 500kV disc insulator face. The trail was due to
the system short circuit after discharging.
3.2. The checking of 500kV #2 transformer abnormal transmission
On December 18th, found 500kV #2 transformer abnormal transmission. The installer found nothing from the checking, which the equipotential bonding screws of electric spark between the connection of GIS case flange and the conduction were normal. When the tester tested the conduction of IV bus 67# grounding switch, which the three phase were connected to the neutral point of 500kV main transformer. The open circuit was found between A and B phase. By using the 1000V megohmmeter, the insulation resistance value was 0MΩ. The value of A and B phase was ∞MΩ. The connection between the 220kV outlet casing of A and B phase, 220kV IV bus was abnormal. Opening the handhole of 220kV outlet casing of A, B phase and 220kV GIS guide, see figure 4 and 5 below.

![Figure 5. The handhole of opening the transformer 220kV side B phase](image)

From the figures above, there was installed fault between the outlet casing of A and B phase, 220kV GIS guide, which due to clearance. The largest clearance was A phase, it reached 15mm or so. There was a penetrating discharge trail on mei flower button contact of A and B phase casing end, GIS guide. The C phase and other parts of GIS were normal.

4. The abnormal phenomenon analysis

4.1. The abnormal voltage analysis of 500kV transmission
See figure 1, when discharging 5012 bus connection switch, the equivalent circuit in dashed line frame is showed in figure 6.

In figure 6: (a) is equivalent, (b) and (c) are simplified equivalent circuit.
- $C_1, C_2$-5012 parallel capacitor of breaker fracture
- $C_3$-5012 breaker pillar capacitance to earth
- $C_4$-equivalent capacitance to earth of high voltage conductor between 500kV II bus PT and 5012 breaker
- $C'-C_1, C_2$ series capacitor
- C-the total equivalent capacitance of simplified circuit
- $L$-inductance of 500kV II bus PT
- $U$-equivalent supply voltage
In figure 6, $C_1$ and $C_2$ are 5012 grading capacitances of breaker fracture. The both of capacity value are 600pF or so. $C_3$ is the capacitance to earth, the value is several tens pF. $C_4$ is the equivalent capacitance to earth of high voltage conductor between 500kV II bus PT and 5012 breaker, the value is 1000—1500 pF. L is the inductance of 500kV II bus PT. Due to the value of $C_3$ is the least, than $C_1$, $C_2$ and $C_4$. The influence can be ignored. So figure (a) can be simplified to figure (b). In figure (b):

$$C' = \frac{C_1C_2}{C_1+C_2} = 300\text{pF};$$

Figure (b) can be simplified to figure (c) according to the venin theorem. In figure (c):

$$C = \frac{C'}{C_4} = 1500\text{pF}$$ (convenient for calculating, $C_4$ takes 1200 pF as value);

$$U = \frac{306\times C' C_4}{(C'+C_4)} = 61.2\text{kV};$$

The PT exciting characteristic curve which manufacturer provided shows the impedance:

$$Z_L = 61.2\text{M} \Omega \approx X_L$$ (the coil DC resistance value is 38kΩ or so, can be ignored), so:

$$U_L = X_L \times U / (X_L - X_c) = 63.4\text{kV};$$

By this token, the voltage value of 500kV PT (63.4kV) matches the voltage value of A and B (60kV). The voltage value of C phase transmission is the largest. Maybe the PT resistance and capacitance to earth of C phase have a difference among there phase, same as the abnormality of 500 kV I bus voltage.

4.2. The breakdown analysis of 500kV disc insulator

On December 6th, at the first power transmission, it was very strange that 500kV disc insulator broke down. Through anatomizing the disc insulator, there were several long cracks on the discharge channel section, see figure 7.

4.3. The abnormal phenomenon analysis of 220kV IV bus voltage

When 500kV transform 220kV side powered on 220kV IV bus, the oscillograph recorded the abnormal voltage waveform of 220kV IV bus A and B phase, which were irregular step wave or square wave. Taking the wave of figure 2 dashed line frame part for example.

According to the tin-opener checking, there was intermittent discharge formed by gap in the transformer gas-oil bushing of A and B phase, GIS conductor. It explained: in figure 8 at $t_1$, the gap broke down. The transient voltages of 220kV IV bus and transformer 220kV side were same. Then the gap discharge stopped. Then the bus voltage held the discharge value (ignore the bus leakage).
Until \( t_2 \), both of gap end voltages had reached breakdown value, broke down again. The bus voltage had been the transformer side AC voltage instantaneous value until \( t_3 \). At \( t_3 \), the gap broke down by reverse AC voltage. The bus voltage was repeated several times. Because of the dispersion and randomness of discharge, there were differences between A and B phase waveform.  

![Figure 8. The partial enlarged drawing of dashed line frame part in figure 2](image)

In fact, process above, the voltage of 220kV IV bus and PT could be denoted:

\[
\begin{align*}
  u_e &= \sum_{n=1}^{n=M} U_{en} e^{-\frac{t}{\tau_n}} + \sum_{m=1}^{m=M} U_{em} \sin(\omega_m + \theta_m) e^{-\frac{t}{\tau_m}} \\
  U_{en}, U_{em}: & \text{ the voltage amplitude of ‘n’ and ‘m’; } T_m, T_n: \text{ the voltage decay time constant of ‘n’ and ‘m’; } \\
  \omega_m, \theta_m: & \text{ the voltage angular frequency and phase angle.}
\end{align*}
\]

The voltage of PT has two parts, the attenuation DC and high frequency shock in equation (1). The voltage of PT approximates the first part of equation (1). It’s showed the PT response condition of attenuation DC voltage. See the equivalent circuit below for analysis.

![Figure 9. The equivalent circuit of PT](image)

\( R_1, R_2 \): the conversion value of primary winding resistance and secondary winding resistance; \( L_1, L_2 \): the conversion value of primary winding leakage inductance and secondary winding leakage inductance; \( L_m \): leakage inductance; \( R_0, L_0 \): the conversion value of load resistance and inductance.

According to the equivalent circuit in figure 9, the equation is obtained:

\[
\begin{align*}
  u_1(p) &= i_1(p)(R_1 + pL_1) + i_0(p)pL_m \\
  i_0(p)pL_m &= i_2(p)(R_2 + pL_2') + u_2(p) \\
  i_1(p) &= i_0(p) \\
  u_2(p) &= i_2(p)(R_0 + pL_B')
\end{align*}
\]

In formula, \( p \) is laplacian operator, if there is the attenuation DC voltage waveform of PT primary side:

\[
  u_1(t) = U_{1s}e^{-\frac{t}{\tau_m}}
\]

In equation (3), \( T_m \) is as the time constant, so:

\[
  u_1(p) = U_{1s} \frac{1}{p + \frac{T_m}{\tau_m}}
\]

Substituting equation (3) into equation (4), to counter inverse laplace transform, obtain:

\[
  u_2(t) = U_{1s} \left[ \frac{1}{1 - \frac{T_m}{\tau_m}} - \frac{T_m}{\tau_m} \cdot e^{-\frac{t}{\tau_m}} + \frac{1}{1 + \frac{T_m}{\tau_m}} - \frac{T_m}{\tau_m} \cdot e^{-\frac{t}{\tau_m}} \right]
\]

In equation (5), \( T = \frac{L_1 + L_2 + L_B'}{R_3 + R_4 + R_B'}, T_m = \frac{L_m + L_1}{R_1} \), \( T_m \) is as the voltage transformer time constant.

In general, the voltage transformer of 220kV above, \( T_m \leq T_m, T_m/T_m \leq 0 \), the second part of equation (5) can be ignored. By the time, \( T \) is small. The third part decays very quickly, ignore the influence. So the primary decides the secondary voltage. The secondary waveform of voltage transformer reflects the connected bus voltage change, they have a nice consistency [5-8].

Following voltage abnormality, the connection of GIS case flange had a spark phenomenon. Owing to the similar between the intermittent pulse discharge and the wave propagation property, when the
pulse discharge travelled in the medium which were GIS conductor and cylinder wall. Then the connected flange wave resistance had changed, the refraction and reflection of wave would discharge.

5. The solving strategies
For this case, incorporated with location condition, focusing on the following tasks:

- To improve the quality of electrical equipment installation
  From the abnormal voltage and GIS tin-opener checking, the main reason is the installer’s false installing without installation process standards, existed the demotivation, the installer approved. Otherwise, lack of supervision is an important reason. So to improve the employee responsibility consciousness, strengthen field management and site supervision assessment. Redesign installation process, stop the faults from taking place again[9]. To respect for science, reasonable installation, commissioning duration are the basis and precondition of quality.

- To strengthen the professional communication of the site equipment installation
  Objectively speaking, even the installation is improper, it must be found before the transmission. If the installation process has a well design, a good communication of installer and debugging, with a simple circuit conduction test, this problem will be found in time. So to strengthen and improve the work is needed.

- To improvement and increase the detection means
  AC withstand voltage test of GIS complies with requirements[10-13], the breakdown had happen all the time in transmission. Some defectives and hidden troubles can’t be tested though the available technology. In GIS, increasing the AC withstand voltage test value (State Grid requires the site AC withstand voltage test value is 90% of delivery voltage test value, 220kV site withstand test value is same as delivery voltage test value). Monitoring ultrasound and UHF PD are effective means. While recent experience shows that lightning impact test, which detects GIS abnormal electrode and dirty has an effective means. It should be applied on site [14-16]. The delivery test of disc insulator should be tested, the impulsive check which are ultrasonic inspection, x-ray inspection, changes to the whole check.

Footnotes should be avoided whenever possible. If required they should be used only for brief notes that don’t fit conveniently into the text.

6. Discussion
In conclusion:

- The reasonable schedule, reasonable installation process, perfect site supervision are the base of equipment installation quality;

- To strengthen the professional communication of the site equipment installation is the important means of reducing vulnerability.

- To increase the detection means is the premise of mastering the equipment condition.

- To change the system operation mode reasonably, is the effective method of removing 500kV bus voltage abnormality (Such as the 500kV transformer is operating with a prepared, the prepared transformer is in no-load operation).

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