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Vibration Analysis of GIS Pipe System in Transformer Substation

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Abstract. Due to the influence of electromagnetic force, the running GIS gas (insulated switchgear) will produce a certain vibration frequency. The other factors, such as resonance, disturbance of internal gas, bring abnormal vibration to the GIS shell. Because of the bad effects followed, the components of GIS can be damaged to the leakage which will lead to power failure in serious cases. In this paper, the vibration analysis of a 1000kV UHV substation 500kV area GIS is carried out. The vibration frequency of the GIS equipment was obtained by field vibration detection, and through the finite element modal analysis, we got the natural frequency and modal shape. It was found that the vibration frequency of the GIS shell is normal reportedly, and the possibility of resonance is ruled out.

Keywords: GIS; vibration; vibration detection; modal analysis.

1. Introduction

GIS enclosed switchgear with the advantages of small volume, less maintenance, good technical performance is a kind of advanced high voltage electrical distribution equipment which is developing rapidly. GIS is filled with SF₆ gas with 0.4 to 0.8MPa working pressure, which acts as insulation and arc extinguishing [1]. Due to various factors, GIS leakage events occurred every year. Data shows that, for the 220kV substation GIS pipeline, there is 9 leakage occurred in Shandong electric grid during 2011-2012. Leakage took place every year, and the number Increased in the 500kV substation. There are GIS condition monitoring and fault detecting methods for the GIS faults, among which UHF technology is the most widely used and relatively more mature. In addition, the ultrasonic method, pulse current method, gas decomposition method and other monitoring methods have been applied in GIS [2-3].

The leakage is mainly due to the abnormal vibration and the insufficient strength of the GIS structure. The insufficient strength is mainly caused by the defects in the design and process. The mechanism of GIS vibration is complex. Not only does the GIS vibration act as the inherent property of GIS in normal operation, but it is affected by faults. Different vibration states will make some influence on the structure



of GIS. If the GIS mechanical vibration resonates with its own natural frequency, the GIS pipe component in this state will produce fatigue damage, which will lead to leakage this persists. The vibration effect analysis of GIS is an effective method for condition monitoring and fault detecting, and has already produced some application achievements. In the late 1980s, Japanese scholar Youichi Ohshita proposed vibration method on GIS monitoring, the spectrum characteristics of different partial discharges are given by experimental study [4]. The professor of Tsinghua University Qian Jiali and Guo Bihong which worked for China Electric Power Research Institute, also have a research on GIS vibration [5-9].

An abnormal noise appeared in a 1000kV UHV substation 500kV area GIS when electrified in May 12th. On the same day, after operating the ultrasonic, ultra-high frequency detection, no abnormal signal was found. The vibration noise still existed after the equipment was loaded. Operators suspected that the equipment produces resonance and affects the safety of power grid, so the influence of GIS vibration was analyzed and studied.

2. Ansys Method

Finite Element Analysis. Through the finite element modal analysis, the natural frequency of GIS structure and the vibration modals of each order are obtained, so as to judge whether the GIS pipe in operation is resonant.

Model Building. The three-dimensional structure of GIS #1 bus is established with SolidWorks, the three-dimensional design software, and then imported into ANSYS. The structure consists of inner conductor, support insulator, flange, insulated basin, outer shell and bellows expansion joint, with a total length of 90.28m. The 3D model is shown in Figure 1.

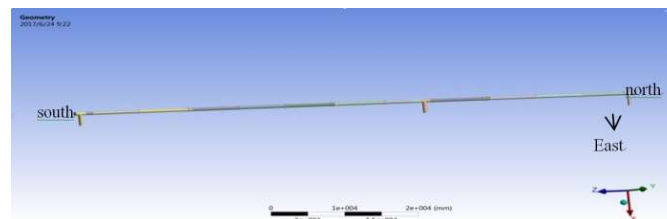


Figure 1. Structure of the whole 1M bus (Top view)

The material parameters of GIS are shown in Table 1.

Table 1. Material parameters table

Name	Elastic modulus MPa	Poisson ratio	Density kg/m ³
Aluminium alloy	71000	0.33	2770
resin	824	0.33	1180

The GIS model is divided into 148365 units and 301717 nodes by free mesh refinement. Local refinement has been applied in the model. Hexahedron uses solid186 element, tetrahedron uses solid187 element. The finished mesh is shown in Figure 2.

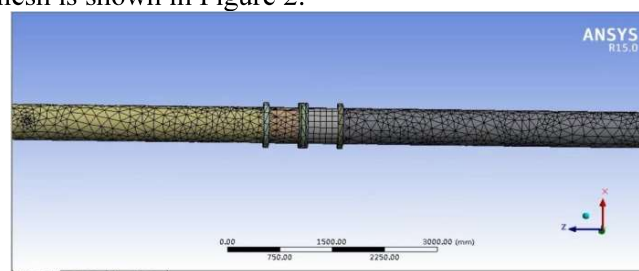


Figure 2. Mesh diagrams for 3-D finite element model

Since modal analysis is a linear analysis process, and it is considered that each component is fastened together, the bonding contact between different parts is used. We set the distal displacement constraint at the tee position to fix all the degrees of freedom of the end face of the tee and set fixed constraint on the fixed support position. The displacement constraint is set at the position of the sliding support and the bracket, and the axial freedom of the constraint region is released. As shown in Figure 3, A, B and C are the distal displacement constraints set at the three-pass position. D and E are fixed support constraints and sliding support constraints, respectively.

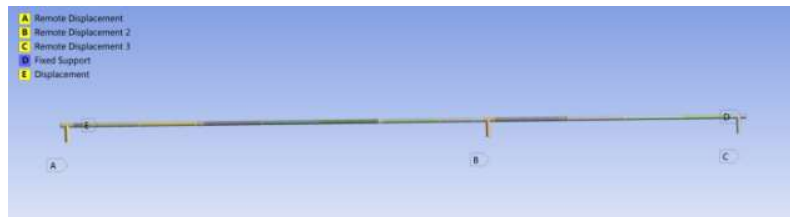


Figure 3. Constraint setting

Field Vibration Detection. At the time of operation, the field vibration testing is first carried out to obtain the mechanical vibration frequency of GIS. The acquisition device including 891-II vibration pickup, acceleration sensor INV9828, applicable frequency 0.2Hz-2.5kHz, acceleration INV9822, applicable frequency and frequency 0.5Hz-8kHz has been used in the field testing. The signal collection and processing are carried out by CST-LAN-Data Acquisition Device (INV3062) which is designed by Beijing Dongfang vibration and Noise Research Institute.

Vibration testing points are arranged 16m away from the southernmost fixed support of the 1# bus which is the noisiest part of the GIS shell, A phase and B phase.

Location of testing points

Point 1: The horizontal direction of the upper pipe (B phase), acceleration sensor INV9828.

Point 2: The vertical direction of the lower pipe (A phase), acceleration sensor INV9828.

Point 3: The vertical direction of the lower pipe (A phase), 891-II vibration pickup, velocity measurement.

Point 4 Shell sliding support, 891-II vibration pickup, velocity measurement.

The arrangement of testing points is shown in Figure 4.

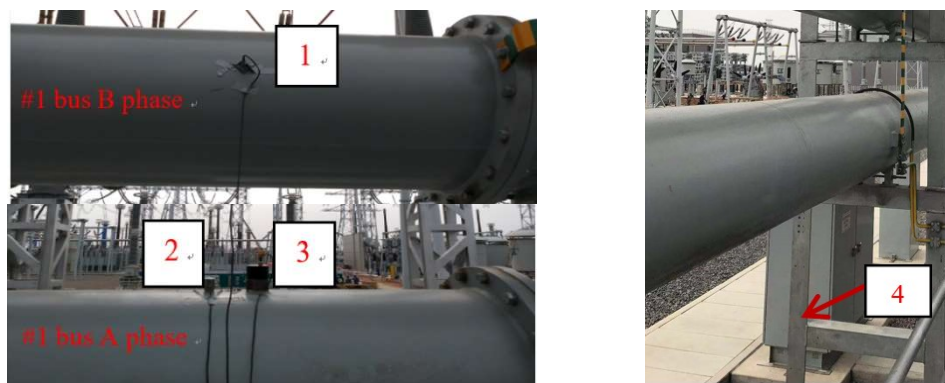


Figure 4. Arrangement of testing points

3. Experimental Data and Results

Finite Element Analysis Results. The natural frequencies of the whole structure are calculated as shown in Table 2. The modal calculation showed that the natural frequency increased with the increase of the order. Although the continuum elastic body has infinite modals, for the structural vibration, the higher order modals with lower energy ratio make too little contribution to the vibration of the whole structure,

so we only consider the lower order modals in Structural vibration analysis. From Table 2, we arrive at the conclusions: the natural frequency of the GIS structure is in low level, and the frequency of the twentieth order modal is 16.15Hz.

Table 2. Natural frequency calculation results

Mode	1	2	3	4	5	6	7	8	9	10
Frequency [Hz]	8.16	9.38	9.48	10.18	10.42	11.04	11.10	11.31	11.47	11.88
Mode	11	12	13	14	15	16	17	18	19	20
Frequency [Hz]	12.34	12.89	12.92	13.64	13.83	14.22	14.82	14.96	15.96	16.15

The first order modal shape of the GIS integral structure is shown in Figure 6. It showed that the internal conductor swung in the horizontal direction. The internal conductor is connected with the shell through the insulating resin so that its inherent frequency is low. It is found that the modal shapes of the first 13 models are mainly the vibration shapes of the internal conductor with the observation, while the 14-20th are mainly the exhibiting the modal shapes of the GIS shell.



Figure 5. First modal shape of structure

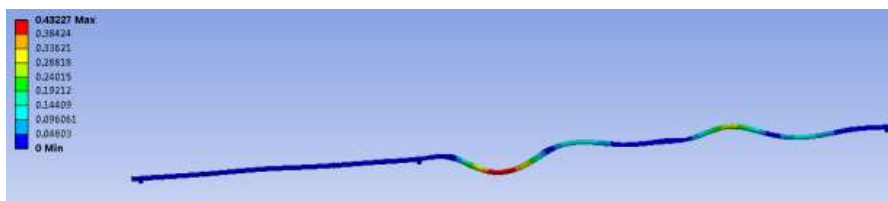


Figure 6. The 14th modal shape of structure (Vertical vibration at the right side)

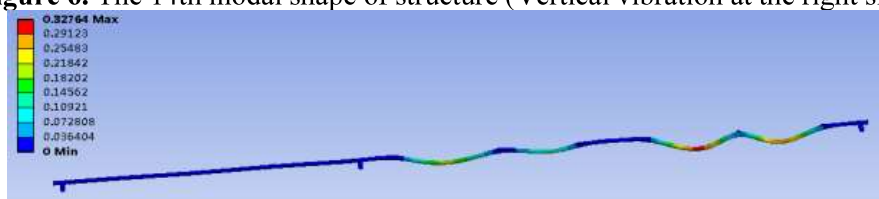


Figure 7. The 20th modal shape of structure (Vertical vibration at the right side)

Vibration Testing Results. The shapes in Figure 8-9 showed the time domain graph of the measured values obtained from each testing point, and the waveform of any section is intercepted to read the peak value of the representative wave. The collected value is shown in Table 3.

Table 3. Collected peak value

Testing point number	Point 1	Point 2	Point 3	Point 4
Acceleration m/SS	0.028	0.03	--	--
Velocity mm/s	--	--	1.88E-5	3.04E-6

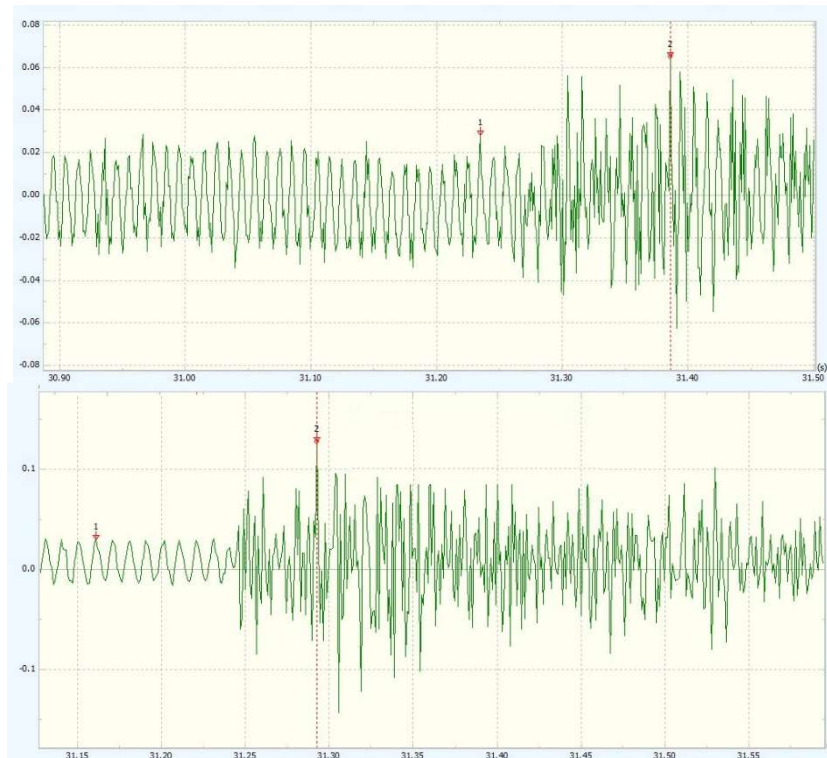


Figure 8. Testing point 1&2 time domain analysis



Figure 9. Testing point 3&4 time domain analysis

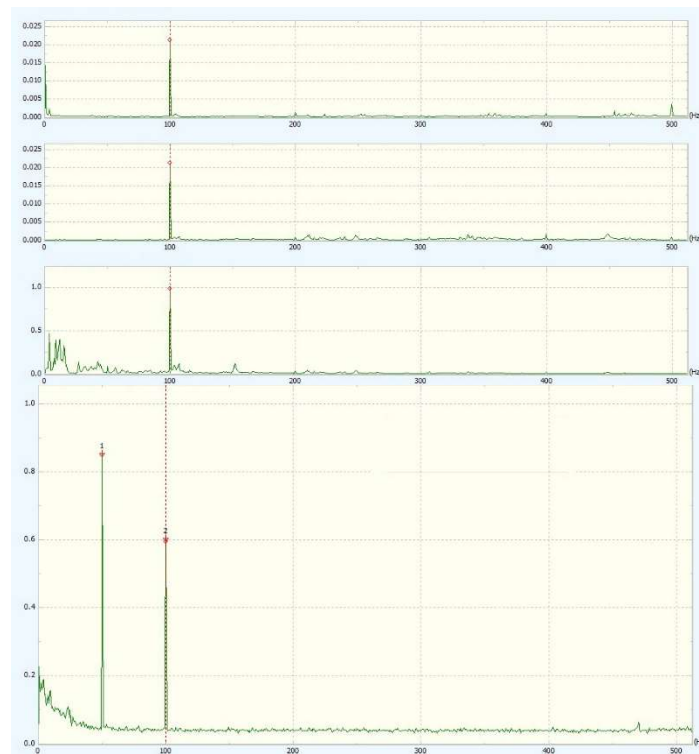


Figure 10. Testing point 1-3& testing point 4 spectrum analysis

As shown in Figure 10, the vibration frequency on the GIS testing point of the #1 bus is 100Hz. Two vibration frequencies of 100Hz and 50Hz are collected from the bracket.

4. Conclusion

Through the field-testing vibration data obtained, it can be seen that the vibration frequency of GIS pipeline is 100Hz, and the vibration on the shell of the GIS in normal operation is mainly caused by electromagnetic force and magnetostriction. The electromagnetic force and Magnetostriction acceleration can be obtained by deduction:

$$F = M_r I_0^2 \sin(2\omega t), \quad a = \frac{-2\omega^2 \epsilon_s \mu_0^2 I_0^2}{\pi R^2} \cos(2\omega t) \quad (1)$$

Such verdict can be got from the analysis of electromagnetic force or magnetostrictive effect that the normal vibration frequency of the GIS shell is at twice the supply frequency(100Hz) [10] which is consistent with the test results. Therefore, the vibration frequency of GIS is judged proper from the measured data of field vibration.

Through the finite element modal calculation results, it can be found that the natural frequency of the structure is in low degree due to the larger length of the model. The stiffness and quality of the structure determine the natural frequency of the model. It is found that the modal shapes of the first 13 models are mainly the vibration shapes of the internal conductor with the observation while the 14-20th are mainly the exhibiting the modal shapes of the GIS shell. Due to the structural shape and the link to the insulating resin, the internal conductor stiffness is lower, so the natural frequency is also relatively low.

Through the comparison between the frequency of the first 20th order natural frequency and the field measured vibration, the difference between the numerical value is obvious and the mechanical vibration of the GIS shell is not considered to be resonant so the possibility of resonance is ruled out.

In addition to the normal operation of alternating current caused by vibration, may also be associated with a variety of other factors, such as internal SF₆ gas in high pressure after the power supply, high current, strong electric field, magnetic field and temperature field under the action of many physical fields such as possible disturbances, etc., while eliminating the resonance hazard, but still must stay in condition monitoring of GIS.

Acknowledgements

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References

- [1] Luo Xuechen. SF₆ Gas Insolated switchgear (GIS)[M].Beijing: China Electric Power Press, 1999, 83-135.
- [2] Lv Fangcheng, Zhang Bo. Recognition of GIS Discharge Types Based on the S_Kohonen Network [J]. Electrical Measurement & Instrumentation, 2014, 51(20): 21-24.
- [3] Lv Fangcheng, Zhang Bo. A Ultrasonic Detection Based GIS Insulating Defect Types Recognition [J]. Electrical Measurement & Instrumentation, 2014, 51(14): 22-26.
- [4] Youichi Ohshita, Akira Hashimoto, Yukio Kurosawa. A diagnostic technique to detect abnormal conditions of contacts measuring vibrations in metal enclosures of gas insulated switchgear [J]. IEEE Trans-actions on Power Delivery, 1989, 4(4): 2090-2094.
- [5] Qian Jiali, Shen Li, Liu Weidong, et al. Vibration phenomena and detection of GIS shell [J]. High Voltage Apparatus, 1990, (6): 3-9.
- [6] Guo Bihong, Zhang hanhua. Prediction of internal faults of GIS by frequency spectrum of typical vibration on the enclosure [J]. Proceedings of 2nd International Conference on Properties and Applications of Dielectric Materials, Beijing, 1988: 148-151.
- [7] Naohiro Okutsu, Setsuyuki Matsuda, Hisao Mukae, et al. Pattern recognition of vibrations in metal enclosures of gas insulated equipment and its application [J]. IEEE Transactions on Power Apparatus and Systems, 1981, PAS-100 (6): 2733-2739.
- [8] Zhang Yalin, Qian Jiali. Experimental study of vibration in GIS caused by partial discharge [J]. High Voltage Apparatus, 1989, (4): 13-16.
- [9] Jiang Xiufeng, Liu Weidong, Qian Jiali. Breakdown location in GIS based on Multi-thresholds of vibration signals [J]. High Voltage Apparatus, 1999, (2): 19-21.
- [10] Li kai,Xu Honghua, et al. Research on vibration mechanism and natural frequency in GIS [J]. Electrical Measurement & Instrumentation, 2017, 54(3): 14-18.