Research on the Influence of Distributed Photovoltaic Grid-Connected on the Operation Characteristics of Wide Range OLTC Transformer

Simin Peng(✉), Xujin Duan, Dai Wan, Miao Zhao, Hengyi Zhou, and Kehui Zhou

State Grid Hunan Electric Power Company Limited Research Institute, Changsha 410007, China
240639880@qq.com

Abstract. After the distributed photovoltaic is connected to the distribution network, its power supply characteristics change the load characteristics of the traditional distribution network, so that the power flow of the distribution network begins to change in two directions. Terminal voltage, which puts forward higher requirements for the bidirectional voltage regulation of the wide-width on-load voltage regulating transformer. At present, there are still no authoritative and directly related technical standards for the voltage regulating part and its control part of the wide-width on-load voltage regulating transformer for reference. The relevant suggestions are put forward for the application of wide-width on-load voltage regulating transformers under grid conditions.

Keywords: Distributed PV · OLTC · Distribution network

1 Introduction

After the distributed photovoltaic is connected to the distribution network, its power supply characteristics change the load characteristics of the traditional distribution network [1]. When a large number of distributed photovoltaics are connected, the phenomenon of power flow return may occur and the back-end voltage of the line may be raised [2]. Especially when the line is lightly loaded, the voltage of the distribution line is basically close to the upper limit, and the distributed photovoltaic cannot be absorbed locally, and the back-end voltage of the line may exceed the upper limit [3]. Therefore, higher requirements are put forward for the bidirectional voltage regulation of the wide-width on-load voltage regulating transformer [4].However, there is still a lack of authoritative and directly related technical standards for the 10 kV wide on-load voltage regulation part and its control [5]. In practical application, it is necessary to clarify requirements in terms of wide width, on-load voltage regulation, and control to guide the configuration of equipment control parameters and on-site application [6].

This paper mainly conducts experimental analysis on wide-width on-load voltage regulating transformers, and puts forward relevant suggestions for the application of wide-width on-load voltage regulating transformers under the condition of distributed photovoltaic grid connection.

H. Yang et al. (Eds.): SmartGIFT 2022, LNICST 483, pp. 423–431, 2023.
https://doi.org/10.1007/978-3-031-31733-0_36

2 Test Situation

In this paper, performance tests such as temperature rise, lightning impulse, short-circuit resistance, no-load, load, and overload voltage regulation are carried out on 13 on-load voltage regulation and distribution transformers. Among them, 8 sets of closed three-dimensional wound core amorphous alloy width change, 3 sets of stacked iron core silicon steel sheet width change, 2 sets of traditional amorphous alloy width change.

2.1 Routine Experiment

The routine routine and insulation tests carried out are all qualified, and the items include insulation resistance, winding resistance measurement, voltage ratio measurement and connection group label verification, no-load loss and no-load current detection, short-circuit impedance and load loss measurement, and external withstand voltage test, Induction withstand voltage test, insulating liquid test, temperature rise test, lightning impulse test, zero sequence impedance measurement.

2.2 Short-Circuit Resistance Test

In the short-circuit resistance test of distribution transformers, 3 distribution transformers failed the short-circuit resistance ability, and 1 distribution transformer failed the oil withstand voltage test. In terms of core material, among the unqualified samples, the width of 2 sets of closed three-dimensional wound core amorphous alloys changed, the width of 1 set of stacked iron core silicon steel sheets changed, and the width of 1 set of traditional amorphous alloys changed. On the whole, the failure rate of amorphous alloy distribution test is higher.

2.3 On-Load Voltage Regulator Power Supply Voltage Characteristic Test

For the power supply voltage characteristic test of the on-load voltage regulation controller, all the on-load voltage regulation and variable voltage regulation control systems can be displayed and adjusted normally within the range of −30% to +20% of the rated working voltage. Some samples can work normally within the range of −50% to +30%. The 7 stepper motor samples can work normally in the range of −50% to +30%. The permanent magnet switch does not support working at lower voltage due to the limitation of capacitor charging voltage.

2.4 On-Load Voltage Regulation Automatic Voltage Regulation Test

By manually adjusting the voltage of the high-voltage side of the distribution transformer, the output voltage of the low-voltage side and the shifting action are monitored. The test results show that all samples can be downshifted when the low-voltage side voltage exceeds 235 V and upshifted when the voltage is lower than 20 5V (the delay of gear shifting detection for each sample varies from 10–60 s) (Figs. 1 and 2).

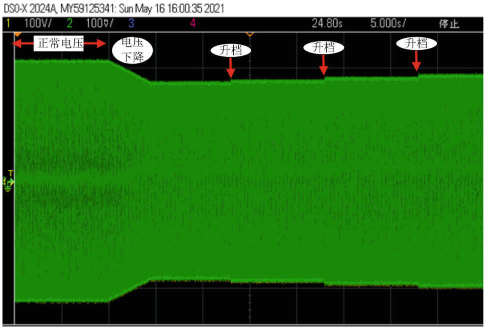

Fig. 1. Test results of automatic voltage regulation of wide-width on-load transformers (automatic downshift)

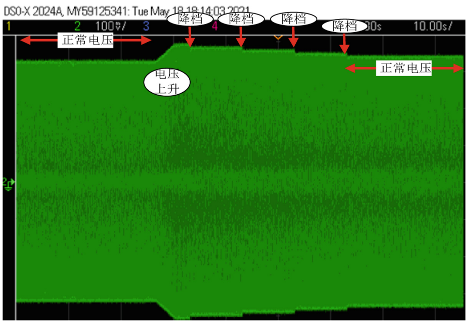

Fig. 2. Test results of automatic voltage regulation of wide-width on-load transformers (automatic upshift)

2.5 Voltage Transient Waveform Under No-Load Condition

Shifting under no-load conditions, and detecting the output voltage waveform of the low-voltage side, it is found that the shifting process can be completed within 1–3 fundamental wave cycles (different sample times are slightly different). There is no obvious voltage dip, swell or voltage interruption during the shifting process, but the output voltage has a us-level glitch during the switching process (Figs. 3 and 4).

2.6 Voltage Transient Waveform Under No-Load Condition

In the test, the output side of each transformer sample is connected to a three-phase balanced constant resistance load (up to 200 kVA). Under the load condition, the samples are switched in the order of rated gear → lowest gear → highest gear → rated gear. Carry out 10 rounds On-load voltage regulation, there is no abnormality after the on-load switch operates.

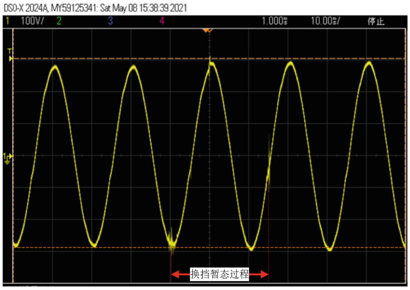

Fig. 3. Output voltage waveform during on-load voltage regulation shifting (a)

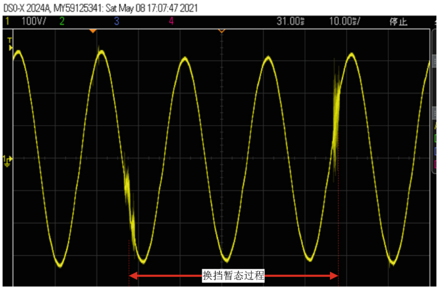

Fig. 4. Output voltage waveform during on-load voltage regulation shifting (b)

2.7 On-Load Switch Mechanical Action Assessment Test

Under the condition that the transformer body is not powered and the control box is powered by an external 220 V power supply, let the on-load switch automatically cycle and adjust the gear every certain time (interval 20–80 s, the specific time refers to the recommended value of each sample manufacturer), and the on-load voltage regulating switch is carried out. Mechanical life test. At present, the maximum number of actions in each sample has reached 50,000 times, and no failure of the on-load voltage regulator body has been found (Table 1).

Table 1. On-load tap changer mechanical life test situation

Sample serial number	1	2	3	4	5	6	7	8	9
Mechanical life (10,000 times)	≥50	≥10	≥50	≥50	≥50	≥50	≥50	≥50	≥50
The number of actions (times)	320	21918	50776	15000	32664	44831	31383	29007	206

2.8 Oil Sample Detection Before and After On-Load Pressure Regulation

Before carrying out the frequent electrified gear shifting assessment test of on-load switches, the oil samples of 5 wide-width on-load voltage regulating transformers were tested, and acetylene (0.15–0.30 uL/L) was detected in 3 of them. The acetylene content in each sample did not change significantly after the gear check (continuous on-load switch on and off). Judging from the influence of the existing adjustment times, it has not been found that the vacuum on-load voltage regulating switch has polluted the oil quality of the transformer.

3 Test Analysis

3.1 Low Pass Rate Resistance to Short Circuit

The overall pass rate of the short-circuit resistance of the voltage regulating transformer is 42.86%, which is lower than the sampling inspection level of full-caliber distribution transformers (the pass rate is 48%). In particular, the unqualified rate of amorphous alloy distribution transformers accounts for as high as 75%.The hanging core inspection was carried out on two closed three-dimensional coil amorphous alloy samples with unqualified short-circuit resistance, as shown in the Figs. 5 and 6.

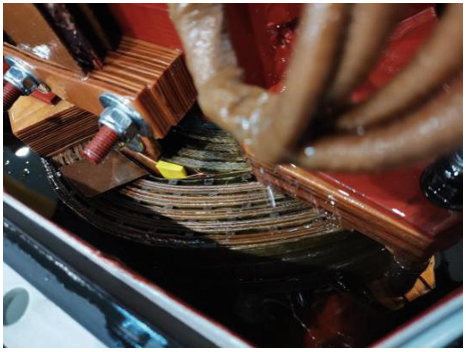

Fig. 5. Output voltage waveform during on-load voltage regulation shifting (a)

It can be seen from the above figure that the radial direction of the low-voltage coil of the distribution transformer is deformed after the short circuit, and the low-voltage coil (copper foil) is sunk inward, resulting in the change of reactance exceeding the standard. The main reason is that the overall rigidity of the coil is not enough. When the low-voltage coil flows through the short-circuit current, under the action of the electromotive force of the amplitude inward and the tangent circle, it forms an inward extrusion force and a rotation force around the center of the circular section, resulting in separation of high and low voltage windings and Deformation of the low voltage winding.

Fig. 6. Output voltage waveform during on-load voltage regulation shifting (b)

3.2 Controller Problem

During the test, it was found that 4 samples had faults such as controller crash and unreliable measurement control system. After the control system is abnormal, it will directly lead to the loss of the expected function of the on-load voltage regulating transformer.

3.3 Magnetic Circuit Saturation and Waveform Distortion Appear Under High Voltage and High Gear

Among the 9 transformer samples tested, in the process of inputting 7–11 kV on the high-voltage side and manually adjusting the low-voltage side from the lowest gear to the highest gear, some cases were detected (when the input voltage is 10.5–11 kV and the transformer gear is high), causing the secondary side voltage to exceed 265 V) the phenomenon of low-voltage side output voltage waveform distortion and abnormal increase in transformer noise.

The main reason is that the conventional distribution transformer has a narrow voltage regulation range (±5%), and the distribution network transformer core is generally designed with a 10–15% margin, so even if the input voltage is high and it is in a non-rated gear, the core will not will be saturated. However, in the wide-width on-load voltage regulating transformer, the transformer is generally designed according to the steady-state operating conditions of low-speed operation (with a large number of input turns) when the primary voltage is high. In theory, when the input voltage is high, it should be input more in the low gear, the magnetic circuit will not be saturated at this time. However, during the operation of the transformer, if the voltage on the high-voltage side of the distribution transformer changes abruptly due to the load and grid voltage, the magnetic circuit saturation and Conditions that cause waveform distortion (Fig. 7).

3.4 Voltage Dip

During the test, it was found that when a 120 kW resistive load was directly added to the low-voltage side load of the on-load voltage regulation distribution transformer from no-load, the output voltage dropped to zero within 1–2 ms. In actual operation, a sudden increase in load may cause the control system to lose power and crash (Fig. 8).

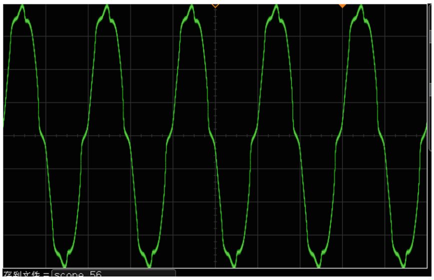

Fig. 7. Distorted waveform when the output voltage is high (high voltage side voltage 10.6 kV, low voltage side 272 V, 8 gears)

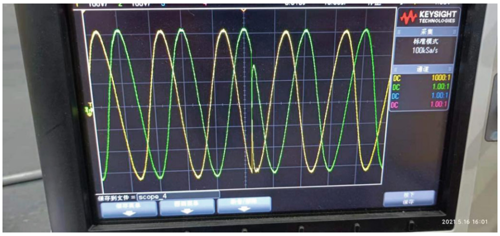

Fig. 8. Output voltage dips briefly to zero during sudden heavy load

3.5 Transformer Oil Problem

The oil samples of 5 wide-width on-load voltage regulating transformers were tested, and it was found that acetylene was detected in 3 samples, and the oil withstand voltage of 1 distribution transformer failed after the short-circuit resistance test. The reliability of the equipment of the wide-amplitude voltage regulating transformer is high, and the quality of the insulating oil directly affects the performance of the body, and it is necessary to increase the quality control.

In order to avoid the magnetic circuit saturation affecting the power quality and user equipment, when selecting equipment parameters, it is necessary to increase the magnetic density margin of the core according to the short-term overvoltage condition; at the same time, the controller needs to differentiate the parameters and logic under the sudden change condition.

4 Application Suggestions for Wide OLTC Transformers

4.1 Core Material and Structure Selection Suggestion

Taking into account the inherent inability to withstand force and strong brittleness of amorphous alloy iron cores, its short-circuit resistance is generally poor. Although the closed three-dimensional wound core amorphous alloy adopts technologies such as magnetic circuit symmetry, the loss performance is greatly improved, but it does not fundamentally change the material characteristics of the amorphous alloy. Short circuit performance. However, when the on-load voltage regulator distribution transformer superimposes high overload performance (the overload performance is mainly achieved by increasing the oil passage, increasing the diameter of the low-voltage wire, and improving the thickness and parameters of the insulating material), the internal space of the fuel tank is more crowded (the on-load voltage regulating switch itself). A part of the space has been squeezed, and the number of leads and gear taps has increased, which makes the internal layout design and manufacturing of the transformer more difficult), and it is more difficult to guarantee the short-circuit resistance. Therefore, it is recommended that the wide-width variable does not superimpose the high overload function, and at the same time increases the short-circuit resistance capability verification and random inspection after the tender to ensure that its short-circuit resistance performance meets the standard requirements. At the same time, the on-load voltage regulating switch preferably can realize modular disassembly and independent maintenance.

4.2 Transmission Mechanism Selection Suggestion

Considering that the vacuum permanent magnet on-load switch has many problems in the company's system, such as the capacity attenuation of the energy storage capacitor under harsh conditions, and the failure of the control system, the switch cannot operate. Therefore, it is recommended that the transmission mechanism adopts a mechanical voltage regulating switch, preferably a stepper motor, to achieve smooth gear shifting and reduce the failure rate of the tap changer. And the switching life is not less than 300,000 times, and provide a type test report.

4.3 Suggestion for Selection of Arc Extinguishing Medium

Referring to the electric power industry standard "DL/T 1853–2018 10kV On-load Capacity-regulating Transformer Technical Specification" and "T/CEC 163–2018 10 kV Low-Maintenance On-load Voltage-regulating Distribution Transformer", it is recommended that the on-load tap-changer should be selected. The vacuum arc extinguishing switch avoids the influence of the arc on the insulating oil and realizes maintenance-free.

4.4 Suggestion for the Selection of Voltage Regulation Range and Gear Range

Two factors are considered comprehensively: one is to avoid the unreliable factors caused by frequent gear shifting in the use of the wide-range variable; the other is to avoid the magnetic saturation problem when the wide-range variable is in low gear. It is recommended that the wide-amplitude variable voltage regulation range is +5% to −15%. Generally, a range of 5% is used, and 5 gears are used, and the distortion rate of the output voltage waveform at any gear should not be greater than 3% (standard required value).); for specific areas with high requirements on power quality and fine voltage regulation, you can choose 2.5% gear adjustment, 9 gears.

4.5 Controller Selection Recommendations

In order to avoid the abnormal voltage regulation caused by the problem of the controller, it is recommended that the controller should have the following functions when selecting the model: First, it has the function of self-starting in abnormal conditions. Second, the control strategy is adjustable. In principle, the completion time of a single command (including the delay) is not more than 1 min, and the blocking time between two shifts is 10 min. The third is that the controller has the function of hot swap, and the normal power supply of the transformer should not be affected during replacement.

4.6 Transformer Oil Quality Selection Recommendation

Considering the reliability of the pressure regulating process, it is suggested that the oil quality of the wide-amplitude pressure regulating transformer should strictly meet the requirements of DL/T 1094 in the technical specification, and the detection requirements for the gas in the oil should be added.

5 Conclusion

Wide-width distribution transformers are preferentially used to solve the problem of low voltage at scattered outlets at the end of the line. In the context of large-scale photovoltaics connected to the distribution network, areas with large load fluctuations and small hydropower grids that lead to drastic voltage changes can be considered for use. The annual low-voltage days at Taiwan's exports shall not be less than 5 days (excluding the influence of voltage imbalance), and the minimum value of the outlet voltage shall not be less than 160 V, which shall be preferentially applied to the range beyond the ordinary on-load voltage regulation and voltage regulation range (±5%, the minimum voltage value about 190 V). In this paper, the relevant test analysis is carried out on the wide-width on-load voltage regulating transformer, and a series of suggestions for the popularization and application of the wide-width on-load voltage regulating transformer are put forward.

Acknowledgment. This work was financially supported by the science and technology project of State Grid Hunan Electric Power Company Limited (5216A5210035).

References

1. Song, D.: The research on grid-connected control of photovoltaic power generation system and its transient process. Tianjin University of Technology, Tianjin (2010)
2. Yang, T.: Introduction to New Energy. Chemical Industry Press, Beijing (2013)
3. Xu, Z., Lang, Z., Su, H.: Impact and improvement of distributed photovoltaic on distribution network voltage. In: China University of Electric Power Systems and Automation Academic Annual Conference
4. Lu, B., Chen, X., Zhang, J., Wang, X., Ding, C.: Experiment and analysis of measurement error of a wide range current transformer. In: 2021 IEEE International Conference on Power Electronics, Computer Applications (ICPECA), pp. 161–164 (2021)
5. Li, X., Wang, W., Zhang, S.: An arcless OLTC model based on arm-bridge structure. Autom. Electr. Power Syst. **30**(7), 55–59 (2006)
6. Zhao, G., Shi, W.: Study on arcless on-load tap changer. High Voltage Eng. **30**(4), 49–51 (2004)