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Failure Analysis of OLTC during Transition Resistor Test

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Abstract

Emerging modern technologies and ever-changing demands compete with each other to bring new changes to the sociotechnical life of human beings. OLTC is one such equipment connected as an integral part of the transformer to change the turns ratio while the transformer is in energized condition, to adjust the output voltage. Changing times and technology brought many changes in the OLTC techniques, design and operation. Traditionally OLTC is a complex mechanical device, which has some deficiencies. OLTC design elements are checked during the transition resistor test. Thus, OLTC testing for transition resistors is a method to enhance the reliability of OLTC design. This paper discusses a typical failure case of OLTC during the transition resistor test conducted in CPRI.

Keywords: On Load Tap Changer (OLTC), Transition Resistor and Mechanical Device

1. Introduction

The Power Transformer is a vital component of the electric power transmission system. It serves as a link between power generation and power consumption centres, and it shares the task to balance the requirements of both parts. An electric power transmission system, working as designed, is the main demonstration of slow dynamics wherein long-standing trends may result in less-than-ideal system operation. Particularly, variations in the system voltage level may occur over durations of hours or minutes to a level where action is required to enhance those parameters.

The purpose of a tap changer is to regulate the output voltage of a transformer. It does this by altering the number of turns in one winding and thereby changing the turn ratio of the transformer by using an on-load tap changer. It is required that the transformer's secondary voltage is restricted to maintain a preset value within a certain tolerance. The tapping is provided at the HV winding of the transformer because the high-voltage winding is wound on the low-voltage winding. Also, the current in the HV winding of the transformer is smaller due to which small contacts and leads are required for tapping connections.

OLTC is the only moving component of a transformer except for oil, which plays the most vital role in power system stability as well as the quality of power delivered to the customer. An international survey by the CIGRE working group during the 80's reveals that 41% of power transformer failures are owing to OLTC. Further research on failure data reveals that the same trend continues till the end of the last decade. Voltage is an important element of a power system. The voltage supplied to consumers needs to be maintained within statutory limits[3].

Failure to maintain system voltage can result in the unsatisfactory performance of the consumer's equipment or even complete failure resulting in damage. Voltage fluctuations are normally the result of varying loads that are connected to the distribution system throughout the day. During heavy loads, the voltage will be pulled down, and at lighter usage periods the voltage will rise. Voltage control systems are used to reduce these variations and keep the voltage within predicted limits. The tap changer mechanism is driven by a small motor and mechanical

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linkage. It is a power-switching device and is immersed in insulating oil hence the possibility of fire is high.

The average number of tap changer operations that could occur over twelve months for an inner city unit with a daily load cycle of 25% to 75% was found to be in the order of 5000. The extreme cases in the sample monitored were 41000 tap changes. The tap changer is the active unit in the power supply system. The expected life of a modern tap changer can be as high as one million operations are considered to be the norm.

The transformer is the most essential and expensive equipment in the power system. The transformer is static equipment, tap changers have moving parts. Failure of a tap changer must be catastrophic. A failure will also have an instantaneous effect on the distribution system supply and power outage for consumers[2]. The tap changer moves from one tap to another, the diverter resistors provide the currents that the diverter contacts are required to break and make for the duration of a tap change. This short circuit current is also generally constant irrespective of whether the transformer is operating at full load or no load. Considering the responsibility of the tap changer and its importance to the operation of the distribution system, the concept of corrective maintenance and equipment replacement following failure is considered unacceptable

To achieve an uninterrupted power supply, it is essential to ensure the reliability of the operation of OLTC.

The defects in OLTC are of the following types:

- Burning of transition resistance.
- Burning and damage of rollers and fixed contacts.
- Misalignment of the tap changer assembly.
- Error in time sequence operation.
- Defects in tap changing driver gear.

The tap changer unit is immersed in insulating oil, which is used both to cool the unit and to assist in arc interruption hence the possibility of fire is high. This oil can depreciate due to the gathering of suspended particles, gathering of soaps and sludge. Production of gasses due to hot spots and arcing, water ingress, and gathering of minute fibres from failing insulation. The objectives for tap changer maintenance are to prevent either that plant from breaking down or to prevent any deterioration in its capability to meet a satisfactory performance requirement. It is reasonable to assume that a serious drop in its ability to perform or the probability of a probable failure is related to the wear of the unit.

Generally, tap changer maintenance is classified into three types:

- Corrective maintenance
- Condition-based preventive maintenance
- Period-based preventive maintenance

It is accepted that the present period-based maintenance schedules are invariably conventional and it is likely that a move to condition-based maintenance would therefore reduce the number of maintenance visits required. This in turn reduces probable interruptions to supply and reduces maintenance costs.

2. Basic Principle

OLTC is a device used for subtracting or adding several turns or reversing the polarity of a section or controlling the winding of a transformer to achieve desired voltage output while the transformer is energized and is on load. To maintain uninterrupted load current during tap changing, the “Make first- Break first” kind of switching sequence is generally adopted where a set of contacts choose the next required tap before the contacts connected to the present tap position are disconnected.

During this process, there is a brief period where both sets of contacts are in a closed condition causing a short circuit across the incoming section of tap winding. To limit the magnitude of circulating current due to this shorting, an impedance called transition impedance in the form of an inductor or resistor is arranged in series with the tapped winding[5].

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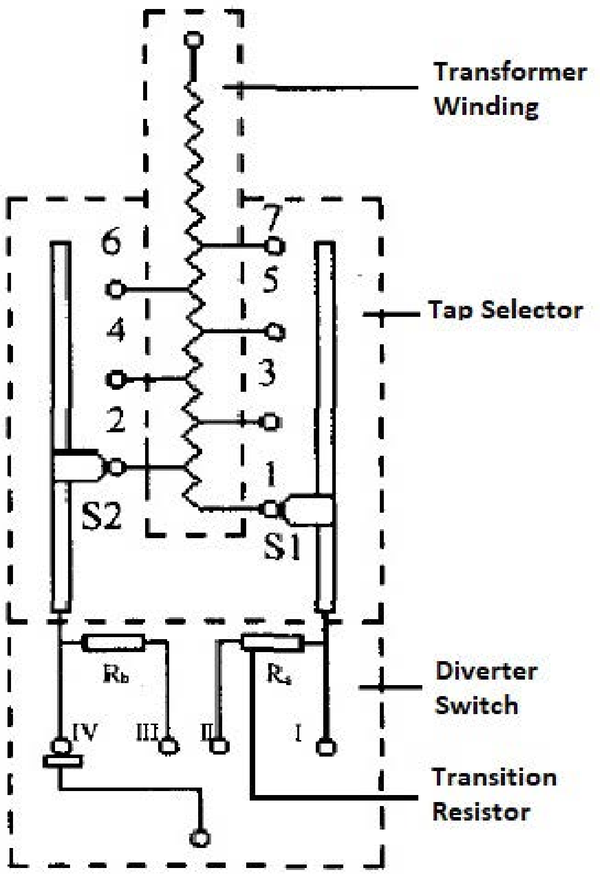

Figure 1. The configuration of a typical tap changer[7].

This tap changer operates remotely and also manually for safety purposes. There is a provision for a separate handle for manual control. The tap selector selects the tapping and its electrical contacts are used to carry the nominal current of the transformer. Arcing occurs at all the fixed contacts during the current breaking and making process, which causes oil contamination and contact erosion in the diverter unit. The transition resistors can cause excessive conduction losses. These, in a power system, are undesirable. With the developments of power electronics technologies, alternative tap-changer designs have been suggested which aspire to address some or all of these deficiencies in recent years.

3. Transition Resistor Test

The transition resistance test relates to the permitted temperature rise in the current limiting resistor in tap changers. The tap changer mechanism operates without interruption and at the usual speed for the complete range of operation at 1.5 periods the tap changer's maximum rated current, and the temperature rise of every component must not exceed 350^{0}C to the surrounding oil and should not harm any components. It is obvious that the tap changer should include some provision to limit that circulating current when in the "bridging" position and this is achieved by placing a resistance in the circulating current path[6]. Switching from one position to another position, performed through resistance between two steps of regulating winding is transition resistance. Method for establishing the equivalent temperature rise of the resistor using power pulse current. Measure and note the temperature of the resistance material and the cooling medium at the start of the test. Measure and note the temperature of the cooling medium at not less than 25mm below the lowest point of the resistance material.

Test current Ip to be calculated from the standard. Ii and Ti are to be considered for the service duty test. Heavy-duty current and light-duty switched current to be calculated from the standard. To meet the overload requirements, the test shall be done with 1.5 times the maximum rated current at the applicable rated step voltage. The resistor must be located in the OLTC as in service. The number of operations must correspond to one-half of a cycle of operation. The operations must be uninterrupted with the mechanism operating at its usual speed. The temperature of the resistor at the last operation must be recorded and determined. The temperature rises higher than the surrounding liquid at 1.5 periods maximum rated through current must not exceed 400K for externally mounted OLTC or 350K for internally mounted OLTC[1]. However, the temperature of resistors and the part adjacent to them must be limited to a value so that the uniqueness of the assembly is not affected. The transition resistors must be tested with a current during the breaking capacity at twice the maximum rated current and applied voltage. The above-calculated current and duration, are to be loaded to the resistor for one of the one cycles of operation with the uninterrupted operation of a driving mechanism at normal speed.

3.1 Criteria for Evaluation of Test

a. Contacts should not get welded together
b. Contacts should not show any abnormal signs to prevent the continuing correct operation at maximum rated through current.

c. No permanent mechanical distortion in other current-carrying parts.

d. The value of the resistors measured before and after the test should be within ±10 % and the overall condition of the resistors shall be such that continuous service is permissible.

4. Test Laboratory Features

Laboratories for the transition resistor test of OLTC draw their short-circuit power directly from the power grid. To interrupt huge currents, HV Circuit Breakers (CB) are designed. With this fast-acting CB and other special protecting equipment major damages to the OLTC under testing are prevented from initial failures such as arcing, fire due to oil spills etc.

Laboratories having their supply from the grid should have protecting equipment whose operating time is in the range of microseconds or as small as required. Breakers operating at high voltage, due to the nature of striking of voltages before closing make it difficult to close which results in a full asymmetrical current. At present, our laboratory uses a 100 MVA online short circuit lab. The 100 MVA, power is drawn from a dedicated line of 132kV from the Madhya Pradesh electricity board. 132 kV SF6 Circuit Breaker (CB) connects the grid supply and three single-phase transformers (T1) which isolate the test laboratory from the grid.

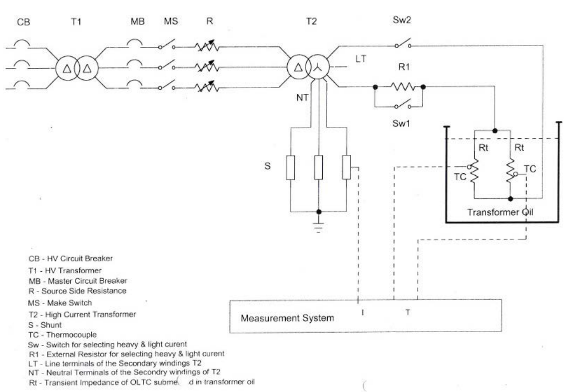

Figure 2. Test circuit diagram of transition resistor test.

Three single-phase transformers are used to convert the 132 kV line to 11 kV. 11 kV Vacuum circuit breaker (MB) connects three single-phase transformers, a High current transformer (T2) and a test object to isolate the test object from the transformer. 132 kV line voltage is converted to 726 V by three single-phase transformers and a high current transformer which provides a short circuit current to test the object (TO) using an 11 kV circuit breaker and a Make Switch (MS). Arrangement for the thermally equivalent situation, SW1 & SW2 for light duty and heavy duty switched current and TC is thermocouple for temperature measurement as shown in Figure 2. Make Switch (MS) which connects the test circuit to the test object, is more controllable at a medium voltage level.

5. Test Results

The impact of the thermal ability to withstand short circuit forces on the energetic part of the OLTC is discussed. When an OLTC was tested for transition resistor test.

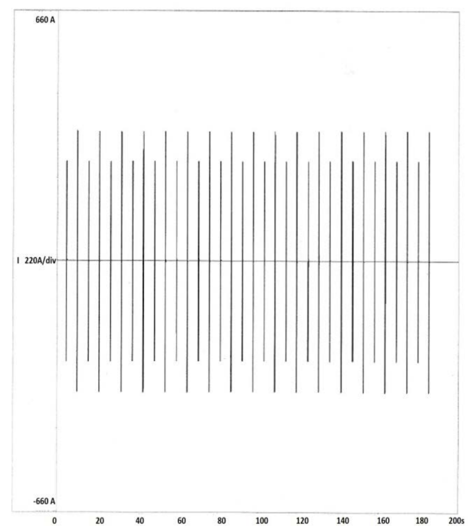

Figure 3. Waveform of OLTC during transition resistor test.

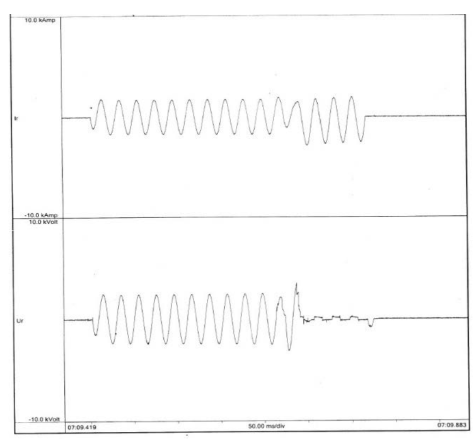

Figure 4. Waveform Of OLTC during transition resistor test

In-tank tap changer with diverter switch rated current 1800A, rated step voltage is 2500 V, the number of positions is 17, calculated on time is 306ms and off time is 5 sec. OLTC withstand the test for light duty and heavy duty current test of 34 pulses as shown in Figure 3. After this test transition resistor was subjected to one current pulse of twice the maximum through current. After 218ms current waveform was distorted, the voltage waveform collapsed as shown in Figure 4 and smoke came out from OLTC. High axial and radial forces were generated in OLTC due to the test current which led to transition resistor deformation as shown in Figure 5. OLTC failed due to high forces during the test which caused transition resistor damage.

Figure 5. Deformation of transition resistor.

6. Conclusions

The conclusion which is made here is that the transition resistor test is an important tool to enhance the reliability of OLTC. The failure in OLTC is a typical insulation collapse due to carbonization accumulation on the insulating surface with associated moisture in the insulating oil. Failures of OLTC in service are well known, but the reason is often not clear. The magnitude of the fault current should also be considered during the selection of the conductor.

7. Acknowledgement

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