Research on Transformer Fast OLTC System

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Abstract. On-Load Tap Changer (OLTC) transformer with adaptive voltage regulation is the common used method of voltage control in power grid. The study on the switching process of OLTC shows that the transition process is dependent on the structure of the load voltage regulating switch. In this paper, the related equivalent circuit and the calculation formula of the impact current are given. Aiming at the problem of transition state switching in OLTC, a tap-changer control method without transition state is proposed and simulated with inductive load. We have given the electrical main circuit and the measured wave forms of no transition state voltage regulation. We use MCT801D intelligent module to develop a non-contact voltage regulator power supply, which can switch taps rapidly under inductive load, and the output current is continuous without impact.

1. Introduction

In power system, in view of the characteristics of large voltage landing, high line loss and poor power quality in power supply and distribution networks, considering factors such as economy, stability and reliability, on the basis of traditional distribution transformer, On-Load Tap-Changer (OLTC) equipment is added to the optimal scheme of voltage regulation[1]. As an important transmission and transformation equipment, the power transformer is very important for the safe and stable operation. However, the current research shows that the static result of adjusting the OLTC variable is one of the main factors affecting the voltage stability[2]. In addition, because OLTC often needs to change tap, the failure rate is high, accounting for more than 27% of the total transformer fault[3], which affects the safe and stable operation of the power system.

Since people began to study the stability of the power system, the OLTC transformer has been paid special attention. With the further research, it is generally believed that OLTC plays an important role in the voltage stability problem and has published the related paper[4-7].

At present, the research on the influence of load voltage on the voltage stability of power system is mostly based on the traditional OLTC of mechanical switch taps. Due to the long transition time of the tap changer and the generation of the circular current, the OLTC has a great influence on the voltage stability of the power system. Some contactless OLTC that use additional resistors or reactors will also generate circular current, affecting voltage stability. The fast OLTC technology for non contactless switches without additional resistance or current limiting reactor has a fast transition from one stable state to another, and the shortest can be converted to a single tap at a time of a voltage circumferential wave, and this non transition fast OLTC technique can be used for different load properties. Implementation of different control strategies has positive significance for power system voltage stability.
2. Transformer on-load regulating principle

2.1. OLTC principle
The principle of transformer on-load voltage regulation is to draw several taps from the windings on one side of the transformer, and switch from one tap to another to change the number of effective turns of windings to adjust the output voltage.

2.2. OLTC switch
At present, most of the OLTC installed in the transformer are mechanical, and the switching unit, as shown in Figure 1, has the characteristics of large voltage regulating range and constant adjusting process. Because of the central task of the OLTC on-load current conversion, it is considered as the heart of the load regulating transformer.

![Figure 1. Split style and integrated style diverter switch.](image)

As the only regular component of transformer, the reliability of OLTC directly determines whether the transformer can operate safely and reliably. The OLTC transform must meet 2 basic conditions: during the process of changing the tap, it is necessary to ensure the continuity of the load current, that is, it is impossible to open; during the process of changing the tap, we must ensure that there is no short circuit between the branches. Therefore, in the process of changing taps, it is necessary to bridge two taps simultaneously at a certain instant to ensure the continuity of load current. In the 2 connection taps, the resistance must be inserted to limit the circulating current and ensure that there is no short circuit between the branches. This allows the transition from one tap to the next tap. Changing the test waveform of the tap switch can describe the transition process of the tap changer during the switching process. The DC test and AC test waveforms are shown in Figure 2[8], respectively. It can be seen that the output voltage of the tap-changer has an obvious transition process during the switching process.

![Figure 2. Test waveform of OLTC.](image)

Hybrid on-load tap-changer is composed of mechanical contact and thyristor[9], in which thyristor is used as an electronic switch to change the tap-changer transition. There is no arc in the switching process, and the current passing through the current switching process between the reverse shunt thyristor and the circuit breaker during the voltage regulation is shown in Figure 3. It can be seen that there is transient process in the process of tap changer.
The traditional transformer on load tap changer adopts mechanical on load tap changer to realize on load voltage regulation through a transition switch. In this way, although the on load voltage regulation can be realized, the instantaneous change of voltage and current will cause impact and transient process. The arc will erode the contact surface during the process of changing the tap, and affect the life of the contact and the existence of arc. The switching speed is slow, the response time is long, the failure rate is high, and the maintenance amount is large, so that the voltage regulation time can not be accurately controlled.

The existence of these problems also requires the development of a new OLTC to improve the safety and reliability of its use. The new type of on-load tap changer has mechanical improved type, auxiliary coil type and power electronic switch type. Although no arc is realized, the operation of voltage regulation mode is simple, but it will produce harmonic, so that the reliability is poor and the response speed of voltage regulation is not improved.

Since 1990s, people have studied the use of power electronic technology and MCU control technology to control the power electronic devices to switch off and change the number of transformer turns, to realize load voltage regulation. The triac is a semi controlled power electronic device, which triggers the conduction and turns off at the zero current of AC current. It can be used as an actuator of an on load tap changer to solve the problems existing in mechanical tap changers. Some of the main components of SSR are triacs. However, an automatic on load tap changer with solid state relay as a contactless tap changer is used. During the process of changing the tap, the regulating winding and the solid state relay will form a closed loop, which will lead to a circulating current in this loop. If the circulating current exceeds the allowable value, the solid state relay will be damaged.

3. OLTC control strategy and equivalent circuit analysis

3.1. OLTC control strategy
At present, most of the OLTC installed in the transformer are mechanical, and the failure rate accounts for more than 27% of the total transformer fault, mainly because OLTC often needs to change tap, so the failure rate is high. In order to reduce the number of actions of on-load tap changer, the document proposed the OLTC control strategy[10], its control model, as shown in Figure 4.
3.2. OLTC equivalent circuit

In order to realize the transformer fast on-load voltage regulation, it is necessary to use non-contact switch devices (such as thyristor) to switch the taps, and the transition resistance or transition reactor can not be used. The equivalent circuit of the transformer is as shown in Figure 5 when the load voltage is regulated[11]. The equivalent resistance and equivalent inductance of the load are $R'_L$ and $L'_L$ in the diagram.

![Figure 5. OLTC transformer equivalent circuit schematic.](image)

3.3. The formation of the impact current of OLTC

Because transformer usually works in the near saturation section of magnetization curve, its voltage regulation dynamic characteristic is nonlinear, so it is difficult to quantitatively analyze the actual working process. In the ideal state of neglecting the exciting current, according to figure 5, the expression of the impact current can be obtained.

$$I_i = I_u \sin(\alpha \theta - \alpha) + A e^{\pm j}$$

(1)

Where:

$$R = R_i + R_t + R_c$$

$$L = L_i + L_t + L_c$$

$$\alpha = \arctan(\omega L / R)$$

$$I_u = \frac{U}{\sqrt{(\omega L)^2 + R^2}}$$

(2)

When changing the tap of the transformer, the steady state impulse current value is normal when switching accurately. The impact current is very easy to damage the thyristor switch device.

4. Transformer Fast OLTC System

4.1. Characteristics of fast OLTC System

The main characteristic of high performance fast on load tap changer is that there is no transition process when switching tap changer. The load regulating device of a transformer containing a mechanical load tap switch has a certain time transition process, because the inertia of the mechanical parts is larger and the speed is slower. Some contactless load tap changers have load voltage regulator. Although researchers have done a lot of research without impact and transition state, the reliability of the transformer is low in practical application, and a group of transition devices have to be added. In a word, in the existing load regulating technology, the loop short circuit current between the two ends of the winding in the shift voltage regulation process is an unavoidable problem. It not only brings the impact and running loss to the transformer itself, but also affects the stable running state of the power load[12]. Especially under inductive load, thyristor components are prone to malfunction and lead to voltage regulation failure, which seriously affects the reliability of transformer on-load voltage regulation[13].

For a transformer with a thyristor as a contactless switch, a voltage regulation product is used as a contactless switch. When the voltage zero point is used to switch the control method of the tap, the infinite current element in the main circuit can only be applied to the pure resistance load or the rectifier load. In this kind of load, the current is zero when the voltage is zero, and the thyristor devices
turn off naturally at the zero point of the current, so it is convenient to switch the taps at the zero point of the voltage to realize the voltage shift switching without the transition process.

However, the power system is complex and changeable, and it will be subject to various kinds of interference at any moment, which will affect the accuracy of detection. For the inductive or capacitive load, the current is not zero when the voltage is zero. If the zero point switching method without transition state is used to control the current, the impact circulating current will inevitably be produced. When the circulating current is too large, the equipment will be damaged and the system can not achieve high performance and high reliability. At this time, not only the anti-interference measures are taken on the circuit and software, but also the integrated voltage and current zero point detection and analysis technology is needed to achieve high performance and high reliability switching without transition process.

4.2. High performance OLTC simulation of change tap at inductive load
Under the R-L load, the switch is switched between the two taps of the transformer with a contactless switch, and the switching time is at the zero point of the current. At this time, the voltage and current waveform produced by the computer simulation is shown in Figure 6. The simulation waveform is shown in the figure, which changes the tap every 40 ms. The red curve 1 is the voltage waveform and the black curve 2 is the current waveform.

4.3. OLTC main circuit and control method without transition state
A main circuit and control diagram of a transformer on load tap changing power supply without transient process are shown in Figure 7. The core control unit uses the MCT801D module with voltage and current zero point accurate detection and analysis technology. The output signal is isolated and amplified to drive the S1 to S4 triac, control the switching of transformer taps, and complete the load voltage regulation.
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The switching control method of transformer tap changer without transition state is to detect the zero point of voltage and current accurately according to the measured load property and load voltage value. Then, interference filtering algorithm is adopted to avoid interference signals, and voltage switching points and handover timing are calculated. In order to switch the taps, the software automatically selects the switching of the zero point or zero point of the current according to the control algorithm, first closes the current thyristor, then opens the prepared thyristor, switches to the required taps, and completes the load voltage regulation.

This kind of transformer without transition state can automatically adapt to the load of capacitance, inductance and HID lamp. It can keep the current continuously and no impact current. It will not cause the HID lamp to be extinguished or re-light, effectively prolonging the service life of the lamps.

In order to ensure the reliable switching of thyristor and the safe operation of the thyristor, the rising rate of voltage at both ends of the thyristor must be reduced by $du/dt$ and the current rising rate of $di/dt$ of the thyristor passing through the thyristor at the moment of opening. The purpose of limiting $du/dt$ and $di/dt$ is to use parallel resistance capacitance circuit at both ends of thyristor.

4.4. Voltage and current waveform under inductive load

Products made according to the principle of circuit 7, the waveform of the actual output voltage current taken by the Tektronix TDS2002 digital oscilloscope at the 10ms/Div scanning rate under the inductance load is changed at each 40ms, and the Yellow curve 1 is the voltage wave and the blue curve 2 is the current wave form.
From figure 8, it can be seen that under the inductance load, there is no transition process when the tap is changed, the output current is continuous and no impact, and the output has no overvoltage or voltage drop.

4.5. Test and Application
According to figure 7, the MJN3 type lighting energy saving power source produced by the circuit is designed, and a set of intelligent monitoring software is designed. In order to verify the correctness of switching control method for transformer taps without transition state, a fast automatic test program is embedded in the software. When the normal inspection test is done before the product is released, the test will be carried out automatically at the speed of 10 thousand times per hour. In laboratory tests, a rapid change of tap test was performed 60 thousand times, 90 thousand times, and 180 thousand times per hour. In a long period of time in a variety of loads (no load, high pressure sodium lamp load, high pressure mercury lamp load, hybrid lamp load, resistance load, inductance load, capacitance load) and the actual use of mass products on the road lighting site, the cumulative shift times more than 300 million times. It is proved that the product can work reliably under various conditions and has stable performance.

5. Conclusion
In view of the current problem of transition state switching in OLTC, a high performance non transition OLTC switch control method is proposed, which is simulated as the most severe inductive load of taps. In the MJN3 contactless tap-changer power supply developed by using MCT801D intelligent module, the correctness of high-performance transition-free OLTC tap-changer control method is verified.

The high performance non transition OLTC switch control method is to detect the voltage and current zero accurately according to the measured load property and the load voltage value. Interference filtering algorithm is adopted to avoid interference signals, and voltage switching points and handover timing are calculated. In order to switch the taps, the software automatically selects the switching of the zero point or zero point of the current according to the control algorithm, first closes the current thyristor, then opens the prepared thyristor, switches to the required taps, and completes the load voltage regulation.

Acknowledgments
This article has been funded by the high level talent research fund project of Nanjing Vocational Institute of Transport Technology (440105001), and the author is here to express his sincere thanks.

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