TRANSFORMER LOAD-TAP CHANGERS: STATE-OF-ART AND TRENDS

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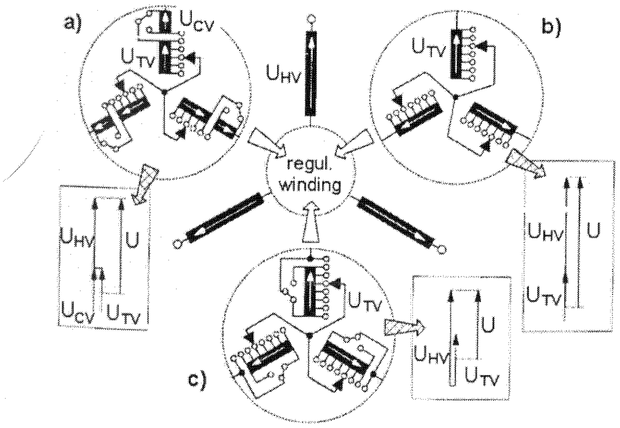
Summary Load tap changers (LTC) are a major component of many transformers. They are used to change the voltage of secondary/primary side of a transformer to compensate for voltage variations in the power system mainly caused by variable loading. The paper describes the various types of load tap changers, especially on-load ones, and various tapping winding configurations. Besides the conventional (electro-mechanical) tap changers, the using of the power-electronic tap changers for mitigation of short term voltage problems, lasting for several cycles, are discussed too.

Abstrakt Přepínače odboček jsou hlavní součástí většiny transformátorů, pomocí nichž je možné měnit napětí na sekundární/primární straně transformátoru, čímž je možné kompenzovat změny napětí v soustavě způsobené zejména změnami zatížení. Článek popisuje různé druhy přepínačů odboček, zejména přepínačů pod zatížením, různé způsoby zapojení přepínacích vinutí. Kromě konvenčních, elektro-mechanických, přepínačů jsou zmíněny i elektronické přepínače odboček a jejich využití pro zmírnění rychlých změn napětí trvajících několik cyklů.

1. INTRODUCTION

Most distribution transformers are equipped with a tap changer for regulation of the secondary side voltage. The purpose of voltage regulation is to compensate for load variations, such that all customer supply voltages are kept within certain bounds. A tap changer is capable of changing the number of active turns on one winding of each phase, and thereby adjusts the transformer ratio. The control is discrete-valued, typically with steps of 1-3 %. The tap changer is normally present on the high voltage side since it carries the lower current. The on-load tap changers (OLTCs) are used for reconnecting the tapping under load. On-load tap changer can be controlled locally or remotely, on basis of local voltage measurement in sub-station, with no coordination of OLTCs on different voltage levels or in different branches of the network.



U_{HV} - voltage at the main winding,
U_{TV} – voltage at the tap winding,
U_{CV} – voltage at the coarse winding,
U – voltage at the transformer terminal

Fig.1. Basic arrangements of tapped windings.

The tap changer provides two basic functions. The fist is to select a tapping connection in an open-circuit condition, the second is to divert or transfer power to that selected tapping without interrupting the through-current. The simplest type OLTC, the selector switch, combines these two functions into one device, whereas separate selectors and diverter or transfer switches are used for higher power requirements.

During the load transfer operation between two adjacent taps, both taps must be temporarily connected to the output terminals. To avoid a short circuit of the winding transition impedances, which can be resistors or reactors, are inserted. Two basis principles have been invented and are still used – the high resistor switching principle and the slow motion reactor switching principle. Today both principles have been developed into reliable OLTCs.

2. ARRANGEMENTS OF TAPPING WINDING

Various tapping winding configurations are possible. The selection function can be without change-over selector (linear), or with change-over selector (reversing or coarse/fine) [1].

In linear switching, tapped turns are added in series with the main winding and their voltage adds to the voltage of the main winding (Fig.1a). No change-over switch is needed for this type. The tapped winding is totally by-passed in the minimum voltage position. The rated position can be any one of the tap positions.

In a reversing type of regulation, the whole tapped winding can be connected in additive or reversed polarity with respect to the main winding. The tapped turns can add or subtract their voltage with respect to the main winding (Fig.1b). The tapped winding is totally by-passed in the neutral (mid-range) voltage position. The rated position is normally the mid one. The total number of positions available is twice the number of sections in the tapped winding plus one.

The coarse-fine regulation can be defined as a two-stage linear regulation where the first or coarse stage contains a large number of turns which can be totally by-passed by the change-over selector (Fig.1c). Fine regulation is achieved with the selector switch. Depending on the number of steps of the fine winding and the number of the coarse tap windings, great number of regulation steps can be achieved.

3. HIGH-SPEED RESISTOR TYPE

The high-speed resistor type OLTC is designed either as a tap selector and a diverter switch, or as a selector switch (Fig.2a). The latter is economical to manufacture, but certain inherent limitations reduce the possible applications to small or medium size transformers.

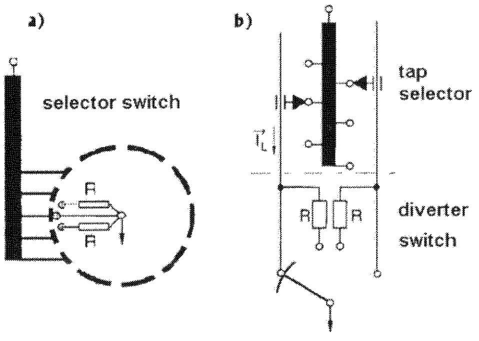


Fig. 2. High-speed resistor type OLTCs.

OLTC comprising a tap selector and diverter switch (Fig.2b) is used for any application up to the highest transformer ratings [3]. The tap changer is effected in two steps. The tap adjacent to the one in service is pre-selected load-free by the tap selector. Thereafter the diverter switch transfers the current from the tap in service to the pre-selected one. The movement of tap selector is slow, but transfer time of diverter switch is approximately 40 to 60 ms. The transition resistors are inserted into circuit for time of approx. 20 to 30 ms. The total time of one tap change operation lies in the range of 3 to 10 seconds. The transition resistors have to be dimensioned only for a short-time load which enables an economic use of OLTCs in case of higher step voltages and power.

The main switching contacts carry the through-current I_L and during tap changing operation have to break it. The recovery voltage at opening switching contact becomes:

$$\bar{U}_{rMS} = R\bar{I}_L \qquad (1)$$

When both transition contacts are connected, the current I_L is shared between the parallel connected resistors R and the circulating current I_C starts flowing due to the step voltage U_S (voltage between adjacent taps). Depending on switching direction the transition contacts have to break current:

$$\bar{I}_T = \bar{I}_C \pm \frac{\bar{I}_L}{2} = \frac{\bar{U}_S}{2R} \pm \frac{\bar{I}_L}{2} \qquad (2)$$

The recovering voltage at the opening transition contact depending on switching direction becomes:

$$\bar{U}_{rT} = \bar{U}_S \pm R\bar{I}_L \qquad (3)$$

The contacts have to be dimensioned on the maximum value of the switched current and the recovery voltage.

4. REACTOR TYPE OLTC

The reactor type OLTC is manufactured mainly according to two principles with respect to the arcing switch. One concept uses two arcing switches with a centre-tapped reactor acted as transition impedance (Fig.3a). Such an OLTC can be designed as a selector switch or as an arcing switch (transfer switch) plus a tap selector. The transfer switch can be constructed as a usual set of contacts or as vacuum interrupters. Speed of the breaking contacts of the modern reactor type OLTCs with vacuum interrupters is comparable to the resistor type OLTCs. A tap changing operation is performed in three steps. Firstly the transfer switch opens and breaks the current. Then the proper tap selector selects the next position. The transfer switch is then reclosed.

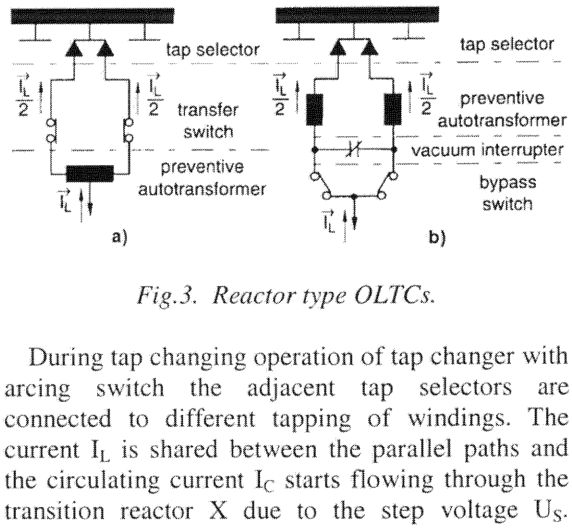


Fig.3. Reactor type OLTCs.

During tap changing operation of tap changer with arcing switch the adjacent tap selectors are connected to different tapping of windings. The current I_L is shared between the parallel paths and the circulating current I_C starts flowing through the transition reactor X due to the step voltage U_S. Depending on switching direction the transition contacts have to break current:

$$\bar{I}_T = \bar{I}_C \pm \frac{\bar{I}_L}{2} = \frac{\bar{U}_S}{jX} \pm \frac{\bar{I}_L}{2} \qquad (4)$$

The recovering voltage at the opening transition contact depending on switching direction becomes:

$$\bar{U}_{rT} = \bar{U}_S \pm jX\frac{\bar{I}_L}{2} \qquad (5)$$

The second principle uses the vacuum interrupter (VI) acting as arcing switch, and two bypass switches (Fig.3b). The transition impedances are located between the tap selector and the vacuum interrupter. Moving from one tap position to the next, one bypass switch opens and commutates the current to the vacuum interrupter path. The second one stays closed. The VI is open before the proper tap selector selects the next tap. After reclosing of VI the bypass switch closes and shunts the VI.

During tap changing operation of tap changer with VI the adjacent tap selectors are connected to different tapping of windings, and bypass contact is open. The current I_L is shared between the parallel paths and the circulating current I_C starts flowing through VI. Depending on switching direction vacuum interrupter has to break current:

$$\bar{I}_{VI} = \frac{\bar{I}_L}{2} \pm \bar{I}_C = \frac{\bar{I}_L}{2} \pm \frac{\bar{U}_S}{jX} \qquad (6)$$

The recovering voltage at the opening vacuum interrupter depends also on switching direction:

$$\bar{U}_{rVI} = \bar{U}_S \pm 2\left(\bar{I}_L \frac{jX}{4}\right) \qquad (7)$$

Note that the values are identical with the tap changer with arcing switches.

The requirements on switching contacts of both reactor and resistor tap changers depend on the methods use to perform the tap-change operation. For more details see [2].

5. CONSTRUCTION AND GENERAL MAINTENANCE OF OLTC

Voltage regulators are relatively simple devices, but they may reduce the reliability of the power system. Electro-mechanical tap changers require regular maintenance [1]. The main areas of concern are the switches and the connecting board if present. The contacts of tap selectors (Fig.4) have to be inspected and verified periodically. The frequency of these inspections depends mainly on the number of operations, the current flowing through the contacts and the cleanliness of the oil.

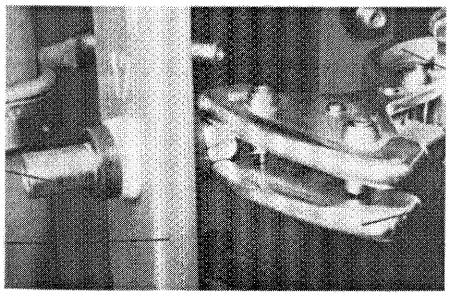


Fig. 4. Contacts of tap selector.

The process of changing tap position includes arcing (except OLTCs with vacuum interrupters as switching devices), which generates gases and carbon particles. The movement of contacts also promotes erosion of the metal and generates small metal particles. In the long run, these particles can affect the dielectric properties of the oil. Moreover, the carbon particles tend to aggregate on contact and increase the contact resistance. For these reasons, the switching devices are located in their own switching compartment with oil filtering device to separate the contaminated oil from the oil in the transformer tank. Selector switches are located within an enclosure inside the transformer tank (in-tank type) or in separate oil-filled housing outside of the transformer tank (compartment type).

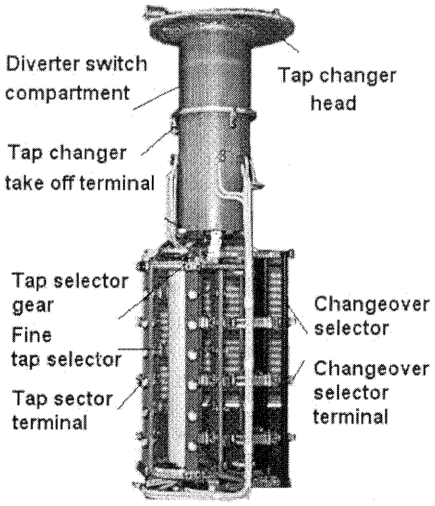


Fig. 5. Tap selector and diverter switch type OLTC.

The OLTCs comprising of the diverter switch and the tap selector are designed in the same way. In case of the in-tank resistor type OLTC only the diverter switch is located in a oil tight compartment, the tap selector is an the transformer tank without compartment (Fig.5). In case of the compartment type OLTCs the diverter switch and the tap selector are located in the same oil compartment, or are located in the separate compartments (the tap selector compartment is filled by same oil as the transformer tank). Reactor OLTCs are always designed as the compartment type.

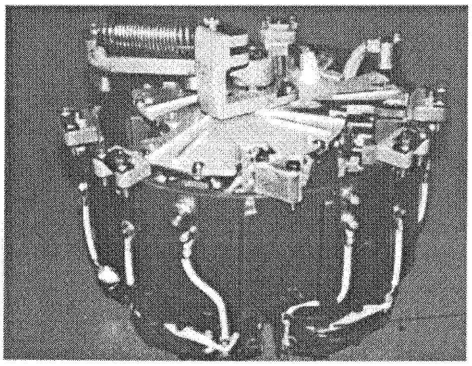


Fig. 6. High-speed resistor OLTC.

Common construction of the switch of the high-speed resistor OLTC with three-phase spring mechanism is on Fig.6. The transition switch resistors are mounted at the bottom part of OLTC and from the reason of cooling conditions they are made as a resistance tapes (Fig.7). Tap selector (Fig.4) is placed below the switch compartment.

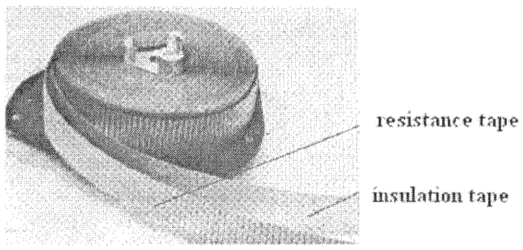


Fig. 6. Arrangement of transition switch resistor.

Instead of taking all transformers out of service for regular and frequent inspections of tap changers, some utilities have introduced monitoring procedures for tap changers without de-energizing their transformers. One of those procedures is dissolved gas analysis (DAS), they regularly take oil samples from tap changer compartments and monitor the gasses. Another possible procedure is to monitor the temperature on the tap changer compartment (indirectly the temperature of contacts) regularly with infrared measuring devices. It is very inexpensive and easy to do. Quite a few problems have been detected this way.

6. NEW TYPES OF TAP CHANGERS

To eliminate the arcing during the switching operations the new concept of OLTCs was developed. The diverter switch of the hybrid OLTCs, so called TADS (Thyristor Aided Diverter Switch), contains both mechanical and thyristor-based switches. The mechanical switches are shunt by one thyristor-based switch. Before opening the mechanical switch the trough-current commutates to thyristor-based switch, so that the mechanical switch will open without arcing. The operation of the hybrid OLTCs is more reliable in comparison with the mechanical OLTCs.

Voltage regulation problems can come in two forms: short term problems (dips, swells), lasting for several cycles, and longer problems, lasting for several seconds to many hours. Some voltage regulators with slow response times are only effective when dealing with longer fluctuations - the short variations are over before the regulator can respond. Besides the conventional (mechanical) tap changers described here, power-electronic tap changers have been considered.

Electronic tap changers (also called Static Voltage Regulators - SVR) use fast static switches to change transformation ratio of a transformer. The secondary winding is divided into several parts interconnected by static switches (Fig.8). Total turns ratio (included all parts of secondary winding) is much higher than nominal turns ratio. For example, if turns ratio can achieve 170%, the output voltage can be between 95% and 105% of nominal voltage for input voltage down to 56% of nominal ones. Electronic tap changers would be capable of high-speed continuous voltage control, without internal arcing. However, the cost of these is presently prohibitively high and they cause substantially larger losses than equivalent mechanical tap changers.

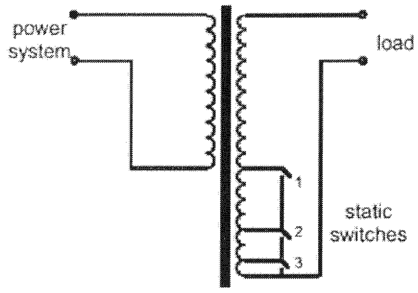


Fig. 8. Electronic tap changer.

Thyristor-based switches, which can only be turned on once per cycle, are used; therefore, the compensation is accomplished with a time delay of at least one half-cycle. Some regulators that contain electronic switching components will shut down or restart when they experience a severe voltage sag or outage. As a result, these devices could convert a short (1 cycle) disturbance into a several cycle outage. The sensitive load, which might ride-through a 1 cycle outage, will see the longer outage and shut down. Thyristor based OLTCs also introduces a harmonic problem.

Transformers with electronic tap changers are currently available as an additional series component between the source and the sensitive load.

7. CONCLUSIONS

In future it may be feasible to install electronic tap changers on distribution transformers and save the additional component. Until significant progress is made in high voltage power-electronics technology, power-electronic tap changers are not likely to be widely used in distribution networks in the near future.

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