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A Novel Model of Arcless On-Load Tap-Changing Transformer and Its Simulation

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Abstract: In this study, a novel arcless on-load tap-changing model is proposed, it adopts inverse paralleled high-power thyristor pair to be control switch and regulate the output voltage by switching in corresponding tap-changing windings and also use thyristor's zero-current cut-off character to cancel transition resistance inserting process to simplify the regulation steps effectively. A 35kV/10.5kV£¬5000kVA two–winding transformer model is built by MATLAB and the simulation wave form of tap-changing process has proved that this model is correct.

Key words: On-Load Tap-Changing, thyristor switch, transition resistor, simulation

INTRODUCTION

In power system, voltage control is a significant measure to the system security and power quality, one of the simplest and commonly used methods of controlling supply voltage is to employ On-Load Tap-Changing Transformer (OLTCT) with tap-changing switches to select appropriate tap point and regulate the transformer's output voltage. Conventional mechanical tap-changing device have complicate structure, respond slowly and even produce electrical arc during switching process, which would disserve the transformer's insulation property and lead transformer accidence. These defects limit the application of on-load tap-changing transformer enormously, therefore, a fastresponse, arcless voltage regulation method is necessary not only for the requirement to keep OLTCT running safely but also for the needs of system steady and voltage stabilization.

From 1970s, as electronic elements' abroad application in power system, the thyristor based, arcless OLTC technology has been researched extensively by domestic and abroad experts, there are two research directions:

- Thyristor assisted mechanical switch for OLTC;
- Power electronic switch for OLTC.

In the first method, the thyristor is inserted across the arcing contacts for only short period during which acing normally occurs. The response speed of this voltage device is still low because the mechanical structure is not simplified and both laboratory experiments and practical running indicated that the arc can not be eradicated in switching process. In power electronic switch method, the mechanical tap-changing switches are replaced by inverse paralleled thyristor pairs. Without mechanical contacts, the electrical arc is eliminated basically in tap-changing process and because of the improvement of electronic elements capability, the thyristor with 4000A /6500V capacity, 400μs switching time is easy to get at present, consequently, compared to the thyristor assisted system, the power electronic unit is much more superior in response speed, controllability and arcless aspect. The regulation process commonly needs 2 to 4 current cycles and a transition resistance is inserted in this period to avoid direct short circuit of tap-changing windings. This study proposes a novel fastresponse OLTC scheme in which the transition resistance is cancelled in main circuit basing on thyristor's character that it turns off automatically at zero crossings of its current. This scheme provides simplified voltage regulating steps and least regulation time, the operation of voltage regulating device was briefly explained and verified through the computer simulation by using MATLAB. Finally,conclusions are given.

OLTC Device

Main circuit: In this study, a 35kV/10.5kV, 5000kVA two-winding OLTCT model is used as an example to illustrate the voltage regulation principle. The tap-changing windings and electronic switches are installed at the high voltage side, and the range of regulation is $\pm 3 \times 2.5\%$ according to power system voltage and reactive power technique guidance (Probationary). Fig. 1 is the transformer's main circuit of phase A, phase B and phase C are the same as it.

In the main circuit, L_0 is the main winding of phase A, L_1□$_6$ are Tap–hanging windings; K_{i1} and

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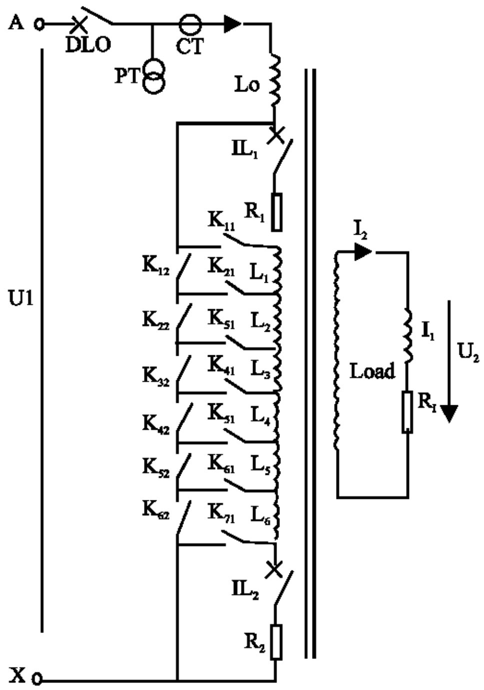


Fig. 1: The main circuit of phase A

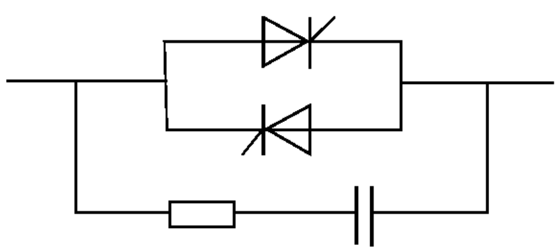


Fig. 2: The structure of thyristor switch

K_{j2}(1=i=7,1=j=6) are two groups of power electronic switch, the switch structure is illustrated in Fig. 2 and group K_{i1} are connected to the taps of regulating windings; resistance R_1 and R_2 are used to limit switchingin flows, they also provide equal voltage condition to electronic switches and protect them from breakdown by overvoltage producing in switching process of the main breaker DL_0; PT and CT collect real time signals of phase current and voltage in regulation side and send these signals to control system; the transformer load Z_L is connected in the secondary side.

Triggering pulse and control system: Thyristor is a half–controlled electronic element, it turns off automatically at zero crossings of its current. Therefore, to keep a thyristor switch closing, we have to trigger it at each zero crossings of transformer's phase current, each thyristor of the pair works half a cycle. In the same way, we can easily turn off a thyristor switch by stopping its triggering pulse. All the triggering pulses are sent out by control system concertedly to guarantee their synchronism.

The control system adopts microcomputer as central control unit, system structure is illustrated in Fig. 3. The phase voltage and current signals from PT and CT is compared with the standard values set in control unit, when the measured voltage value exceeds the principle voltage interval, controller sends out voltage regulating command, then the zero-crossing current detective circuit and the triggering circuit work together to provide continuing initiating-pulses to some thyristor switches to activate and maintain corresponding taps on and stop triggering another switches to turn off corresponding taps.

OLTC Theory

Transformer initial switch on and no-load switch out proces: Before transformer switching on, breakers DL_0, DL_1 and DL_2 are open, all the electronic switches are holdoff. In the switch on process, we close DL_1 and DL_2 at first to insert current limiting resistances R_1 and R_2, which suppress the switchingin flows and provide equal voltage condition to thyrostor switches and then switch on the main breaker DL_0 to energize the no-load transformer. After that, DL_1 and DL_2 are closed, all the switches are open, as is show in Fig.1, regulating winding from L_1 to L_6 are all put into operation and thus the output voltage of transformer secondary side is at minimum, therefore the regulating taps should be adjusted to actual voltage level after switch-on process and breaker DL_1 and DL_2 will switch off when the transformer comes into stable state.

In switch out process, firstly we stop the triggering pulses of all the electronic switches to turn off them at next current zero-crossing, the high voltage side has actually departed from power supply terminal by this operation and then we can turn off the main breaker DL_0 without producing any overvoltage.

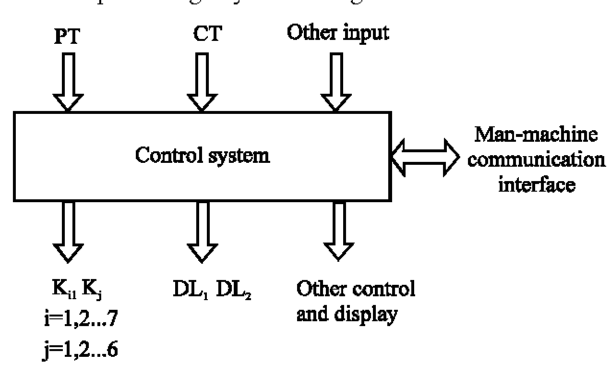


Fig. 3: The control system

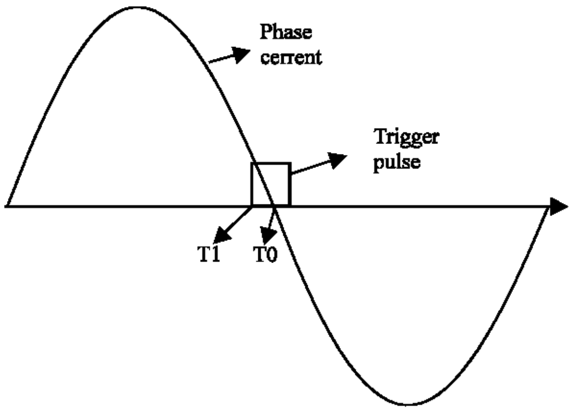


Fig. 4: The zero-current trigger pulse

Transformer on-load tap-changing process: We use a voltage increasing process as an example to illustrate the tap-changing process. The steps that output voltage increase by 2.5% from rated value is as following:

- Before regulation, thyristor switches K_{11}, K_{41}, K_{42}, K_{52}, K_{62} are closed, tap-changing windings L_1, L_2 and L_3 are connected into main circuit and transformer are running steadily in rated condition;
- Triggering thyristor switches K_{31} and K_{32} and stopping triggering K_{41} at the same time. Since the detection circuit can not detect zero-crossings of current precisely that phase current is considered as zero when it less than a special value the circuit can not inspect, in addition the triggering circuit start to send out pulse at that point, the triggering pulse front edge is a little ahead of precise zero-crossing as shown in Fig.4. Therefore, before K_{11} turning off automatically at T_0 point, K_{31} and K_{32} have already turned on at T_1 point, winding current can not be cut off in regulating period;
- Tap changing L_3 is isolated with main circuit and transformer running in the new steady state. Regulation process is over.

We can see that, with the novel regulation process, transformer achieves tap changing aim by only once effective triggering, the full operation steps need less than half a cycle of current, the responding speed has been improved greatly and besides, the winding current is constant in regulation process.

There is a matter have to take attention to. As shown in Figure.4, because of the thyristor's zero-current cut-off character, in the period between T_0 and T_1, thyristor switches K_{31}, K_{32} and K_{41} are all closed and tap changing winding L_3 is short circuited. Without transition resistance, the influence of cycle current can only be limited by pulse width control. Tests were undertaken on this condition and the results indicate that, the short circuit current is not appreciable if the duration of short circuit is less than 1ms. So we adopt 2ms as pulse width in simulation.

RESULT AND DISCUSSION

In this study, a single phase OLTCT model is built by using SimPowerSystem and Simulink in MATLAB, parameters are set as following: peak amplitude of AC voltage source is, $35\sqrt{2} \times 10^3$ V frequency is 50Hz, transformer load is $Z_L = 50 + j15.7\Omega$. Since it has been proved that there will be no transience process after transformer switching on operation if the source phase is equal to transformer impedance angle and transformer switching on at zero crossings of winding current, we set the initial phase angle of voltage source as 30°C and turn on thyristor switches at zero crossings of phase current.

The voltage increasing process that the output voltage varied from standard to the max was simulated in MATLAB. Since the triggering pulse is zero-crossing symmetrical and pulse width is chose as 2ms, before K_{11} and K_{41} turning off automatically at a current zero crossing t=1.0s, K_{12}, K_{22} and K_{32} had been triggered on at 0.999s point, this meant tap changing windings $L_1L_2L_3$ were in short circuit between 0.999s point and 1.0s point. We chose 8 cycles waveform to observe the influence bringing by the shottime short circuit.

The thyristor control pulses is shown in Fig.5. Before tap changing operation, transform was running steadily in rated state, control system sent out continuous triggering pulses to K_{11}, K_{41}, K_{42}, K_{52}, K_{62} to maintain them on, other thyristor switches were open without any triggering pulses and K_{12}, K_{22}, K_{32} were carrying full voltage of corresponding tap-changing winding. By turning on switches K_{12}, K_{22} and K_{32} at 0.999s point, the voltage they withstanding decreased to zero, then after the short circuit period, K_{11} and K_{41} turned off automatically at 1.0s and cut off the cycle current across them. Through these steps, tap changing windings $L_1L_2L_3$ were disconnected with voltage source and supply voltage accordingly increased to the max. The simulation results are shown in Fig.6.

Simulation results establish the availability of this proposed novel OLTC scheme in three aspects: (1) transient short circuit will not bring obvious impact to regulation process, voltage and phase current of both first side and secondary side all vary constantly and come into steady situation quickly after adjusting operation; (2) thyristor switches can act responsibly according to the orders of control system to cut off or insert tap changing windings to meet the requirement of voltage supply; (3)

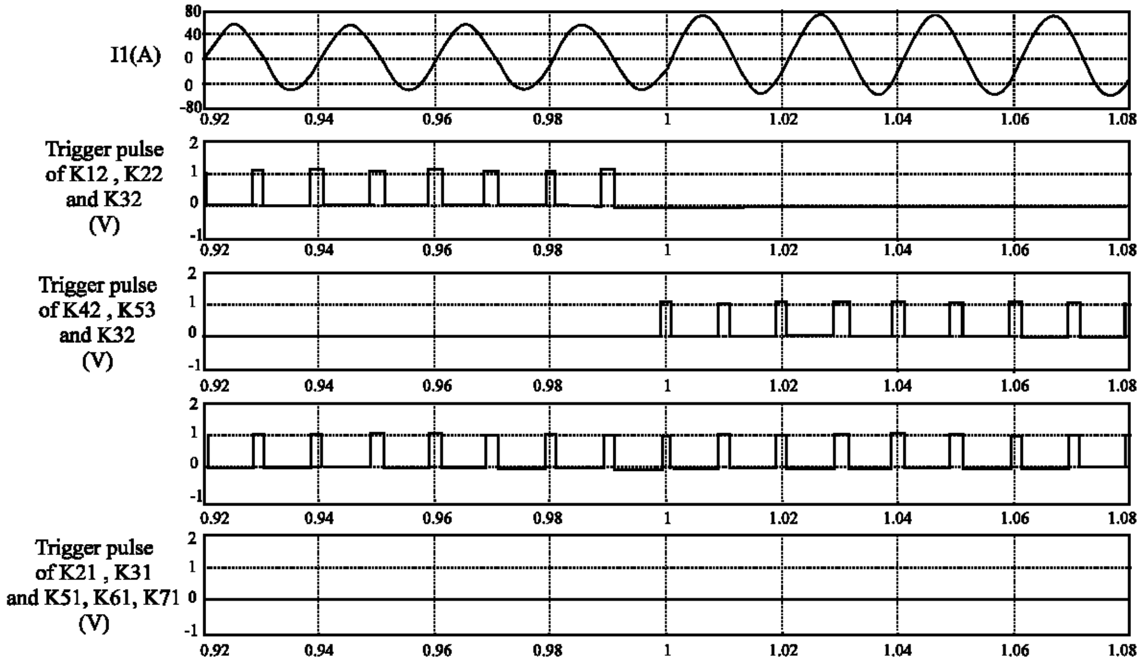
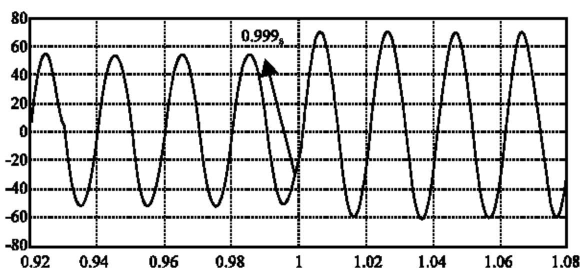
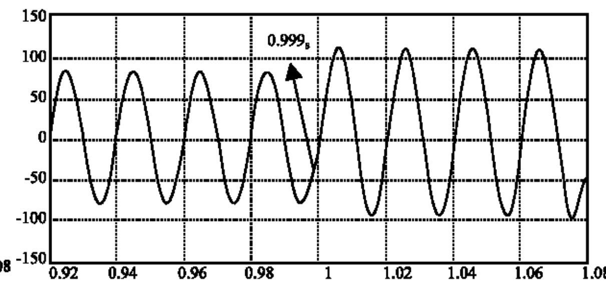


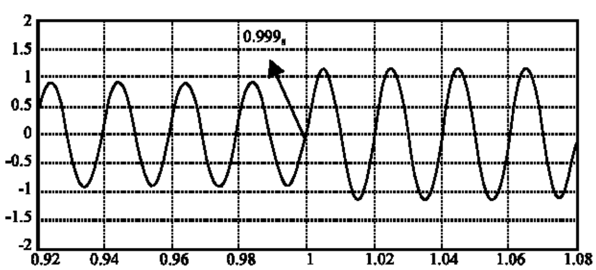
Fig. 5: The thyristor control pulse in regulation process



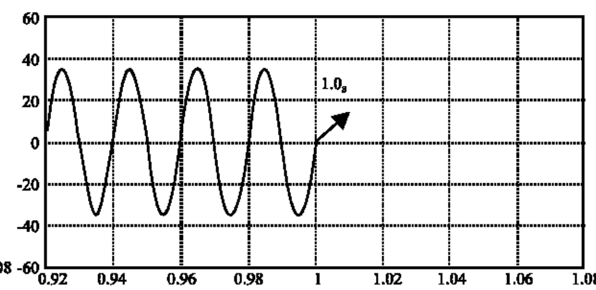
A: The phase current of transformer first side



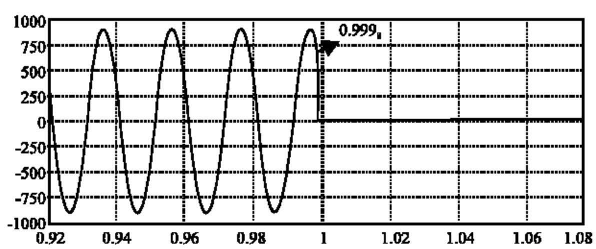
B: The phase current of transformer secondary side



C:The phase voltage of transformer secondary side



D: The current crossing thyristor switch K41



E: The voltage on thyristor switch K12

the current crossing electronic switches is the phase current of transformer first side, which is less than 60A and the voltage undertaken by open switche of group K_{j2}(1=j=6) is equal to its corresponding tap–changing winding's voltage which is about 900V, thus both the current and voltage a thyristor may carry are in the allowable band of a normal thyristor capability (4000A /6500V).

CONCLUSIONS

The novel OLTC model explained in this study has mainly resolved three problems.

Arcless: replacing the mechanical switch contacts of the electronic switches to eliminate the arcing at the contacts basically;

Fast response: reducing the regulation period form seconds to 20~30ms with thyristor's zero-crossing cutoff character;

Continuity and no-transient: cutting off and inserting tap-changing windings in special condition to avoid transient phenomena, in addition the current and voltage supply will not be cut off during regulation process.

Considering high-power thyristor's withstanding voltage level and cost, this new model is fit for 35kV and lower voltage lever network. If the worker voltage lever exceeds thyristor's endurance, we can use several thyristor pairs in series to share voltage and in addition adopt synchronous onoff control theory in switching process to avoid their breakdown by overvoltage.

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