

# The macro model of hybrid on-load tap-changer passive trigger

Peng Li<sup>1</sup>, Yu Yin<sup>1</sup>, Shuqi Zhang<sup>1</sup>, Fei Gao<sup>1</sup>, Pengfei Jia<sup>1,\*</sup>, Xueli Liu<sup>1</sup>, and Fei Shi<sup>2</sup>

<sup>1</sup>China Electric Power Research Institute, High Voltage Research, Beijing, China

<sup>2</sup>Shandong taikai Electric Power Equipment Co., Tai'an, China

**Abstract.** Using thyristor as arc medium hybrid on-load tap-changer, completely solve the problem of switch produce arc, reduce the ablation of mechanical contact, improve the working environment of transformer oil, both mechanical switch and brake switch tube, the advantages of both resistance to overload, over current, over voltage capability, high reliability, long service life, maintenance workload small, suitable for frequent regulating occasions, reduce the operation cost transformer.

## 1 Introduction

Based on auxiliary thyristor arc hybrid OLTC trigger principle of passive trigger system analysis, and the study of the affect law of the trigger characteristics of mechanical system, the research thought of mechanical system impact factor model should be taken into account in accordance with the arc model.

In the passive trigger system of thyristor in hybrid on-load tap-changer, there are many factors affecting the trigger characteristics of thyristor. At present, there is no research on these factors and their influencing rules. For hybrid on-load tap-changer, there is no research on passive trigger characteristics. Especially when the trigger signal generated by sequential action of mechanical contacts is much different from that generated by secondary trigger circuit, the reliability of passive trigger system of thyristor module needs to be specially studied.

## 2 Trigger characteristic analysis model of hybrid OLTC thyristor module

### 2.1 Establishment of transient analysis model for thyristor

The transient analysis model of thyristor is shown in Fig.1. The whole model is divided into three parts: main block, control block and reverse recovery block. In this model, different branch circuits are used to describe the various working states of thyristors: forward bias, reverse bias and forward and reverse recovery processes.

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\* Corresponding author: [jiapengfei@epri.sgcc.com.cn](mailto:jiapengfei@epri.sgcc.com.cn)

### 2.1.1 Forward characteristic

Voltage control voltage source. When the thyristor is on, its value is 0; when the thyristor is off, its value varies with the applied voltage  $V_{ctrl}$  of the thyristor, depending on the control voltage in the control block ( $= 0$  or  $1$ ), and the relationship between them is as follows:

$$E_1 = V_{AK} \cdot V_{ctrl} \quad (1)$$

The sum of  $V_2$ ,  $V_3$ ,  $V_4$ ,  $V_5$  and  $V_6$  is a zero voltage source, which acts as a current detector to detect the forward and reverse currents flowing through the thyristor. When the thyristor is on, the non-linear characteristics of the thyristor are described by diodes.  $R_L$  is used to reflect the leakage current when thyristor is broken. The gate trigger characteristics of thyristors are simulated by sum.

### 2.1.2 Reverse recovery characteristics

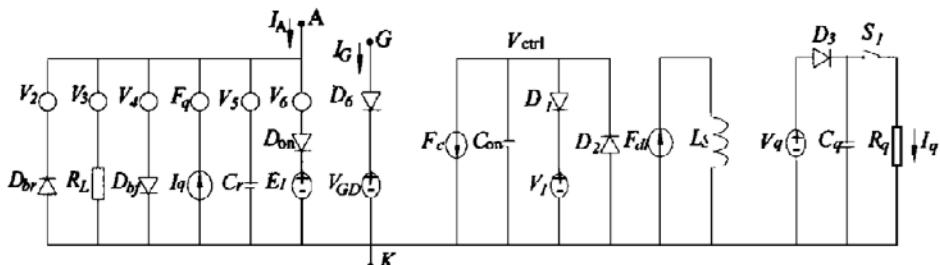
In the reverse recovery process of thyristor, the reverse recovery charge  $Q_r$  of the device is related not only to the forward current value  $I_F$  flowing through the device, but also to the drop rate of the current. According to the reverse recovery charge curve provided in the device product manual, the above relationship can be fitted and the expression of  $I_F$  and  $di_A/dt$  can be obtained, which can be used to simulate the shutdown process of thyristor.

### 2.1.3 Equivalent circuit of gate limit current resistance

The actual resistance cannot be ideal, there are parasitic capacitance, parasitic inductance and loss. The resistance values of the same resistor element are different when they are connected by DC and current. Under high frequency AC, the influence of lead inductance  $L_0$  and distributed capacitance  $C_0$  of resistance element should be considered.

### 2.1.4 Equivalent circuit of varistor

In the peripheral circuit of thyristor module, varistor can protect thyristor from damage when it withstands reverse recovery voltage. It has the advantages of sensitivity, flat volt-ampere characteristics, low residual voltage and reliable operation. At present, the most widely used equivalent circuits are IEEE model and P-G model. In this project, we consider using P-G model to describe the non-linear characteristics of varistors.



**Fig. 1.** Structural chart of transient analysis model of thyristor.

## 2.2 Key stress parameters of thyristor during switching

In the switching process of thyristor-assisted arc-extinguishing hybrid on-load tap changer, according to the special triggering and switching mode of thyristor, the stress parameters of thyristor that need to be paid attention to include:

(1) Reverse Repetitive Peak Voltage ( $V_{RRM}$ ): The maximum repetitive instantaneous reverse voltage at both ends of the reverse blocking thyristor, including all repetitive transient voltages, but not all non-repetitive transient voltages.

(2) Reverse non-repetitive peak voltage ( $V_{RSM}$ ): Any non-repetitive maximum instantaneous reverse voltage occurring at both ends of the reverse blocking thyristor.

(3) Off-state repetitive peak voltage ( $V_{DRM}$ ): When the gate is open and the junction temperature is rated, it is allowed to repeat the forward peak voltage added to the device.

(4) Off-state non-repetitive peak voltage ( $V_{DSM}$ ): When the gate is open and the junction temperature is rated, the forward peak voltage added to the device cannot be repeated. The general value is  $V_{DRM} + 100V$ .

(5) Surge Current ( $I_{TSM}$ ): A non-repetitive maximum on-state overload current caused by circuit anomalies (e.g. faults) that cause junction temperatures to exceed the rated junction temperatures.

(6) critical on-state current rise rate ( $di/dt$ ): The maximum on-state average current rise rate that thyristors can withstand without damage when triggered by gates under specified conditions. If the current rising speed is too fast, when the thyristor is switched on, a large amount of current will be concentrated in a small area near the gate, which will easily cause local overheating and damage the thyristor.

(7) Critical Voltage Rise Rate ( $dv/dt$ ): Under the condition of specified junction temperature and open gate circuit, the maximum voltage rise rate of thyristor from break to on-state is not caused. If the thyristor is subjected to excessive break-state voltage rise rate, it will be misleading.

(8) Gate trigger voltage ( $V_{GT}$ ): The minimum gate voltage necessary to generate gate trigger current.

(9) Maximum rated junction temperature ( $T_{jm}$ ): The maximum junction temperature allowed by thyristors in normal operation.

(10) Gate trigger current peak ( $I_{FGM}$ ): Thyristor trigger maximum gate current peak.

(11) Single half-wave on-state average current ( $I_{TS(AV)}$ ): The average value of the maximum sinusoidal half-wave current allowed to flow through the thyristor when the junction temperature of the thyristor has reached the rated junction temperature under the specified test conditions, i.e. the maximum temperature rise of the transformer and the specified cooling conditions.

## 3 Macro-model of thyristor-assisted arc-quenching hybrid OLTC passive trigger system

### 3.1 Arc model for breaking and closing process of mechanical contacts

At present, arc models can be roughly divided into physical model, black box model and parameter model. The physical model is based on hydrodynamics, thermodynamics and Maxwell equations, and focuses on the use of complex mathematical methods to describe the physical shape of the arc. The black box model focuses on describing arc behavior and studying the relationship between arc conductance and other variables in the circuit. The parametric model accurately describes the specific arc through complex data and tables. There are many black box models, such as early Mayer model and Cassie model. On this

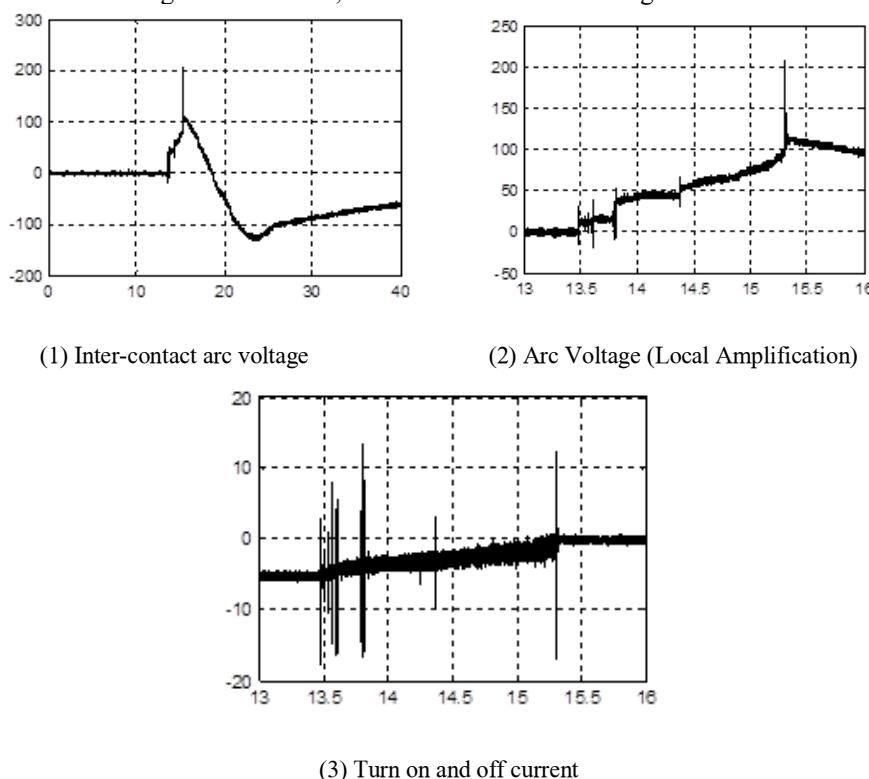
basis, many modified models are proposed, such as Habedank model, Modified Mayr model, Schwarz model, KEMA model and Schavemaker model.

In this project, KEMA model is used to describe the breaking and closing of contacts. KEMA model is a semi-empirical arc model based on Cassie and Mayr equation and a large number of experiments. Because the mathematical description of KEMA model comes from Cassie and Mayr equation, it has complete physical significance and is based on a large number of experimental basis, so it can accurately simulate various kinds of interrupting arcs in theory.

### 3.2 Experimental Study on Arc Voltage Characteristics of Contacts Acting in Transformer Oil

In order to determine the selection of trigger current and gate resistance of thyristors, the arc voltage characteristics of contacts in transformers should be studied.

A large number of interruption tests were carried out in the laboratory using on-load tap-changer model prototype to simulate the arc voltage characteristics between contacts under different interruption current sizes and different load properties. Figure 2 shows a typical situation of arc voltage development and change measured. At this time, the power supply voltage is 120/1.414V, the interruption current is 4A, and the arc shown in Figure 2(1)-(3) is analyzed. The development process of voltage can be obtained: without thyristor-assisted arc extinguishing, the development of arc voltage presents a ladder shape with the applied voltage of the port and the opening distance of the port. The ablation of the arc lasts for nearly 2ms. When the contact starts to move, the arc voltage will jump step by step. The initial stage is about 30 V, and the maximum arc voltage can reach 200 V.



**Fig. 2.** Contact arc voltage and switching current without thyristor.

### (1) Simulation and experimental study on the on-off characteristics of anti-parallel thyristors

Under the action of forward anode voltage, when the gate enters the trigger current, the main current concentrates near the gate at the initial turn-on moment. With the increase of time, the turn-on area gradually enlarges until all the junctions are turned on. For the trigger-on of thyristor in on-load tap-changer, due to the different phase of the voltage when the contacts are closed, the current rise rate of the trigger-on of thyristor will be different. Especially under capacitive load, the simulation and experimental study on the key parameters of the trigger-on characteristics of thyristor are carried out. The simulation results show that the current through the thyristor will rise to the steady state almost instantaneously when the thyristor is turned on under capacitive load. Therefore, the correctness of the theoretical analysis mechanism is verified, which lays a foundation for the determination of the key technical parameters of the next selection of thyristors.

### (2) Simulation and experimental study on turn-off characteristics of reverse parallel thyristor

When the thyristor is turned off naturally through zero, because the carrier stored in the base area cannot disappear immediately, it is impossible to restore its blocking ability immediately. The residual carriers in the thyristor must be compounded before the thyristor can restore the blocking. This process is called the reverse recovery process of thyristor. It can be seen from the figure that the thyristor cannot be turned off when the current passes zero. Instead, the reversal slope  $di/dt$  determined by the leakage inductance of the circuit establishes the recovery current in the opposite direction, i.e. the current continues to decrease to a negative value until the charge is completely recombined. At this time, the current reaches the reverse maximum  $I_{RM}$ . At this time, the thyristor can resume the reverse blocking ability and turn off reliably. Because the thyristor is turned off, this reverse will occur. The current began to decrease rapidly to zero. Because the peak value of reverse current is quite high and the turn-off time is very short, the turn-off time of ordinary thyristor is about tens of microseconds. When the recovery current decreases rapidly, there will be a relatively large voltage jump  $\Delta V$  on the inductance of the connected circuit (including the conductor inductance). This induced voltage, together with the inherent reverse voltage applied on the thyristor, will lead to a spike at both ends of the thyristor. Voltage. If this voltage is too high, it will damage the thyristor.

## 4 Conclusion

Group of thyristor transient analysis model is established and the model of the peripheral circuit including door limit flow resistance, diode, and pressure sensitive resistance, set the thyristor trigger characteristics test loop, the inverse parallel thyristor trigger conduction current transient characteristic and the zero natural shut off when the voltage transient characteristics are studied, has been clear about the hybrid OLTC switching process of microtek thyatron key stress parameters; Of mechanical contact arc mechanism of the breaking and closing process was analyzed, and the structures, the rule of mechanical system impact test loop, the suspension and arc pressure characteristics of mechanical contact potential is studied; Established the mechanical contact the breaking and closing process of the arc model, combined with the transient analysis model of the thyristor and peripheral circuit model is established in the macro model of source trigger system.

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