2-C # Modeling and Experiment Research on Turn-off Characteristics of Pulse Power Thyristor

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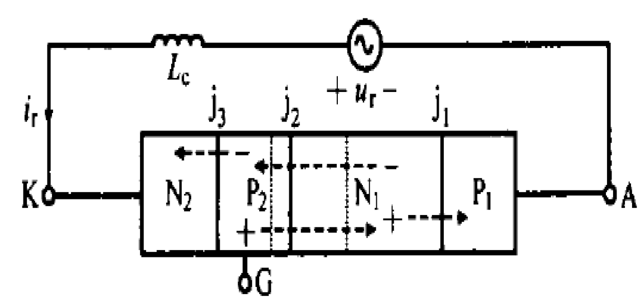
1 ABSTRACT

Pulse power thyristor has been widely used in pulsed power system for its numerous advantages. To study the device's electrical characteristics and the circuit transient process, a marco model of pulse power thyristor applying to MATLAB software platform was established in this paper. This model combined ideal thyristor model in MATLAB with reverse recovery current module, which was designed to describe the reverse recovery process of thyristor after the conducting current rapidly decreased to zero. In the model, reverse current increased with a constant di/dt when accumulated carriers rapidly decreased; and then when space charge region started to recover, the thyristor's recovery current curve was described by two hyperbolic secant curves with different time constant. This established model achieved the smooth transition of current curve from storage time to dropping time, and thus improving the precision of thyristor model comparing with the original one. In addition, experiment was designed to verify the marco model. According to the experimental data, the reverse recovery voltage and recovery current curve calculated by the marco model fitted well with the experiment results.

2 THEORETICAL ANALYSES

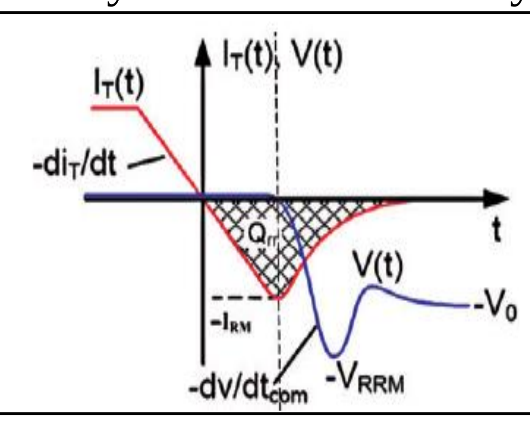
Figure 1 shows the physical structure of a four-layer thyristor with 3 PN junctions. As the current passes through zero, the device continues to conduct due to excess minority carriers remaining in the thyristor. These carriers require a certain amount of time be removed by reverse current flow and by recombination with opposite charge carriers. Figure 2 shows the change trends of current and voltage when thyristor turns off.

Due to the existence of reverse recovery process, inductor in series with the thyristor suffers relatively high voltage when reverse current sharply decreases. Thus leading to the reverse overvoltage of the thyristor.



A is anode of thyristor; K is cathode; G is gate. L_C is inductor in circuit. u_r is voltage source in circuit.

Figure 1. Physical structure of thyristor



I_{RM} is peak value of reverse recovery current. V_{RrM} is peak value of reverse voltage.

Figure 2. Turn-off process of thyristor

A pulse thyristor damaged by overvoltage is shown in figure 3. In order to explain detailed transient turn-off process, it is necessary to build a transient recovery mathematical macro-model and verify the correctness of it .

Figure 3. Thyristor damaged by overvoltage

3 EXPERIMENTS AND RESUTLS

A pulsed forming unit is established to measure turn-off characteristics of thyristor. The measuring system is shown in figure 4. The stability of the current probes is the key factors affecting the accuracy of the measurement.

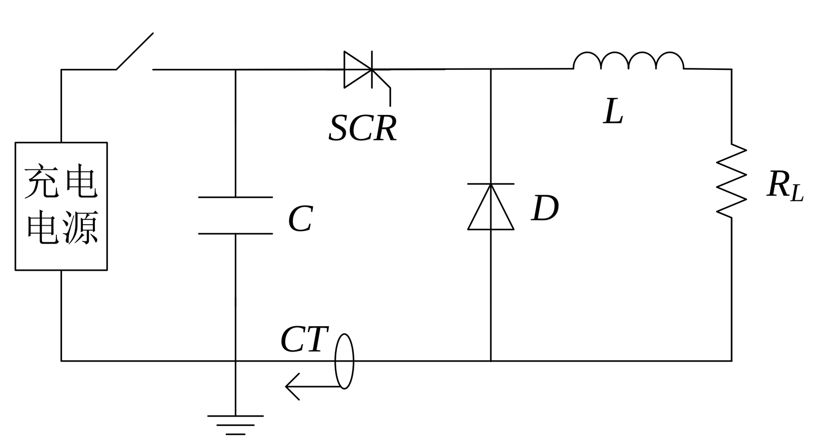


Figure 4. Experiment schematic

Capacitance C: 1785μF
Inductance L: 10μH
Load resistance R_L: 5mΩ

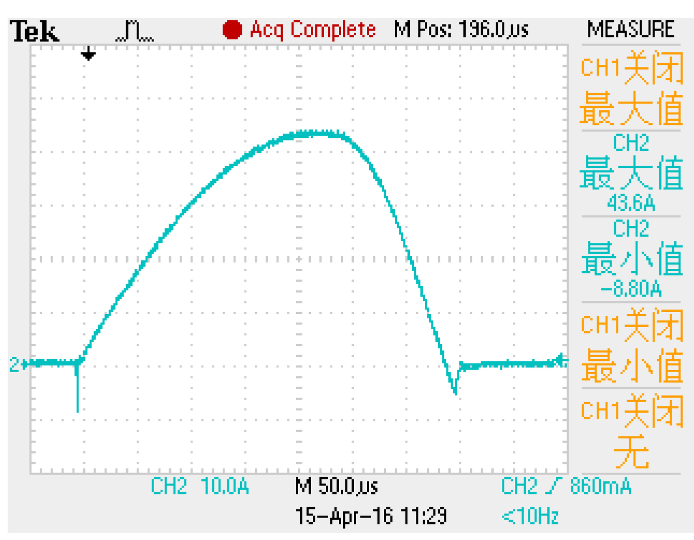


Figure 5. Typical current waveform of thyristor in PFU

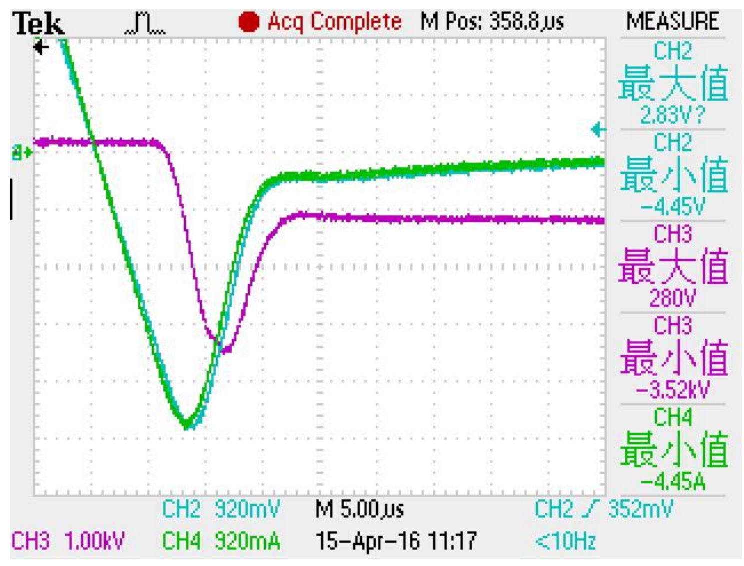


Figure 6. Typical current and voltage waveform of thyristor in reverse process

Table 1. Experiment data

Charging voltage (V)	I_F（kA）	I_{RM}（kA）	U_{RM}（V）	di/dt（A/μs）	Q_{rr}（μC）
200	2.04	0.481	228	27.14	8456
500	5.32	0.972	508	70.38	15003
1000	10.7	1.65	976	145.75	21812
1500	16.2	2.19	1480	222.19	26064
2000	21.8	2.715	1900	299.04	28852
2500	27	3.185	2340	375.49	31880
3000	32.8	3.6	2760	455.0	33650
3500	38.4	4.015	3160	537.37	36006
4000	43.6	4.45	3520	611.73	39714

$$I_{RM} = -5E\text{-}6*(di/dt)^2 + 0.0095*di/dt + 0.295$$

$$Q_{rr} = 0.0003*(di/dt)^3 - 0.3334*(di/dt)^2 + 156.8*di/dt + 4913.8$$

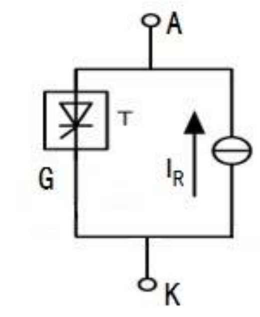
4 THYRISTOR MODELING

The macro model uses conventional devices to emulate the external behavior of a thyristor. The thyristor's hyperbolic secant model created by MATLAB consists of two parts:

1) original thyristor model
2) reverse recovery current circuit

A piecewise function with 3 stages is proposed to describe the reverse current of thyristor.

$$I_R(t) = \begin{cases} -t*di/dt \\ -I_{RM}*\operatorname{sec}h\left[(t-t_2)/\tau_a\right] \\ -I_{RM}*\operatorname{sec}h\left[(t-t_2)/\tau_b\right] \end{cases}$$



Experiment circuit is simulated using created thysirtor model based on MATLAB.

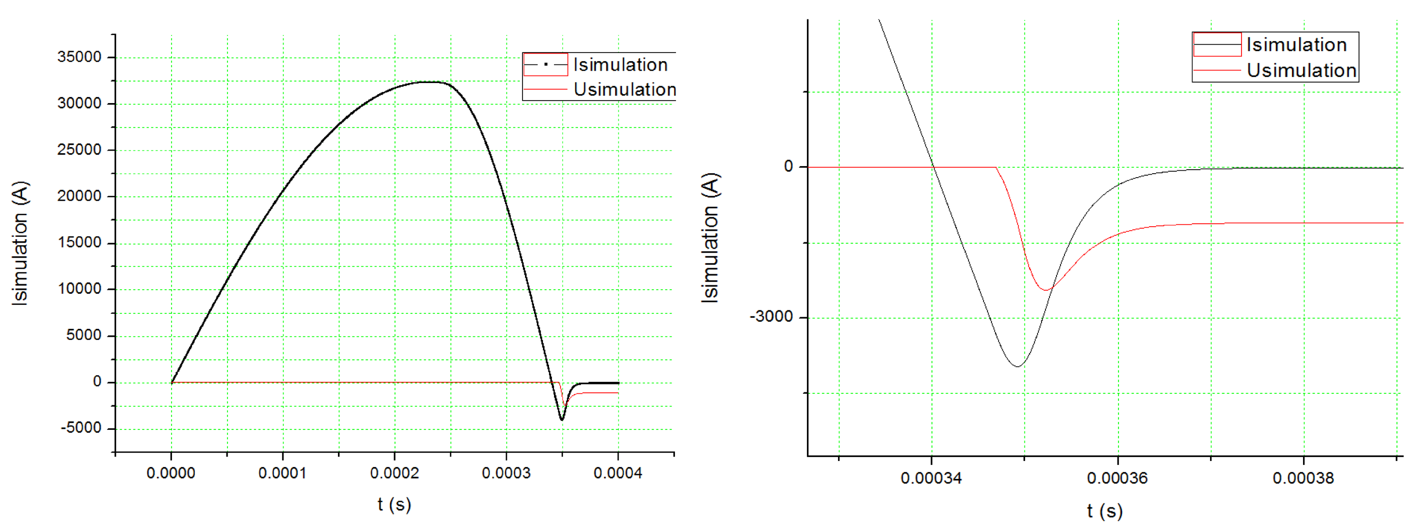


Figure 7. Simulation results with charging voltage 4000V

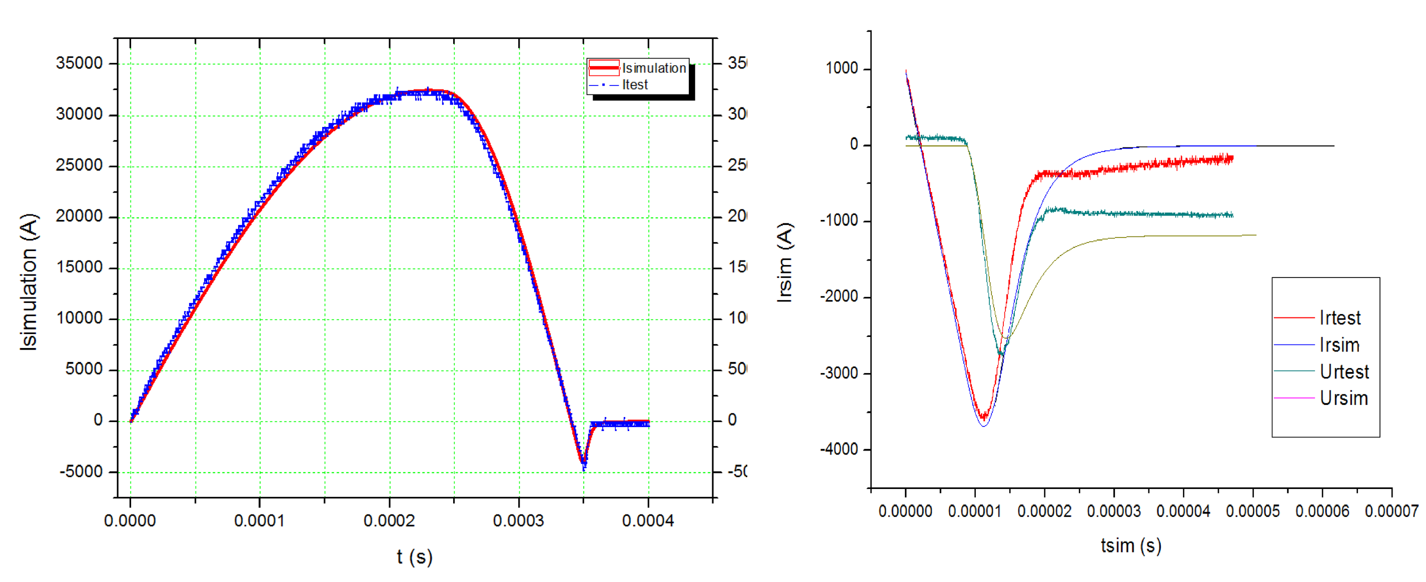


Figure 8. comparison between experiment results and simulation results

5 CONCLUSIONS

(1) A pulsed forming unit is established to measure turn-off characteristics of thyristor. The results indicate that the changing rate of current decreasing to zero (di/dt) has a linear relationship with peak value of on-state current.

(2) Hyperbolic secant model can authentically describe the reverse current of thyristor .

SHUYUN TIAN was graduated with a master's degree in HUST in Wuhan, China in 2014 and continue her study in HUST up to now. She has been working on pulsed power technology and high voltage engineering. Email: tsyecho@mail.hust.edu.cn.