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Gas Discharge Tube Modeling With PSpice

Julio Guillermo Zola

***Abstract*—Gas discharge tubes (GDT)—sometimes named spark gaps (SGs)—are commonly used to suppress transients in many applications, from high-frequency communications to ac medium-power supply lines. The sharp GDT breakdown characteristics enable them to provide suitable transient suppression performance. A simple model of GDT for personal simulation program with integrated circuit emphasis (PSpice) simulation, based on theoretical triac behavior, is proposed in this correspondence. The comparison between real measured characteristics and the proposed model results in a suitable approach for the overvoltage transient response without typical problems of numerical convergence.**

***Index Terms*—Overvoltage protection, simulation program with integrated circuit emphasis (SPICE), spark gaps (SGs).**

I. Introduction

Gas discharge tubes (GDTs), also called spark gaps (SGs), work based on an ionized gas discharge (inert gas or air) when a transient overvoltage is applied. At low values of applied voltage, a GDT acts as a high-value impedance (picofarad capacitance). Above a threshold voltage, the GDT switches to a very low impedance state, presenting a negative resistance effect and clamping at a holdover voltage (threshold voltage), lower than the applied sparkover voltage.

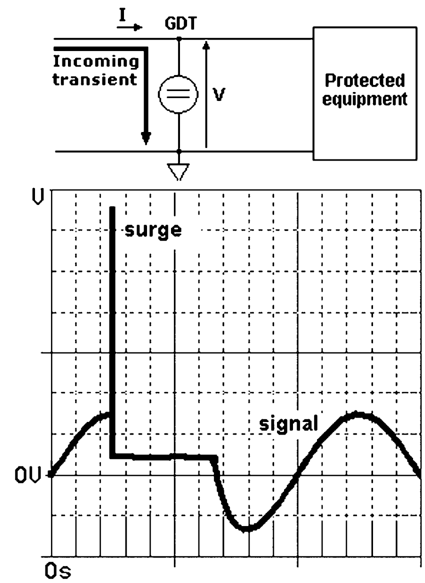

Fig. 1. Equipment protected with GDT.

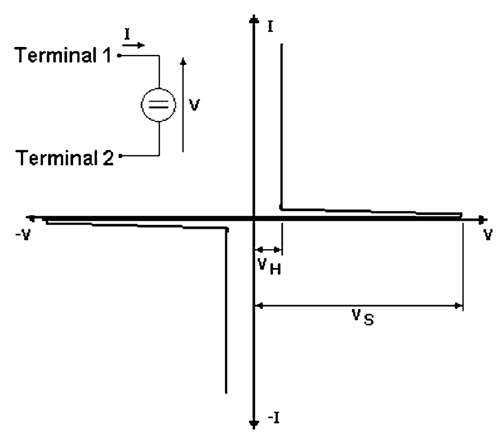

Fig. 2. I–V dc characteristic.

When the voltage applied is lower than the threshold voltage, the GDT becomes nonconductive again. With these properties, GDTs are employed in electrical applications, such as power lines, communication lines, signal lines, and data transmission lines, to protect circuitry from transient overvoltages (damage caused by transient surge voltages that typically result from lightning strikes and equipment switching operations).

For protection purposes, GDTs are shunted with the system to be protected, between the signal line and ground (see Fig. 1), diverting the energy away from the sensitive equipment when overvoltages are applied. The potentially destructive energy of the incoming transient pulse is absorbed by the GDT, thereby protecting vulnerable circuit components and preventing potentially costly system damage [1].

For precise simulation, it is necessary to consider the dynamic properties of GDTs. During a low frequency pulse, the voltage across the GDT decreases quickly to the threshold value (see Fig. 2), similar to the theoretical triac behavior. This I–V characteristic is the basis for the proposed model of the GDT.

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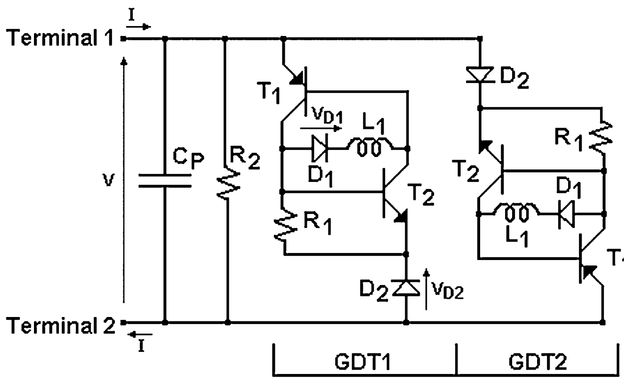


Fig. 3. Proposed model.

TABLE I
EXAMPLE OF MODEL PARAMETERS EXTRACTION

SL1002A090: Device characteristics	SL1002A090: Model parameters
DC Voltage: 90V	$V_S = V_{BD1} + V_{BD2} = 90V$
Threshold Voltage: 50 V	$V_H = V_{BD2} = 50\ V \Rightarrow V_{BD1} = 40\ V$
Leakage Current: 100 nA (measured at 50V)	$R_2 = 50V / 100\ nA = 500\ M\Omega$
Capacitance: 1.2 pF	$C_P = 1.2\ pF$
Dynamic Breakover Voltage: 360V	$V_{dS} = 360\ V = V_S + L_1(\Delta I / \Delta t)$
Repetitive Impulse Discharge Current (8/20 μs): 5 KA	$\Rightarrow 270\ V \cong L_1(5\ KA / 8\ \mu s)$ $\Rightarrow L_1 \cong 0.4\ \mu H$
Voltage vs. Time Characteristic: Time response ≅ 300 ns	TF1 + TF2 = 300 ns $\Rightarrow$ TF1 = TF2 = 150 ns
Glow-Arc transition Current: < 0.5 A	$R_1 = V_{jBE2} / 0.5\ A = 1\ \Omega$ $V_{jBE2} \cong 0.5$ V is T_2 base-emitter junction voltage before to on state

A simple model of GDT for personal simulation program with integrated circuit emphasis (PSpice) simulation, based on theoretical triac behavior, is proposed in this correspondence. The parameters of the model, which are lower than current models of GDT, are extracted from electrical characteristics datasheets of GDT. This is suitable to build a model of a particular GDT quickly, and test by simulation the performance of GDT surge protection over the equipment to be protected. Behavior model is validated by measurement.

Since the model has been applied to GDT from different manufacturers, having different electrical characteristics, the repeatability of the proposed model is assured.

II. Building the Model

The proposed model of the GDT for PSpice simulation, (Orcad–PSpice, Intusoft–Spice, or MicroCap–Spectrum) [2], is based on the triac model. Fig. 3 shows a circuit model, a half circuit GDT1 for dc and another half GDT2, for reverse current.

The transistors T_1 and T_2 are the triac bases. The dc sparkover voltage (V_S) and threshold voltage (V_H) are fixed for D_1 and D_2 reverse breakdown voltages ($V_{\rm BD1}$ and $V_{\rm BD2}$, respectively)

$$V_S = V_{\rm BD1} + V_{\rm BD2} \qquad V_H = V_{\rm BD2}. \tag{1}$$

R_1 (glow current value) and R_2 (isolated resistance) significantly help numerical convergence. Table I shows an example of model parameters extraction using datasheet values.

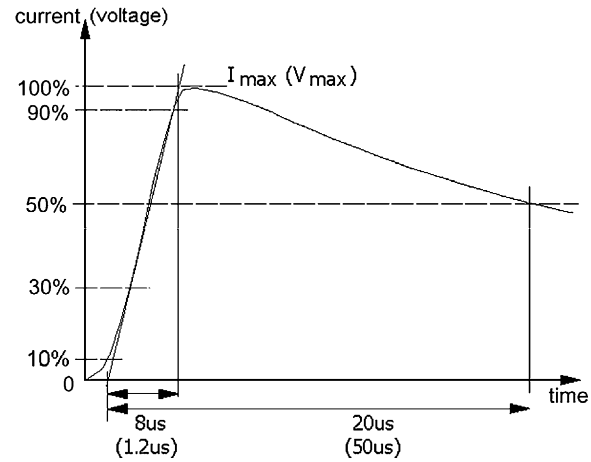


Fig. 4. Standard waveform.

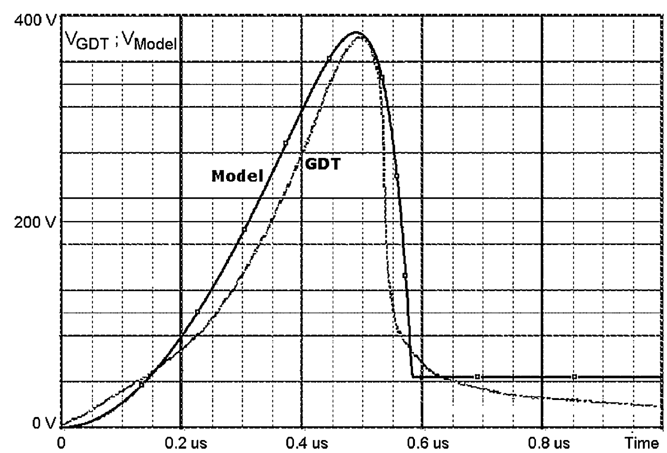


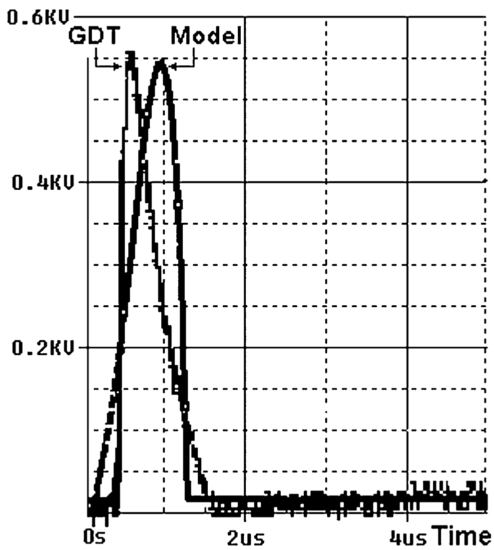
Fig. 5. GDT versus model response when a standard combination wave is applied.

On the other hand, the dynamic sparkover voltage (or dynamic breakover voltage) $V_{\rm dS}$ depends on the impulse voltage applied dV/dt. For example, most datasheets show dynamic breakover voltages at 100 V/μs. The maximun $V_{\rm dS}$ in these cases is higher than V_S (two or three times). The inductance L_1 (0.1–1 μH) in series with D_1 and the time parameter of bipolar junction transistors models TF (10–100 ns), take into account this dynamic response. The parallel capacitance C_P shows the behavior at nonconductive state.

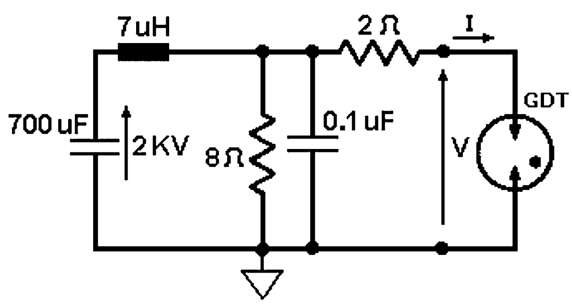
III. Proposed Model Versus Measured GDTs

Lightning, inductive load switching, or capacitor bank switching are often the sources of these overvoltage transients. The wave shape of a typical surge is similar to that of Fig. 4. The voltage surge is defined as a 1.2/50-μs waveform, while the current surge is an 8/20-μs waveform [3], [4]. Other standard current waveforms are 10/200, 10/1000 μs, etc. [5].

Figs. 5 and 6 show the comparison between the time response for the proposed model, using Orcad–PSpice 9 [6], [7], and measured 90- and 230-V GDTs.



(a)



(b)

Fig. 6. (a) GDT versus model response to 1-kA 10/1000-μs waveform. (b) Surge generator model.

Fig. 5 shows the voltage versus time characteristic of GDT SL1002A090, extracted from datasheets and the proposed model response, when a standard combination wave is applied.

The standard impulse of a combination waveform generator is characterized by the output voltage under open-circuit conditions and the output current under short-circuit conditions. The open-circuit voltage shall have a front time of 1.2 μs and a time of half value of 50 μs. The short-circuit current shall have a front time of 8 μs and a time to half value of 20 μs [8]. In this case, we have 20-kV 1.2/50-μs open circuit and 5-KA 8/20-μs short circuit.

Fig. 6(a) shows the GDT N81-A230X and the proposed model response when a 1-KA 10/1000-μs waveform is applied. Fig. 6(b) shows the surge generator model used for simulation.

For this measurement, a surge generator (2-kV 1.2/3000-μs open circuit and 1-KA 10/1000-μs short circuit) and a digital scope Tektronix model TDS1002 (60 MHz, 1 GSample/s and 10× probe) were used (see Fig. 7).

Note that the measured voltage in Fig. 6 has a negative zero crossing. This is due to normal sample error at very low voltages values that are neglected for the measurement.

The resistors of surge generator in Fig. 7, specified in IEEE Standard C62.31, R_1 (impulse-shaping resistor) and R_2 (impulse-shaping and current-limiting resistor) have values between 8 to 10 and 1 to 2 Ω, respectively. The voltage of GDT is reduced 100 times at the scope input (see Fig. 7).

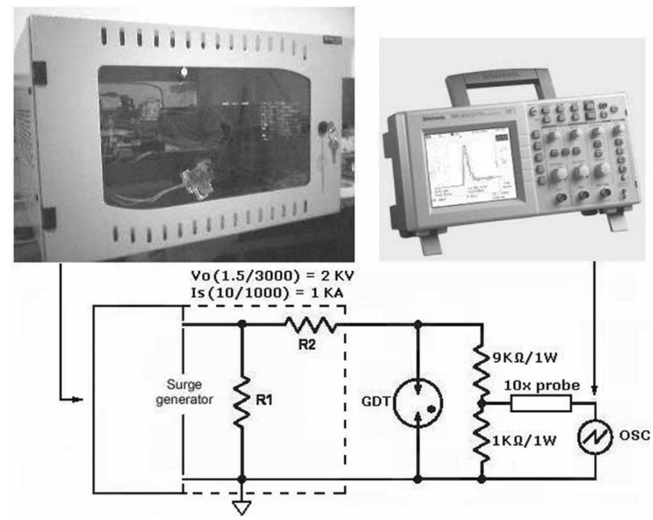


Fig. 7. Measurement diagram.

TABLE II
NETLISTS COMPARISON

Current model	Proposed model
.subckt sprkgp 1 2	.subckt sprkgp 1 2
EB_C 6 0 value={if(abs(v(1,2)) >90	RP 1 2 .5G
+ | abs(I(vs)) >4m,12,0)}	CP 2 1 1.2P
DT1 6 7 1N4148	R1 3 4 1
CT1 7 0 .25U	D1 3 100 D1
RT1 7 0 50	L1 100 5 .4U
SB 1 3 7 0 C_S	Q1 3 5 1 P
.model C_S vswitch Voff=0 Von=10	Q2 5 3 4 N
+ Ron=500u Roff=50meg	D2 2 4 D2
VS 5 2	.model D1 D bv=40
EA_C 8 0 value={if(abs(I(vs)) >0.2,12,0)}	.model D2 D bv=50
DT2 8 9 1N4148	.model P pnp tf=.15U
CT2 9 0 .1U	.model N npn tf=.15U
RT2 9 0 50	R10 30 40 1
SA 3 10 9 0 C_S	D10 30 200 D1
D1 3 4 GW	L10 200 50 .4U
D2 5 4 GW	Q10 30 50 2 P
.model GW d bv=20 is=1u rs=5u ibv=10u	Q20 50 30 40 N
D3 10 11 ARC	D20 1 40 D2
D4 5 11 ARC	.ends
.model ARC d bv= 50 is=1U rs=5u ibv=10U	
.model 1N4148 d is=2.7n n=1.8 rs=.6 Vj=.5	
+ ikf=44m xti=3 eg=1.11 cjo=4p m=.33 fc=.5	
+isr=1.6n nr=2 bv=100 ibv=100u tt=11.5n	
.ends	

IV. CONCLUSION

The triac-based GDT model allows us to obtain a good fit to measured characteristics with few parameters and an improvement in numerical convergence.

Table II shows an example of PSpice netlists: current model (used in [9]–[11]) and proposed model (used in [12]).

The following facts should be noted.

1) The number of parameters to be preset to create the new model is reduced.
2) The proposed model does not use switches. In the current models, the switch parameters, R_{ON}, R_{OFF}, and its ratio $R_{\mathrm{ON}}/R_{\mathrm{OFF}}$, must be carefully selected to avoid problems of numerical convergence.

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