

Simulation of Electric Arc Characteristics Based on MATLAB/Simulink

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Abstract. In high-voltage circuit breakers and high-speed railway Pantograph-OCS system, the plasma arc directly causes economic loss to the ablation of the equipment. It is important to study the electrical characteristics of the arc. Therefore, based on MATLAB/Simulink, several existing arc models are simulated to obtain the voltage and current waveforms of the arc and the volt-ampere characteristics. Through comparative analysis, the applicable conditions, advantages and disadvantages of several models are clarified, which provides a reference for the improvement of future arc models. The results show that the high-current arcing phase and the high-resistance and low-current phase of the arc are considered separately, and the simulation results are more accurate. The arc model time constant and the dissipated power are regarded as the functions of the arc conductance, and the simulation results can better reflect the dynamic changes of the arc conductance.

1. Introduction

Plasma arc is widely used in the industrial field [1]. However, in the high-voltage circuit breaker, when the contacts of the circuit breaker are separated, the air gap between the contacts is broken under the action of the strong electric field and the applied voltage on the surface of the two poles, thereby generating an alternating current arc, which not only prolongs the opening time of the circuit breaker. Breaking time will also cause ablation of the contact surface of the circuit breaker and shorten its service life [2]. In addition, in the high-speed railway Pantograph-OCS system, the offline arc of the pantograph generated when the pantograph and the catenary are offline, which will make the power supply voltage unstable, cause electromagnetic interference and affect the communication system [3], and also corrode the catenary and the pantograph carbon skateboard, causing economic losses. Therefore, research on plasma arcs can help to deepen understanding and make it better developed and utilized [4].

In this paper, the electrical characteristics of the arc are studied [5]. By modelling and simulating several existing arc models in MATLAB/Simulink, the voltage and current waveforms of the arc and the arc volt-ampere characteristic curve (U-I) are obtained. The advantages and disadvantages of several arc models and their applicable conditions were analyzed to guide the selection of suitable models when studying arcs. The simulation results of several models are analyzed from the perspective of modeling, which has reference significance for the further improvement of the arc model.



2. Arc Model Equation

Since the internal conditions of the arc are very complicated, in order to facilitate the study of the electrical characteristics of the arc, the black box model is generally used to represent the arc. The arc black box model [6] defines the interaction between the arc and the circuit during the current interruption. The existing arc model based on MATLAB/Simulink is based on the physical principle and the appropriate simplified arc forming process, using differential equations. Indicates the change of arc conductance.

Based on the principle of conservation of energy, from the perspective of energy balance, the arc can be expressed in the form of differential equations as:

$$\frac{dq}{dt} = u \cdot i - p_{loss} \quad (1)$$

Renfu Wang et al. [7] derived the general mathematical form of the arc model:

$$\frac{1}{g} \left(\frac{dg}{dt} \right) = \frac{1}{\tau} \left(\frac{gu^2}{p_{loss}} - 1 \right) = \frac{1}{\tau} \left(\frac{u \cdot i}{p_{loss}} - 1 \right) \quad (2)$$

(1) The Cassie arc model assumes that the arc has a cylindrical gas passage with a uniformly distributed temperature in its cross section; the conductance outside the diameter is small, and the conductance within the diameter is large. It is considered that the arc temperature remains constant in time and space; the energy and energy dissipation velocity is proportional to the change of the cross section of the arc column, and the energy dispersion It is caused by the airflow or the change of the arc column related to the airflow, and does not consider the energy radiated from the electrode [7]. The model equation is:

$$\frac{1}{g} \left(\frac{dg}{dt} \right) = \frac{d \ln g}{dt} = \frac{1}{\tau_0} \left(\frac{gu^2}{p_{loss}} - 1 \right) = \frac{1}{\tau_0} \left(\frac{u^2}{U_c^2} - 1 \right) \quad (3)$$

(2) The Mayr model is based on the principles of thermal free, thermal inertia and heat balance [8]. The Mayr arc model assumes that the arc column is a cylinder of constant diameter, in which the temperature decreases with increasing distance from the axis; the Mayr model only studies the case of long arc. And the heat radiated from the electrode; the emission of the arc column power is mainly due to conduction and a part of the radiation, regardless of convection, the energy emitted from the arc gap is constant; the relationship between the thermos physical properties of the gas in the arc column and the temperature is not considered; The thermal freeness in the column can be determined by the ShaHa equation. The model equation is:

$$\frac{1}{g} \left(\frac{dg}{dt} \right) = \frac{d \ln g}{dt} = \frac{1}{\tau_M} \left(\frac{ui}{p_{loss}} - 1 \right) \quad (4)$$

(3) The Habedank model is a series of Cassie arc model and Mayr arc model. The model equation is:

$$\begin{cases} \frac{dg_c}{dt} = \frac{1}{\tau_c} \left(\frac{u^2 g^2}{U_c^2 g_c} - g_c \right) \\ \frac{dg_m}{dt} = \frac{1}{\tau_m} \left(\frac{u^2 g^2}{P_0} - g_m \right) \\ \frac{1}{g} = \frac{1}{g_c} + \frac{1}{g_m} \end{cases} \quad (5)$$

(4) The Schwarz arc model is improved on the basis of the Mayr model [9]. It is considered that the time constant and the dissipated power are functions of the arc conductance, namely:

$$\begin{cases} \tau_m = \tau g^a \\ P_{loss} = P g^b \end{cases}$$

The model equation is:

$$\frac{1}{g} \frac{dg}{dt} = \frac{d \ln g}{dt} = \frac{1}{\tau g^a} \left(\frac{ui}{P g^b} - 1 \right) \quad (6)$$

3. Arc Modeling in MATLAB/Simulink

As is shown in Figure 3-1, a simulation circuit for studying the electrical characteristics of arcs is modeling. In the circuit, the access frequency is 50Hz, the voltage is 25kV AC power supply, the internal resistance of the power supply [9] is $r=0.2497\Omega$, and the load is a pure resistance $R=125\Omega$. The arc model in the circuit is represented as a circuit breaker.

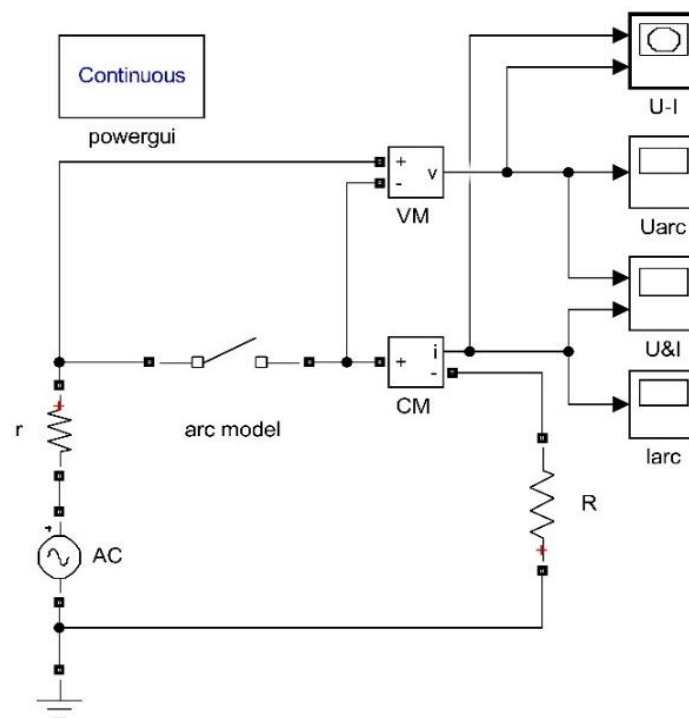


Figure 1. Arc model simulation external circuit.

The arc model is constructed as Figure 3-2, which includes DEE, Step, Voltage Measurement, Controlled Current Source, and Hit Crossing five modules.

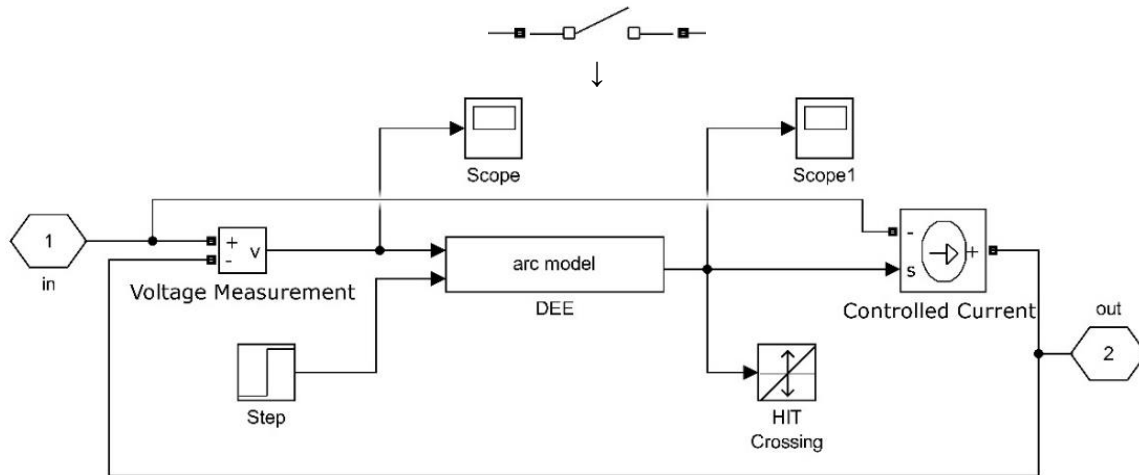


Figure 2. Internal structure of the arc model

The specific function of each module [10]:

(1) Differential Equation Editor (DEE): The differential equation of the arc model is implemented in the DEE. The model equation can be directly input in the editor to make the two equations of the Mayr model connected.

(2) Hit Crossing: used to detect the zero crossing of the arc current. In the process of arc generation, the detection of voltage and current zero-crossing time is very important, and accurate calculation should be carried out to ensure the simulation results are credible.

(3) Step: A step signal from 0 to 1 is generated at the specified contact separation time. Used to control the start time of contact and separation of the arc generating device.

4. Simulation Results

As is shown in the figure3, the arc voltage and current waveforms obtained by different models.

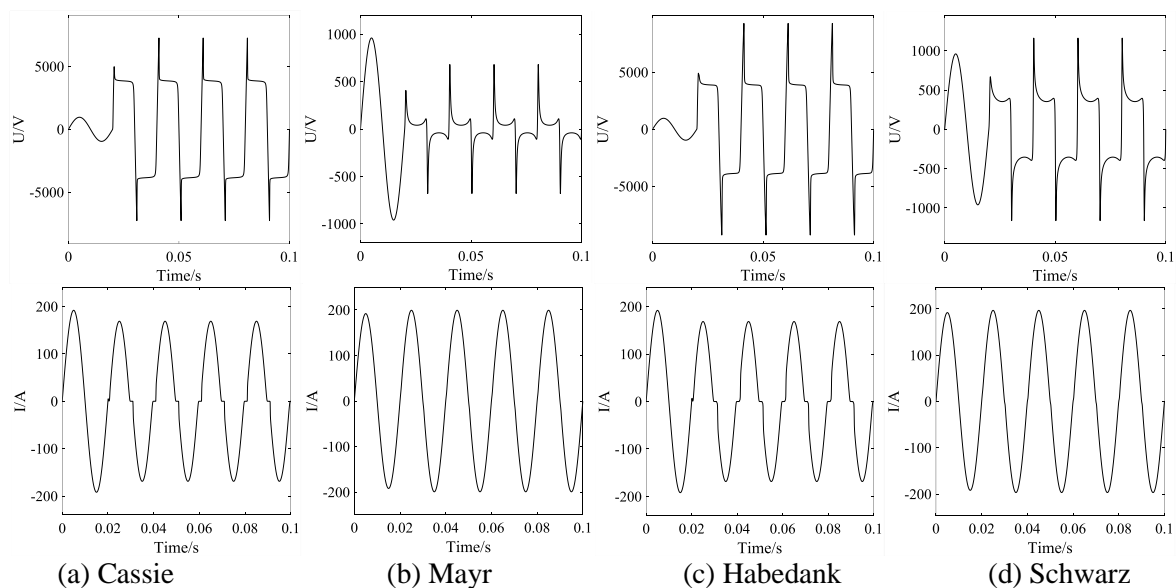


Figure 3. The arc voltage and current waveforms.

It can be seen from the voltage and current waveform diagram of the simulation result that the current has a zero-crossing point in every half cycle. There is a sudden change in voltage at the moment when the circuit breaker is disconnected at 0.02s in the figure. This is because the air gap formed by the moment when the circuit breaker is disconnected, and the voltage across the circuit breaker is approximated equal to the power supply voltage. As the power supply voltage increases, the field strength increases between the air gaps, when the air gap is broken down, the arc is generated. After the arc is formed, a variable resistor is connected in series in the circuit. As the supply voltage decreases, the arc is extinguished (current zero crossing), and immediately after the reverse pressurization, the air gap is broken down again, repeating the previous process to form a cycle.

The volt-ampere characteristic curves obtained by several models are shown in figure4.

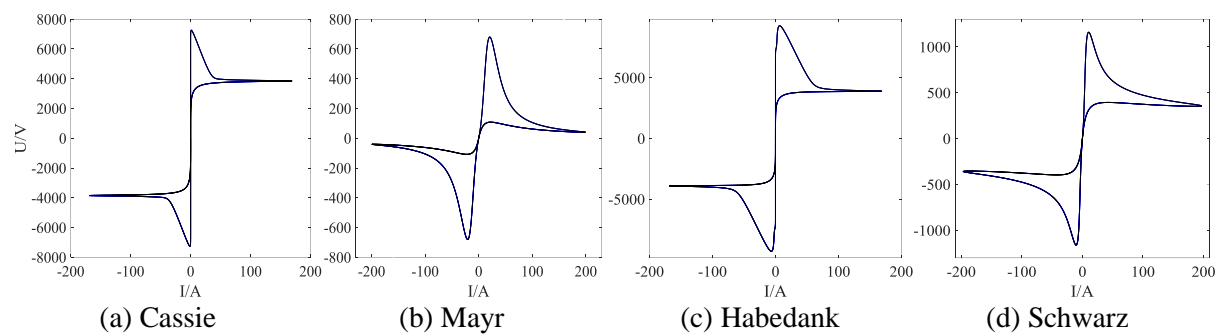


Figure 4. The arc volt-ampere characteristic curves

The volt-ampere characteristic curve of the arc has hysteresis characteristics [10]. It can be seen from the arc U-I characteristic curve of the above figure that the arc voltage and the arc current have an extreme value in each half cycle.

5. Conclusion

The Cassie model is suitable for simulating the arcing of small resistors and large currents. It is suitable for arc characteristics under high current and low arc impedance conditions [11]. It has high accuracy in describing the continuous arcing phase, and insufficient description of arc current zero crossing zone characteristics. The Mayr model is suitable for the simulation of high-resistance and low-current arc. The Mayr model is more accurate than other models in describing the arc volt-ampere characteristics of the current zero zone, but it is lacking for the description of high-current arcing. The Habedank model is a simple series of Cassie model and Mayr model. It combines the characteristics of the two models. The simulation results show that this model describes the situation of small current arc insufficiently. Therefore, the simple series model can improve the accuracy of the model to a limited extent. The Schwarz arc model is improved on the basis of the Mayr model. It is considered that the time constant and the dissipated power are functions of the arc conductance. The arc conductance and other parameters interact with each other, so that the electrical characteristics of the arc are dynamically changed, and the simulation result is currently the best.

According to the modeling principle, the high current arcing phase and the high resistance and small current phase of the arc are considered separately, and the simulation results are more accurate. The arc model time constant and the dissipated power are regarded as functions of the arc conductance, and the simulation results are more able to reflect the dynamic changes of the arc conductance.

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