International Journal of
Science and Engineering Investigations vol. 2, issue 16, May 2013
ISSN: 2251-8843

The Modeling of Electric Arc in High Voltage Circuit Breakers with Use of Schavemaker Model and Negative Feedback

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Abstract-In this paper, modeling of the electric arc and models of high voltage circuit breakers Kema, Schwarz, Schavemaker has been studied. Using the concept of negative feedback, and use a new method to improve the break situation of the breaker on Schavemaker model is presented and results have been extracted. Finally, current and voltage indicators breaker for different modes were compared and showed that models with negative feedback Schavemaker the above methods will produce the best performance.

Keywords- *High Voltage Circuit breaker, Electric Arc Model, Schavemaker Arc Model, Cassie-Mayr Arc Model, Negative Feedback.*

I. INTRODUCTION

In this paper, the performance of high voltage circuit breaker with electric arc simulation models in Matlab / Simulink is investigated. High voltage breaker is a key tool to protect the power systems. Hence, a detailed study on the performance of it required. High voltage breaker operates correctly whereas 1) is a good conductor when it is closed, 2) is a good insulator when it is opened, 3) Doesn't cause over-voltages when operating, 4) Fast switching capabilities. Types of the high voltage breaker are hydraulic press, air press (steam air) and SF6 gas. When the switch is on the verge of opening, due to an electrical arc occurs with high temperature [9]. The arc voltage is one of the significant pillars that need to be considered. Variety of models suchas Cassie, Mayr, Modified Mayr, Schavemaker, Schwarz, Kema and Habedank have studied [1-8].

Two main models which other models are derived, are Cassie and Mayr models the mathematical equations governing these models are respectively as follows [3,5,6]:

$$\text{Cassie}: \frac{1}{g}\frac{dg}{dt} = \frac{1}{\tau}\left(\frac{u^2}{U_c^2} - 1\right) \tag{1}$$

$$\text{Mayr}: \frac{1}{g}\frac{dg}{dt} = \frac{1}{\tau}\left(\frac{ui}{P} - 1\right) \tag{2}$$

In the above equations, g is the conductance of the arc, u is arc voltage, i is the current through the switch (arc current), Uc is voltage curve, P is the power of cooling and τ is time constant. The models derived from these two models, the goals are reducing of the Arc Voltage Extinguishing Peak and speed of off switch. Feedback is used to modify deviations System behavior than desired behavior and putting it in a high performance model Schavemaker this has been done.

II. ARC MODEL AND TEST CIRCUIT

In this section, the differential equation governing the model Kema, Schwarz, Schavemaker and Negative feedback method applying in the model of Schavemaker and Single-phase test circuit is also studied and compared to models that have been proposed.

A. Kema Arc Model

It was derived from three modified Mayr arc model in series. The equations of this model are as follows [8].

$$\frac{dg_i}{dt} = \frac{A_i}{\tau_i} g_i^{\lambda_i} u_i^2 - \frac{1}{\tau_i} g_i \quad i = 1,2,3 \tag{3}$$

$$\frac{1}{g} = \sum_{i=1}^{3} \frac{1}{g_i}, \ u = \sum_{i=1}^{3} u_i \ , \ i = g.u \tag{4}$$

Where, gn is the conductance of the n-th arc, u_n is the voltage across the n-th arc, τ_n is time constant arc n th, An constant cooling curve n i, Kn parameters free, λ_n Control Cassie - mayr arc n th , where λ=1arch Cassie and λ=2 Mayr arc results, we also:

$$\lambda_1 = 1.4375, \lambda_2 = 1.9, \lambda_3 = 2$$

$$\tau_2 = \frac{\tau_1}{k_1}, \tau_3 = \frac{\tau_2}{k_2}, A_2 = \frac{A_3}{k_3} \tag{5}$$

B. Schavemaker Arc Model

Differential equation for this model is as follows [2].

$$\frac{1}{g}\frac{dg}{dt} = \frac{1}{\tau}\left(\frac{ui}{\max\left(u_{arc}\left|i\right|, P_0 + P_1 ui\right)} - 1\right) \tag{6}$$

Cooling constant P0, P1 constant cooling, which was zero when the current passes through zero, uarc is arc voltage constant in high current areas and in this study is assumed to be 1100 volts.

In the high current area, equation 6 reduces to the following differential equation.

$$\frac{1}{g}\frac{dg}{dt}=\frac{1}{\tau}\left(\frac{ui}{u_{arc}\left|i\right|}-1\right)=\frac{1}{\tau}\left(\frac{u}{u_{arc}}-1\right) \qquad (7)$$

This equation shows a clear conformity with the Cassie arc model. At current zero, equation (7) reduces to the following differential equation.

$$\frac{1}{g}\frac{dg}{dt}=\frac{1}{\tau}\left(\frac{ui}{P_0}-1\right) \qquad (8)$$

This is exactly the Myar arc model.

C. Schwarz Arc Model

This model, a model that is modified Mayr arc time constant and power steering cooling is dependent on the differential equation for this model is as follows[7].

$$\frac{1}{g}\frac{dg}{dt}=\frac{1}{\tau g^a}\left(\frac{ui}{Pg^b}-1\right) \qquad (9)$$

Where, a=0.15 and b=0.6.

D. Single Phase Test Circuit

Figure 1 shows the single-phase test circuit arc models that have been studied. As the circuit in figure 1, first the current passing through the switch and voltage in three Kema, Schwarz, Schavemaker are compared, then the performance of the Schavemaker model with Genetic Algorithm Optimization and performance of the Schavemaker model with negative feedback compared.

Figure 1 test circuit disconnect switch at 0.2 s. figures 2 and 3 arc current and voltage and table 1 shows the performance of three model Kema, Schavemaker, Schwarz.

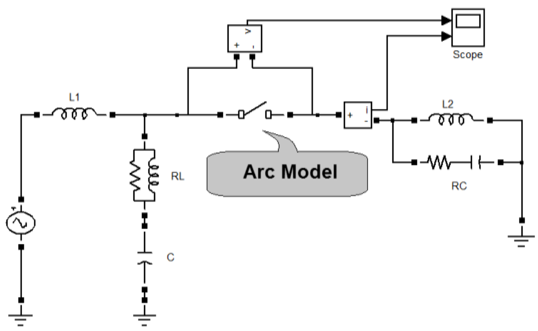

Fig1. Single phase test circuit

In figure 1, Vs phase angle of 90 degrees with peak amplitude of 59.196 volts and frequency is 60 Hz, and we have:

RC:R=450Ohms، C=1.93 nF

RL:R=29.80Ohms ،L=5.28mH

L_1=3.52mH، L_2=0.6256mH، C=1.98μF

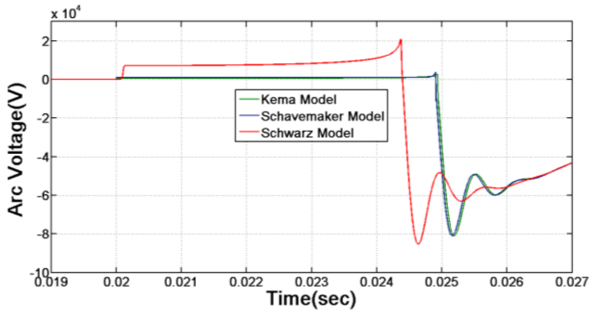

Fig2.Over the voltage switch off in Kema, Schavemaker, Schwarz models

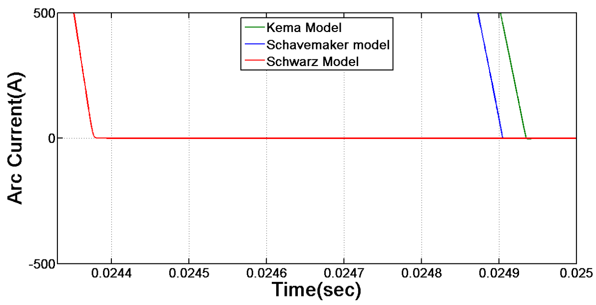

Fig3.Arc Current at zero crossing

TABLE1. PERFORMANCE COMPARISON OF THREE MODELS OF KEMA, SCHAVEMAKER, SCHWARZ IN SINGLE PHASE TEST CIRCUIT

Arc Voltage Extinguishing Peak	Time of Breaking	model
2796V	0.0249s	Kema
3857V	0.0249s	Schavemaker
21035V	0.0244s	Schwarz

Figures 2 and 3 and Table 1 show that Schwarz model breaks faster than two other models but voltage of breaker (switch) is higher. According to Table 1, the time to zero Schavemaker and Kema models are equal but in Figure 3, it is clear that the Schavemaker model breaks faster. So Schavemaker model for optimization is more appropriate.

E. Schavemaker Model With Negative Feedback

There are ways to optimize the performance of the model, one of which is the use of genetic algorithms. The purpose of the model parameters by which the change takes place, the current-voltage curve in Figure 4 and 5 Schavemaker optimization model with genetic algorithm has been shown [9].

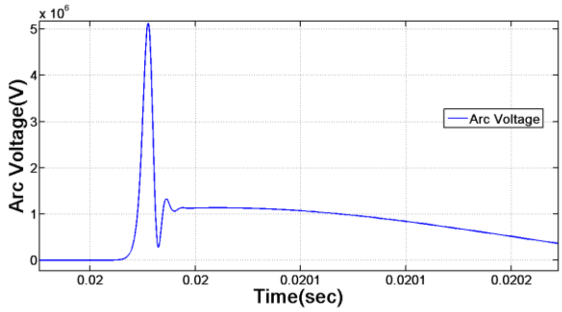

Fig4. Arc voltage Schavemaker model optimized by Genetic Algorithm

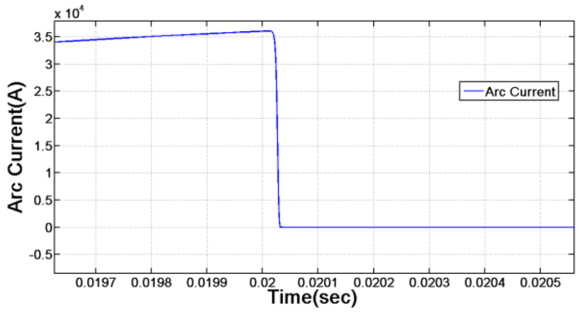

Fig5. Arc current Schavemaker model optimized by Genetic Algorithm

As is clear from Figures 4 and 5, Althought the arc current is zero quickly (0.0201 seconds) but the maximum voltage is too high about 5.1 MV so this model is not appropriate for the study.

Another method is to use the concept of negative feedback, feedback is used when the time and the nature(essence) of the error is unknown. in this strategy, the overall system behavior deviates from the desired behavior (target system) are considered to act to correct these deviations. Here the goal is to accelerate the switch off. Using this method, the negative feedback is that the model like Schavemaker model before breaking and opening switch negative feedback is applied to model. The model is simulated in Figure 6.

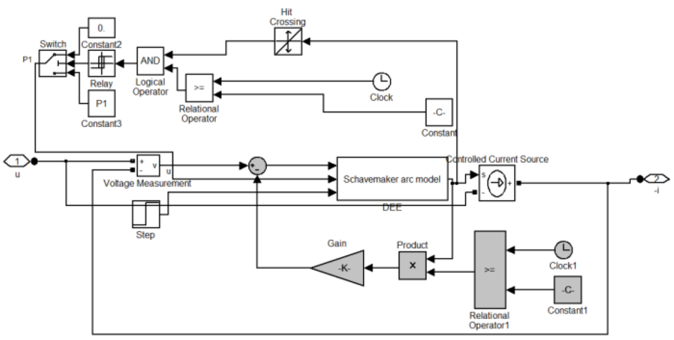

Fig6. Schavemaker model circuit with negative feedback.

Usage of this model depends on the amount of gain in this model. Changing the gain causes arc voltage and current are experiencing many changes during the breaking. Since fast opening the breaker is our optimization goal, gain variations can only reach it, but you should be very careful maximum voltage of breaker.

Arc current and voltage model Schavemaker with negative feedback with different Gain values are shown in Figures 7 and 8.

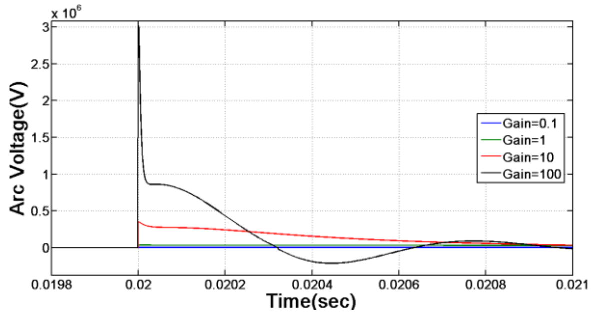

Fig7.Arc voltage Schavemaker model with negative feedback

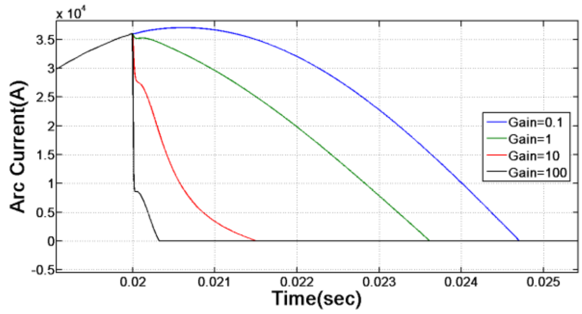

Fig8.Arc current Schavemaker model with negative feedback.

As is clear from Figure 7 and 8, gain value is greater, breaker cut off faster, but voltage goes up. The breaker design and simulation feedback should be noted that most of the breaker bearing on how much voltage. Thus, a compromise must be made. The Gain can be set between 0.1-1 and the result was good. Figures 9 and 10 show arc voltage and current at gains of 0.2 and 0.4 and 0.6. The performance comparison is shown in Table 2.

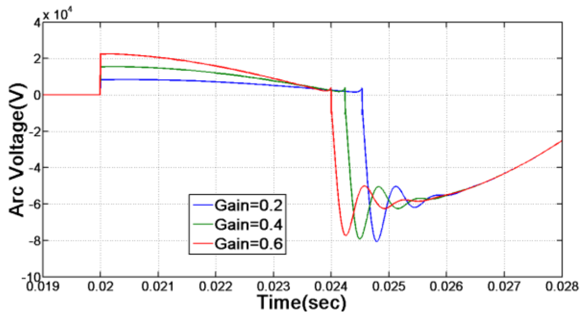

Fig9.Arc voltage model Schavemaker with negative feedback in 3 different Gains.

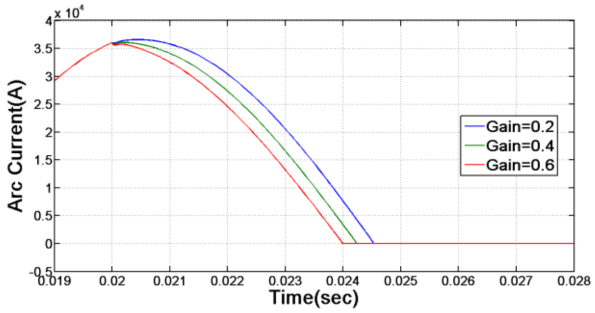

Fig10.Arc Current model Schavemaker with negative feedback in 3 different Gains.

TABLE2.PERFORMANCE COMPARISON OF SCHAVEMAKER MODEL WITH NEGATIVE FEEDBACK IN 3 DIFFERENT GAINS

Arc Voltage Extinguishing Peak	Time of Breaking	Gain
8416V	0.0245s	0.2
15525V	0.0242s	0.4
22671V	0.024s	0.6

As Figures 9 and 10 and Table 2 show Schavemaker model with negative feedback with Gain 0.6 interrupted earlier than the rest of the state, but the maximum arc voltage is high and with Gain 0.2, arc voltage is low but it needs more time to cut off . With this interpretation, model with Gain=0.4 is closer to reality in comparison with other gain as a model for high performance simulation used in studies of high voltage circuit breaker.

CONCLUSIONS

In this paper, the modelling of electric arc in high voltage in circuit breakers and Kema, Schwarz, Schavemaker models were studied and compared to show the superiority of the model Schavemaker, improving of break the model using the concept of negative feedback in this model. Then we see that Schavemaker model with negative feedback has the best performance compared to other models.

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