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High Impedance Faults Modeling in Electrical Power Distribution Networks

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***Abstract*-** High impedance fault (HIF) is an undesirable electrical contact between an energized conductor and a non-conducting object such as tree limbs, concrete walls and different ground surfaces. Besides public hazards, HIF increases power dissipation and may endanger network equipment. Detection of this fault by common protective devices existing in electrical power distribution systems is particularly difficult, because its occurrence causes only a small increase in load current which is usually below the detection level of such protective devices. Thus, conventional over-current protective devices cannot reliably detect HIFs. Although various protection schemes and detectors have been proposed to confront this fault, HIF detection is still remains an unsolved problem in power distribution level. The scope of this paper is to find a more accurate HIF modeling in order to achieve a better approximation of power system transient response in its faulted state, which is dramatically useful in developing or improving HIF detection algorithms and equipment. In this paper, a HIF arises from falling a tree on a medium voltage distribution network conductor is accurately modeled by two series time-varying resistors in EMTP/EMTP Works. Eventually, the simulation results of the proposed HIF model are compared with experimental results in order to examine the validity and accuracy of the proposed model.

***Keywords*-** *Electromagnetic Transient Program (EMTP), High Impedance Fault (HIF), HIF Modeling, HIF Detection, HIF Characteristic, Universal Arc Model.*

I. INTRODUCTION

Electrical power distribution networks conductors are always facing the risk of occurring unwanted contacts with surrounding objects such as trees, building walls and ground surfaces. The fact that these objects are prevalently close to distribution network conductors increases the possibility of occurrence of these contacts at any time. HIF is defined as an undesirable electrical contact between an energized network conductor and a high impedance foreign object. These objects are made of non-conducting materials which means they resist against carrying electricity current. Only under high voltages they may conduct low electricity current due to their high impedance electrical behavior. Therefore, such faults cannot be easily detected by conventional over-current protective devices exist in distribution networks. Most types of HIFs cannot be detected by over-current protection schemes since they appear as a common load increase.

It is widely known that HIF must be detected as soon as it occurs; otherwise it will jeopardize human's safety and produces public hazards [1]. Besides, the power will be dissipated to the ground through fault object which is accidentally in contact with the network conductor. Therefore, the total amount of energy generated by power suppliers would not deliver to power consumers, while the network total power losses will be increased. Regardless its public safety hazards, the latter significantly increases the cost of transmission of electricity [1].

A more accurate HIF modeling leads to achieve a better approximation of power system transient response in faulted state, which can be dramatically helpful in developing or improving HIF detection algorithms and equipment. HIF is a complex phenomenon with nonlinear and asymmetrical characteristics. Nonlinearity is an intrinsic feature of HIFs due to their nonlinear voltage-current characteristic curves. Asymmetry is another distinctive HIFs feature which indicates that the fault current behavior in positive half-cycle differs from its negative half-cycle waveform.

Various models have been presented in literatures to simulate this phenomenon. In [2], HIF was modeled by adding a linear resistance to the fault location in the simulation circuit. In order to model HIF considering its current asymmetry, reference [3] proposed a model consists of two anti-parallel DC sources, each one in series with a diode.

In [4], the authors modeled HIF using EMTP by means of nonlinear impedance and a time-varying voltage source connected to a TACS controlled switch which forms asymmetrical and nonlinear fault behavior by controlling the fault circuit opening/closing. The authors in [5] improved a HIF model composed of two anti-parallel DC sources, each one connected in series with a diode. The latter HIF model is shown in Fig. 1. In [6] each anti-parallel branch consisted of a nonlinear resistance, a DC source and a diode.

Reference [7] proposed a model for high impedance arcing faults which is composed of two series time-varying resistances that has been widely used in literatures. In this model, one of the resistances represents large nonlinear resistance of fault current path to ground and the other one models transient arc resistance.

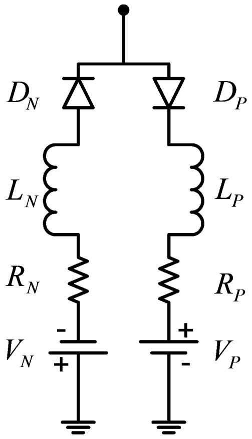


Figure 1. HIF model representing fault current asymmetry between positive and negative half-cycles [5]

The authors in [9] proposed a universal arc representation based on arc thermal equilibrium by utilizing the capabilities of TACS field in EMTP. In [8], the fault path resistance is assumed to be constant and the transient arc resistance was modeled based on universal arc representation proposed in [9]. The main drawback of the model proposed in [8] is its inability in modeling asymmetrical feature of fault current. In other word, the simulated HIF voltage-current characteristic curve was symmetrical contrary to its nature, i.e. both positive and negative half-cycle waveforms were identical. However, the fault current asymmetry is obtained by means of a controlling signal obtained from experimental tests.

In this paper, an improved HIF model is proposed based on the model developed in [8]. The asymmetrical features of the HIF current in both half-cycle are taken into account precisely in the proposed model. The proposed HIF model regarding a HIF due to a leaning tree on medium voltage distribution network is implemented in EMTP/EMTP Works and its simulation results are compared with the experimental results in [8] for the purpose of demonstrating validity and accuracy of the proposed model.

II. THE PROPOSED HIF MODEL

The proposed HIF model and its implementation in EMTP are illustrated in this section. The proposed HIF model is established through improving the model developed in [8] which is based on two series resistances including a fault path resistance and a transient arc resistance. Experimental results indicate that the fault path resistance varies depending on fault object and environmental conditions; nevertheless it can be approximated by a constant value that can be achieved from experimental tests. Since the amount of fault path resistance is commonly high, it restricts the HIF current. The transient arc resistance is a discrete nonlinear time-varying resistance which represents the arc dynamics. The general structure of HIF modeling by means of two series resistance in EMTP is shown in Fig. 2. As it is shown in Fig. 2, the transient arc resistance is modeled by using the capabilities of TACS control devices which are available in EMTP.

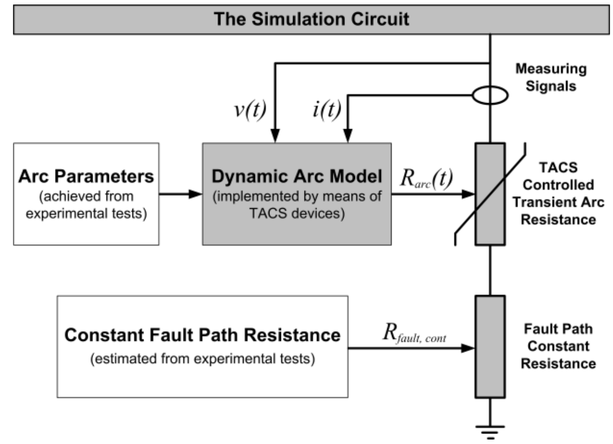


Figure 2. The general structure of HIF modeling by means of two series resistances in EMTP

HIFs are prevalently gone along with arcing phenomena due to shaky contact made between energized conductor and fault object. The electric arc behavior has been studied in literatures for a long time. There exist a variety of models that can be used for representation of electric arc behavior in circuit breakers and arcing faults. Arc model based on thermal arc characteristics is the most commonly used model among all types of arc models. Thermal model was introduced by Cassie [10] and Mayr [11] based on arc thermal equilibrium in form of a first order differential equation.

In case of high impedance arcing faults the transient arc conductance can be calculated based on arc thermal equilibrium as follows [12]:

$$\frac{dg}{dt} = \frac{1}{\tau}(G - g) \tag{1}$$

where g is the time-varying arc conductance, $G=|i|/V_{arc}$ is the stationary arc conductance, $|i|$ is the absolute value of the arc current, V_{arc} is the constant arc voltage parameter which is the arc voltage at the instant when $dg/dt=0$ occurs, and τ is the arc time constant. The above equation parameters must be measured from experimental tests, so that the simulation results resemble the experimental results. The arc time constant τ can be expressed as:

$$\tau = Ae^{Bg} \tag{2}$$

Wherein A and B are constant coefficients which are estimated from experimental results. Modeling asymmetry of HIFs voltage-current characteristic curves compel the arc time constant to have different values for positive and negative half-cycles. Therefore, each coefficient A and B are made of two constant values, one belongs to positive half-cycle and the other belongs to negative half-cycle.

The flowchart of universal arc representation utilized in [8] is illustrated in Fig. 3. Universal arc representation calculates the transient arc resistance in each simulation time step based on thermal arc model, while its input variable is instantaneous arc current. CTR is a control signal of TACS controlled integrator. The output of controlled integrator is equal to RES signal when the value of CTR control signal is low, otherwise, its output will be the input signal integration. The control signal CTR is used for modeling the arc extinction and reignition phenomena. Fig. 4 shows the CTR signal used in this paper which is similar to CTR signal obtained from experimental results in [8]. The RES signal represents the time-varying arc conductance in the vicinity of arc current zero-crossing, i.e. after arc extinction and before its reignition, and it is estimated from experimental current and voltage waveforms.

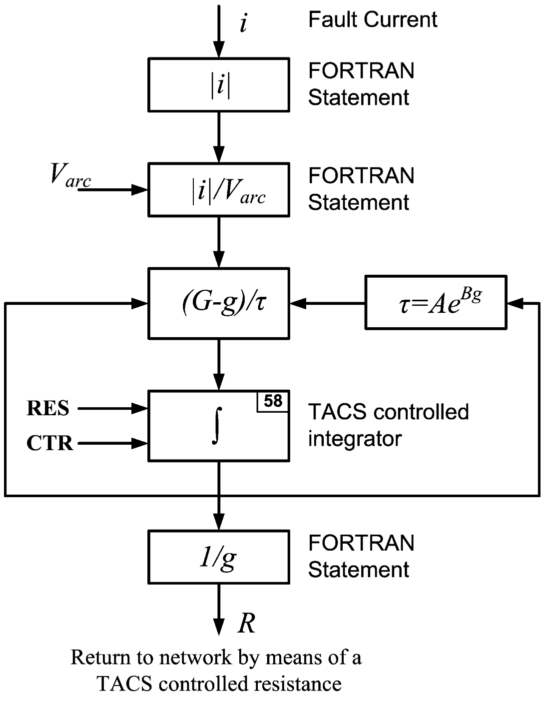


Figure 3. Universal arc representation [8]

As it was noted previously, parameters A, B, V_{arc} and τ could be estimated each by two different values for positive and negative half-cycles of fault voltage-current characteristic curve. In spite of that, asymmetrical behavior of HIF in two positive and negative half-cycles of voltage and current waveforms is one of its most distinctive features. The HIF model developed in [8] was not capable of modeling this phenomenon. In [8], parameters A, B, V_{arc} and τ assumed to be unchanged in both half-cycles.

In this paper, in each positive and negative half-cycle, the proposed HIF model uses its corresponding parameters. This will result more realistic voltage and current waveform and consequently its voltage-current characteristic curve will be asymmetric.

III. VALIDATION OF THE PROPOSED HIF MODEL

The validity and accuracy of the proposed HIF model are investigated through comparison of its simulation results with experimental results existing in [8].

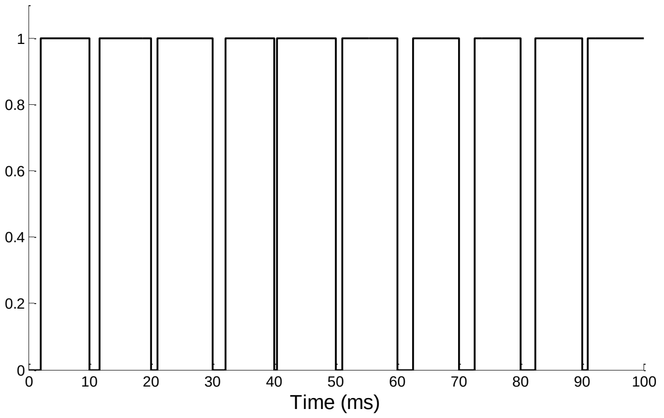


Figure 4. CTR control signal

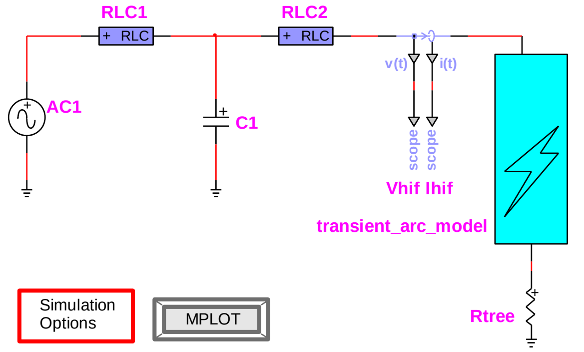


Figure 5. The HIF simulation circuit in EMTPWorks

Fig. 5 shows the HIF simulation circuit in EMTPWorks which represents the experimental setup in [8]. the HIF block In Fig. 5 is a sub-circuit block whereby the transient arc resistance. The proposed HIF sub-circuit and its complete implementation in EMTP Works by using TACS devices is shown in Fig. 6.

In order to compare the results, the amount of input parameters used in this paper is the same as reference [8]. For the positive half-cycle it is assumed that $V_{arc} = 2520V$, $A = 6.6E-5$, and $B = 41977$, for the negative half-cycle it is assumed that $V_{arc} = 2100V$, $A = 2.0E-5$, and $B = 85970.30$, when the HIF occurs in the foliage.

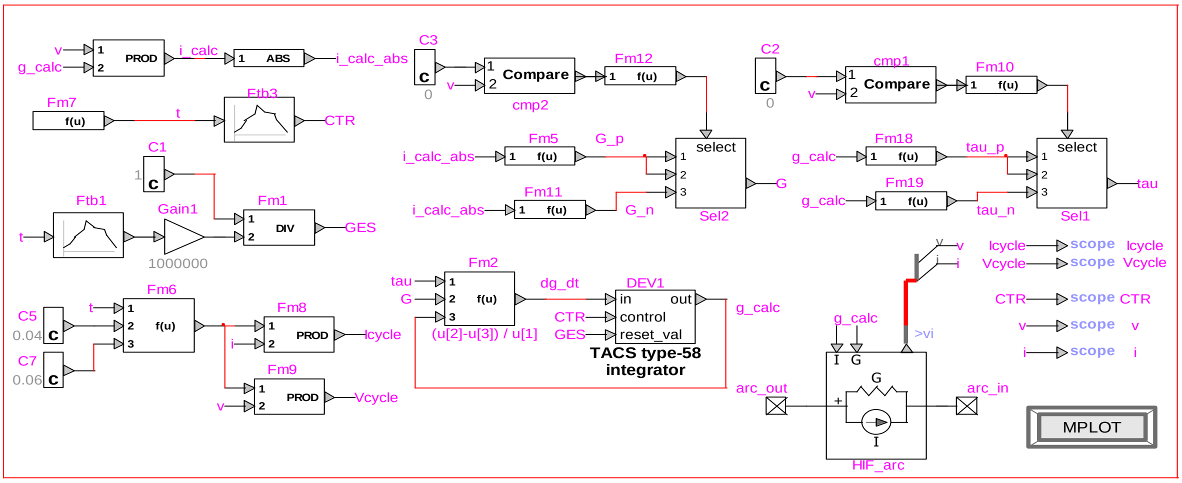
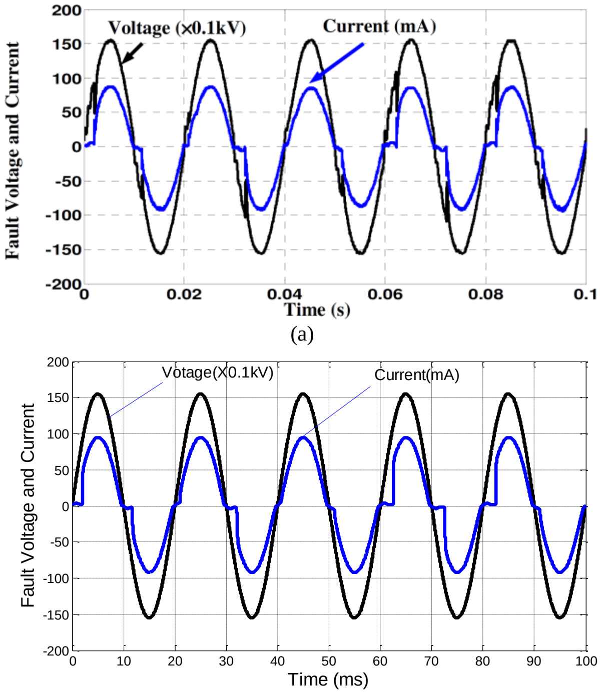


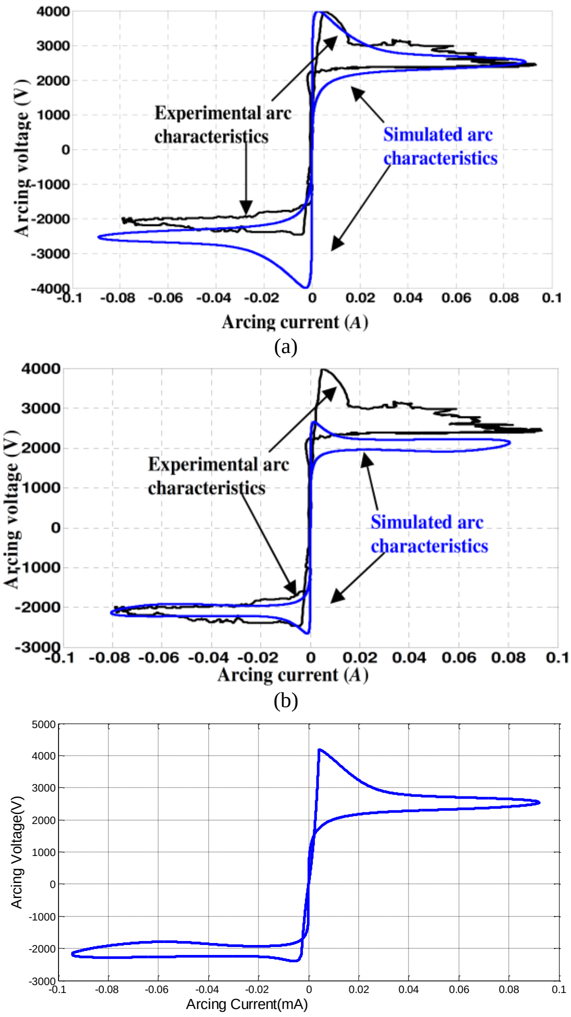
Figure 6. Implementation of the proposed HIF model in EMTPWork



(a)

(b)

Figure 7. Voltage and current of high impedance fault resulting from, a) experimental results and b) simulation of the proposed model



(a)

(b)

(c)

Figure 8. The HIF voltage-current characteristic curve; a) experimental results and developed model in [8] considering parameters related to positive half-cycle, b) experimental results and developed model in [8] considering parameters related to negative half-cycle and c) Simulation of the proposed model

It is assumed that the RES will increase linearly by the slope of $0.5M\Omega/ms$ in $1ms$ time interval after arc extinction moment, and then it will increase by the slope of $4M\Omega/ms$ until the arc reignition moment.

The high impedance fault current and voltage experimental results and simulation results are shown in Fig. 7. As it can be observed in Fig. 7, the simulation results of the proposed model are similar to the experimental results. Therefore, it can be concluded that the HIF due to a leaning tree is accurately modeled.

In order to clarify the capabilities of the proposed model, voltage-current characteristic curves resulting from simulation of the proposed model and simulation of the model developed in [8] are shown Fig. 8. As it can be seen in Fig. 8, the characteristic curve resulting from the proposed model is asymmetrical; however, the characteristic curve obtained in [8] is symmetric.

Comparing the HIF voltage-current characteristic curves of the proposed model with experimental results and the simulation results of the model developed in [8], shows the capability of the proposed model in dynamic modeling of HIFs in medium voltage distribution networks.

IV. CONCLUSION

In this paper, a new model is proposed for high impedance fault. The proposed model is based on universal arc model and is implemented in EMTP/EMTP Works software package. The advantage of the proposed model in comparison with other model is its capability in modeling the asymmetrical behavior of fault voltage and current in positive and negative half-cycles. The validity and accuracy of the proposed model is demonstrated via comparing the simulation results with the existing experimental results.

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