Modeling an arcing high impedances fault Based on the physical process involved in the arc

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Abstract
There is an increasing demand for more detailed and exact modelling techniques for predicting the transient response of power system caused in particular by high impedance arcing faults. This is particularly so in relation to the design and development of improved equipment and new protection techniques. An accurate prediction of the fault transients requires a detailed and comprehensive representation of all the components in a system, and the transient studies have to be conducted into the frequency range well above the normal power frequency. The HIF is very complex phenomenon and exhibits a very high nonlinear behaviour. The most distinctive characteristics are nonlinearity and asymmetry. The non-linearity rises from the fact that the voltage-current characteristic curve of HIF is nonlinear. It is observed that fault current has different waveform for positive and negative half cycle which is called asymmetry. The nonlinearity and asymmetry exist at every cycle after HIF. In order to obtain a model for HIF, it is necessary to develop model that gives us the above mentioned characteristics and harmonic content of HIF.

Introduction
In the case of arcing HIF, when an energized conductor contacts ground, the electric contact is not solid. Due to the existence of air between ground and conductor, the high potential difference in such a short distance excites the appearance of the arc.

High impedance faults (HIF) have characteristics in their transient and steady state regimes that make them identifiable. It also show arcing and it is the result of air gaps due to the poor contact made with the ground or grounded objects and it occurs when a conductor breaks and falls on a non-conducting surface such as asphalt road, sand, cement, grass or perhaps a tree limb, producing very little if any measurable current.

An accurate modelling method of HIF is essential for the development of a reliable detecting algorithm. The HIF modelled method data should contain the complex characteristics of HIF such as nonlinearity, asymmetry, the low frequency phenomena typical of an arcing fault and the angle shift of the third harmonics. Some modeling methods of HIFs have been proposed. A modeling method using diode is presented in [1] also HIF is modeled as a voltage source in [2, 3] and another model in [4] used two series time-varying resistances. Although all the methods represent well the nonlinear characteristic of HIFs, difficulty arises when the other characteristics are represented.

According to experimental work of Korea Electric power corporation (KEPCO) [4], HIF experimental data was collected on a 22.9 (kV) distribution system. The total number of experiment is thirty two and the sampling frequency is 10 kHz. Figure 1 exemplify the currents for the 20^{th} and 40^{th} cycle after HIF, both currents have the characteristics of asymmetry; Figure 2 shows the voltage-current characteristic curve and the characteristics of nonlinearity. We can see that the "signature" of current curve and the current-voltage curve for high impedance fault has a very unique shape.

In order to obtain a model for HIF, it is necessary to develop model that gives us the above mentioned characteristics and harmonic content of HIF.

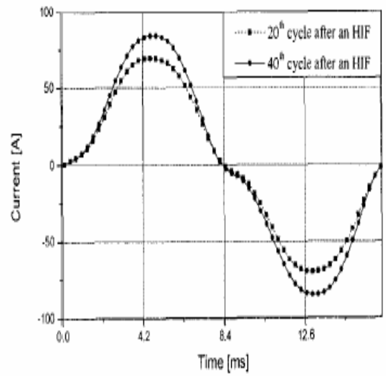

Figure 1 Current for 20^{th} and 40^{th} Cycle after HIF (asymmetry) [4]

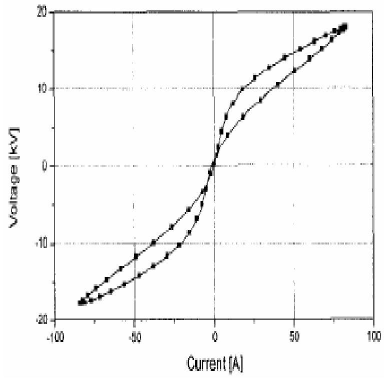

Figure 2 Voltage-current characteristic curve for one cycle in the steady state after HIF (nonlinearity) [4]

The physical process involved in the arc

By nature all gases are normally good electrical insulators, but it is well known that the application of a sufficient high electric filed may cause a breakdown of the insulating properties, after which current may be passed through the gas as an electric discharge. The term arc is usually applied only to stable or quasi-stable discharges, and arc may be regarded as the ultimate form of discharge, and it is defined as a luminous electrical discharge flowing through a gas between two electrodes. Electric discharges are commonly known from natural phenomena like sparks whose lengths can vary.
Discharges can occur not only in gases, but also in fluids or solids or in just any matter that can turn from a state of low or vanishing conductivity to a state of high conductivity, when a sufficiently strong field is applied.
According to [5-7] starting with a uniform distribution of ions when the current and voltage are zero. The increase in voltage will cause space charge sheaths to form next to the electrodes and because the mobility of the electrons is much greater than that of positive ions, most of the applied voltage will be across the space charge sheath at the anode as seen in figure 4. The current densities in this sheath are very small and in order to restrike the arc, the space charge sheath must be broken down. If there are no ionizing agents, the breakdown must be ionization by collision. It will therefore, require a minimum of several hundred volts. Under the action of electric field strength electrons are emitted from the cathode spot. These collide with neutral molecules thereby and ionizing them electrically. The ions now in the arc column fly under the effect of the field strength toward both electrodes and heat them by impact to high temperature. The negative electrons hit the anode, and the positive ions hit the cathode. In this way new electrons are liberated within the arc column and at the electrodes, and the process starts again. According to [6] the dynamic characteristics of arcs are represented in figure 5 and 6.

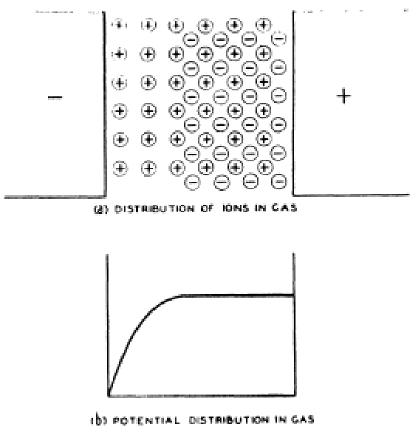

Figure 4 Ions and potential distribution in arc discharge through Gas

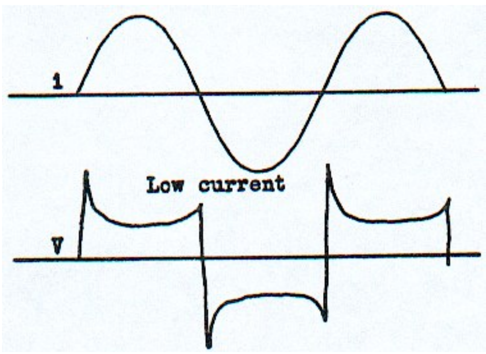

Figure 5 Voltage and current during electric arc [6]

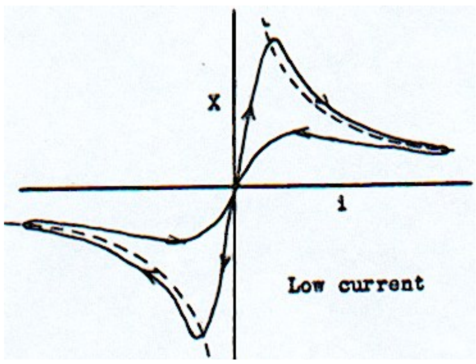

Figure 6 V-I characteristics during arc [6]

The physical process involved in the HIF arc

Arcing associated with HIF resulted in energy dissipation in the form of heat that turned the moisture in the soil into steam and burned the grass into smoke The arcing phenomenon associated with downed power lines due to the existence of air between ground and conductor, the high potential difference in such a short distance excites the appearance of the arc (it resembles anode-cathode phenomenon). It normally occurs in a largely resistive circuit, and is characterized by short arc length, small current magnitude, and could persist for a long period of time [8] The arc which penetrates the soil, has typical values of temperature at the arcing spot of the order of: 2000 to 3000 °C for metallic electrodes; 3000 to 4000 °C for carbon electrodes; and 5000 to 8000 °C in the gas column [9]. The arc heat is enough to fuse sand and silica in the soil into a glass-like substance, silicon carbide tubes. These glass-like tubes reach a length of 5 cm. They were found to have a linear resistance of the order of 2 to 100 kΩ/ m [1].

The arcing faults voltage-current characteristic and the fault current signal behavior will be a result of a complex interaction of :

- the nonlinearity of the arc and conductor-soil interface [8].
- the development of silicon carbide tubes.
- the bounce of the conductor on the ground surface.
- the heat capacity of the conductor, earth, and arc gas.
- the moisture content in the soil.
- the generation of smoke and steam.
- the movement of the soil particles.
- the ground material itself.

As for the Fault Current Behavior, It has been observed that the positive half-cycles of the current may be greater in magnitude than the negative half-cycles, or vice versa, and the fault current magnitude may vary greatly from one cycle to the other [1]

The asymmetry of the fault current in some cases could be as a result of the rectifying action exhibited by the soil. The glass-like tubes surrounding the conductor act as a hot cathodic spot that emits electrons. The voltage drop across the cathode spots is small when the conductor is positive: Fig. 5. The arc voltage in the negative half-cycle is thus larger than that at the positive half-cycle. Consequently the current conduction period, and hence its magnitude is smaller in the negative half-cycle. The amount of moisture in the soil and the packing of its particles affect the values of the arc voltage in each half-cycle. Drier soil yields higher difference in arc voltages and, therefore, a larger degree of asymmetry than wet soil. harmonics are generated on account of this asymmetry [1, 9]. The varying current magnitude could be explained as a result of arcing at the fault, which rearranges the characteristics of the air gaps surrounding the downed conductor as well as accumulation of silicon carbide tubes around the conductor

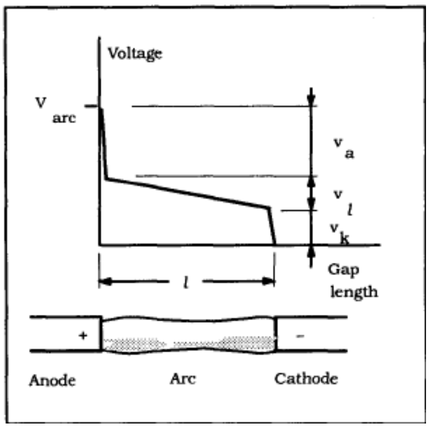

Figure 7 Voltage distributions between arc electrodes. Va:anode drop, Vk:cathode drop, Vl:arc drop

In a field test done by [1] their work presents measured values of current harmonics at a staged high impedance ground fault, and the measured low frequency spectrum is compared with current harmonics recorded continuously for one week at the substation. It has been confirmed that faults with currents above 1A have a stable arc with nearly constant rms value for long periods of time, and arc currents lower than 1A are characterized by shorter periods of stable arc current, and by random initiation and quenching of the arc. From the laboratory measurements in [1] Figure.8 shows oscillograms of currents and voltages which illustrate and validate the characteristic of large as well as for small fault currents. In Figure.9 the symmetry is also noticeable in the V-I curve of the arc as well as in the arc voltage.

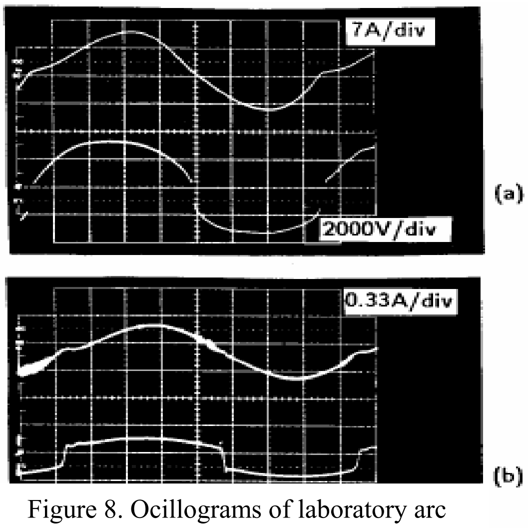

Figure 8. Ocillograms of laboratory arc currents; (a) large arc current (b) small arc current

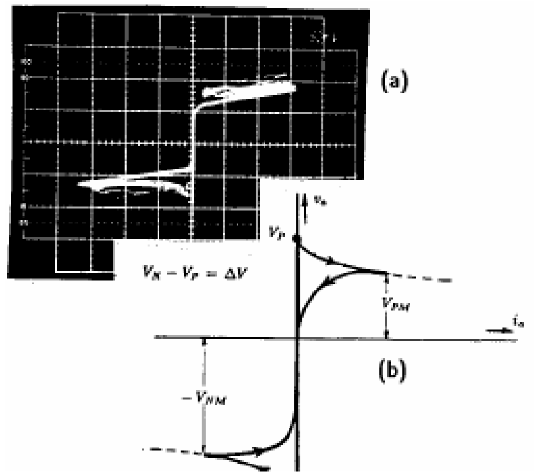

Figure 9. v-i characteristic of arc; (a) laboratory oscilligram; (b) Theoretical description.

Proposed technique to model HIF

Many authors have worked on the theory and dynamics of voltage and current in an electric arc based on laboratory study. Reference [10, 11], proposed a valid model explaining this phenomenon using spark gap. This air gap will not conduct until the applied voltage reaches the breakdown point. Then, the current flows and reaches a maximum when the applied voltage equals the arc voltage. After that, the arc current decreases and becomes zero, i.e. the arc is extinguished. When extinction occurs, the arc requires a potential known as restrike voltage to re-ignite. This re-ignition will have opposite polarity. All this procedure explains the typical voltage–current waveform of an arc shown in Figure 8. Electric models have been proposed describing arc behavior, and they have been recently gathered together by [12, 13].

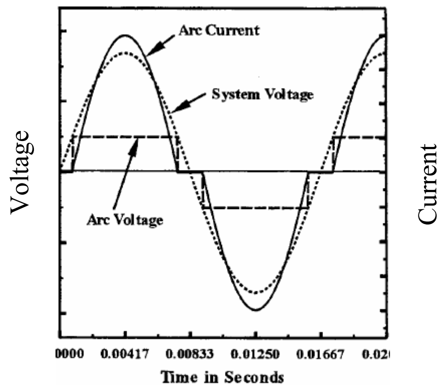

Figure 10 Electric arc voltage and current shapes

The high impedance fault model proposed by this paper includes two DC sources, Vp and Vn, which represent the *arcing voltage* of air in soil and/or between trees and the distribution line, Two resistances, Rp and Rn, between diodes represent the resistance of trees and/or the *earth resistance*, and since most observed arcs occur in highly inductive circuits [8] two Inductance, Lp and Ln were added to the circuit. The effect of the inductance gave us the nonlinearity loop shape in the V-I curve and give us the desired asymmetrical shape for the HIF current. When the line voltage is greater than the positive DC voltage Vp, the fault current starts flowing towards the ground. The fault current reverses backward from the ground when the line voltage is less than the negative DC voltage Vn. In case the line voltage is in between Vp and Vn, line voltage is counter-balanced by Vp or Vn so that no fault current flows. The typical fault current and V-I curve voltage are shown below.

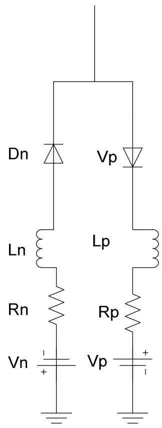

Figure. 11 Two diode fault model for HIF with Rn, Rp,Ln,L*p*

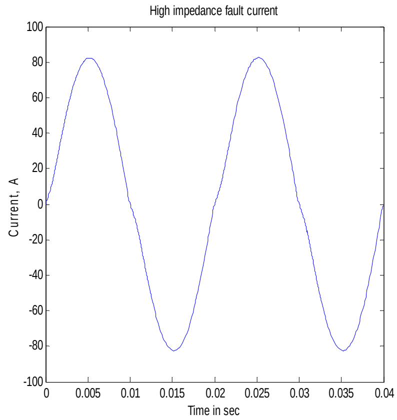

Figure. 12 Current Curve for HIF

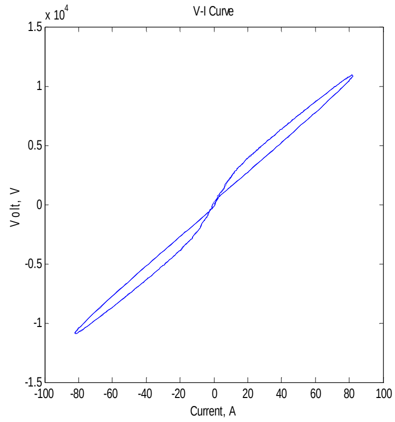

Figure. 13 Voltage-current characteristic

The harmonic content of HIF model

The primary purpose of this part is to show the harmonic content of the high impedance fault model and its current curve. This will leads us to decomposing the line current into its spectral content and studying its harmonic content. Harmonic analysis involves the use of Matlab to identify the potential harmonic and its magnitude with respect to the fundamental frequency. In our HIF model case we will be looking at the lower harmonics, starting from the 1st to the 7th. In the HIF model signal we notice the existence of the odd harmonics, and the existence of the asymmetry shape in the fundamental current. It has been observed that a phase shift for the 3rd and 5th harmonics current with respect to fundamental current has happened.

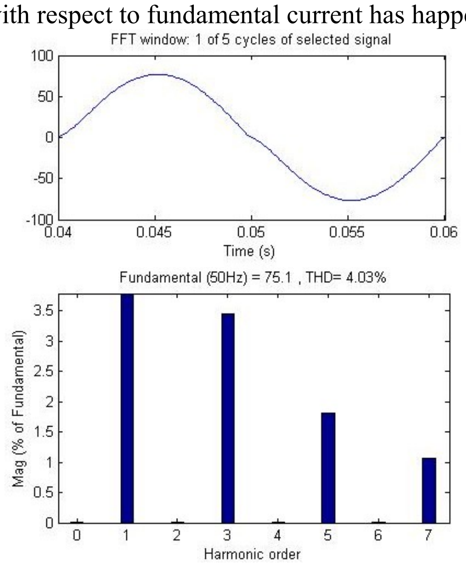

Figure 14 the HIF current and its harmonic content

Conclusion

The aim of this paper was to design a model that gives us all high impedance fault characteristics including the nonlinearity, asymmetry, harmonic content and phase shift of 3rd harmonic. The physical process involved in the arc has shown that it has a unique characteristics signature. A model for high impedance fault is proposed and tested and from the test we can see it gives us a close curves as to the physical process involved in the arc. the model has given us the unique shape of high impedance fault which volt and current, and it also has given us the harmonics content of high impedance fault and the phase shift of the 3rd harmonics. The proposed model has given us a good representation for high impedance characteristics and therefore it can be applied to generate various data necessary for developing more reliable HIF detecting algorithms.

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