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Numerical Algorithm for Distance Protection and Arcing Fault Recognitior

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Abstract - In this paper a new numerical algorithm for fault distance calculation and arcing fault recognition based on one terminal data and derived in time domain is presented. The algorithm is derived for the case of most frequent single-phase line to ground fault. The faulted phase voltage at the fault place is modeled as a serial connection of fault resistance and arc voltage. The fault distance and arc voltage amplitude are estimated using Least Error Squares Technique. The algorithm can be applied for distance protection, intelligent autoreclosure and for fault location. The results of algorithm tested through computer simulation are given.

Keywords: numerical protection, distance protection, arcing faults. autoreclosure

1. Introduction

The development of new microprocessor technology gave us an opportunity to improve the hitherto implemented techniques of power system relaying. In this respect, a few interesting approaches to calculate fault distance and at the same time to make a distinction between the transient and the permanent faults for the purpose of blocking automatic reclosing on transmission lines with permanent faults are published [1-4].

In this paper, a new numerical algorithm for fault distance estimation and arcing faults detection is presented. It is based on the fundamental differential equation describing the transients on a transmission line before, during and after the fault occurrence, and on the application of the Least Error Squares Technique for the unknown model parameter estimation. The arc voltage is involved in the line model, an improved algorithm for the distance protection and the fault location is obtained. The arc voltage is assumed to be of square wave shape, in phase with the fault arc current [1,2]. The estimated value of the arc voltage amplitude gave us an opportunity to determine which kind of fault occurred, permanent or transient fault, in order to avoid unsuccessful autoreclosures.

The new algorithm was successfully tested thr computer simulated numerous arcing and non-short circuits.

2. The Fault Model

The current path for ground faults includes the electrical arc and the tower footing resistance, what is depicted in Fig.1. The fault voltage v_F is a serial connection of the voltage drop on fault resistance R_F and arc voltage v_a so $v_F = v_a + R_F i_F$, where i_F is the fault (arc) current.

An arc is a highly nonlinear phenomenon. The arc voltage can be assumed to be of square wave shape, in phase with the arc current. and corrupted by the random noise. Thus, the faulted phase voltage becomes:

$$v_F = V_a sgn(i_F) + R_F i_F + \xi \quad (1)$$

where V_a is the arc voltage amplitude and ξ is a random noise.

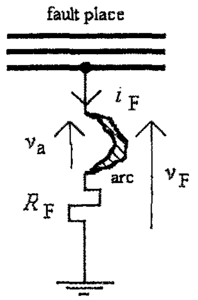

Figure 1. Fault Model

Function sgn is defined as: $sgn(x) = 1$ if $x \geq 0$ and $sgn(x) = 0$ if $x < 0$. The value of V_a can be obtained from the product of arc-voltage gradient (over the range of currents, 100 A to 20 kA, the average arc-voltage gradient lies between 12 and 15 V/cm [5]) and the length of the path, i.e. the flashover length of a suspension insulator string, or flashover length between conductors. Over the range of the arc currents from 100A to 20kA the average arc-voltage gradient lies between 1.2 and 1.5kV/m [5]

3. Algorithm Derivation

Let us consider the most frequent single-phase to ground fault on a transmission line fed from both line terminals.

For the known line per unit length resistance r and reactance x, the faulted phase voltage measured by the relay can be expressed as follows:

$$v = [r(i + K_R i_0) + \frac{x}{\omega_0}\frac{d}{dt}(i + K_L i_0)]l$$

$$+ sgn(i-i_L)V_a + (i-i_L)R_e + \varepsilon \qquad (2)$$

where: l is fault distance, i is faulted phase current, i_0 is zero sequence current measured at relay place, i_L is prefault load current, x_0 is line per unit length zero sequence reactance, r_0 is line per unit length zero sequence registance, $K_L = (x_0 - x)/x$ and $K_R = (r_0 - r)/r$ are coefficients which can be precalculated, $R_e = k_a R_F$ is an equivalent resistance, ω_0 is the fundamental angular velocity and ε is the error modeling all measuring errors and errors in modeling the transmission line and electrical arc.

Equation (2) is derived under the assumption that there exists a proportionality between the fault current and faulted phase current measured at relay point minus memorized prefault load current, i.e. $i_F = k_a(i - i_L)$, where k_a is a proportional coefficient. The value of k_a is not necessary to be known in advance.

Equation (2) requires the numerical calculation of the derivative of current (di/dt). The following approximate formula may be used for this calculation:

$$\frac{di(t)}{dt} \approx \frac{i_{n+1} - i_{n-1}}{2T} \qquad (3)$$

At one line terminal, e.g. the left one, line voltages and currents can be uniformly sampled with the preselected sampling frequency f_s and used as an input to the algorithm. A set of N voltage and N+2 current samples can be obtained.

For the k-th sample $(k = 1, \ldots, N)$, the following holds:

$$\begin{aligned} v_k &= \Big\{ r(i_k + K_R i_{0k}) \\ &\quad + \frac{x}{2T\omega_0}[i_{k+1} - i_{k-1} + K_L(i_{0(k+1)} - i_{0(k-1)})]\Big\} l \\ &\quad + sgn(i-i_L)V_a + (i-i_L)R_e + \varepsilon_k \end{aligned} \qquad (4)$$

Discrete-time equation (4) can be rewritten in the following abbreviated matrix form:

$$u_k = [a_{k1}\, a_{k2}\, a_{k3}]\,\mathbf{x} + \varepsilon_k \qquad (5)$$

where:

$$\begin{aligned} a_{k1} &= r(i_k + K_L i_{0k}) \\ &\quad + \frac{x}{2T\omega_0}[i_{k+1} - i_{k-1} + K_L(i_{0(k+1)} - i_{0(k-1)})]\Big\} \end{aligned}$$

$$a_{k2} = sgn(i - i_L)$$

and

$$a_{k3} = i - i_L$$

are timely dependent coefficients and $\mathbf{x}^T = [l, V_a, R_e]$ is the vector of unknown model parameters, to be estimated.

By writing equation (5) for all k samples, the following matrix equation is obtained:

$$\mathbf{u} = \mathbf{A}\mathbf{x} + \varepsilon \qquad (6)$$

where $\mathbf{v} = [v_1, \ldots, v_N]^T$. $\mathbf{A}$ is an $N \times 3$ coefficie matrix and $\varepsilon = [\varepsilon_1, \ldots, \varepsilon_N]^T$.

Now, the vector of unknown model parameters may be estimated by using Least Error Squares Technique, i.e. by minimizing the error vector ε:

$$\mathbf{x} = (\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T\mathbf{v} \qquad (7)$$

The algorithm presented in this paper estimates both the fault distance and the arc voltage amplitude. It provides the solution for the most frequent unsymmetrical single-phase to ground faults.

The algorithm is not sensitive to decaying DC component appearing in fault current, as well as to the changes of power system frequency, which is a drawback of algorithms developed in the spectral domain and on the application of Discrete Fourier Technique. Due to this important feature, the convergence (speed) and accuracy of the algorithm are improved.

Since the fault resistance has been also taken into account, the algorithm covers the cases of high impedance faults.

The existence of a positive arc voltage amplitude value indicates the existence of arc at the location of the fault, so such faults can be considered as transient faults. In these cases autoreclosure should operate. On the other hand, for arcless (permanent) faults this value is zero (or near zero) and in these cases autoreclosure should be blocked. Such *intelligent autoreclosure technique* can avoid reclosure onto the permanent faults and thus reduce damages on the elements of power system.

In the next Section the main results obtained through computer simulated tests will be presented.

4. Computer Simulated Tests

The tests have been done using the Electromagnetic Transient Program (EMTP) [6]. The schematic diagram of the 400 kV power system on which the tests are based is shown in Fig. 2. Here $v(t)$ and $i(t)$ are digitized voltages and currents, and D is the line length. The line parameters, calculated via line constants program were D=100km, r = 0.0325 Ω/km, x = 0.36 Ω/km, r_0 = 0.0975 Ω/km and x_0 = 1.08 Ω/km. Data for network A were: R_A = 1Ω, L_A = 0.064H, R_{A0} = 2Ω and L_A = 0.128H. Data for network B were: R_B = 0.5Ω , L_B = 0.032H, R_{B0} = 1Ω and L_B = 0.064H. The equivalent electromotive forces of networks A and B were E_A = 416kV and E_B = 3400kV, respectively. The phase angle between them was 20 degrees.

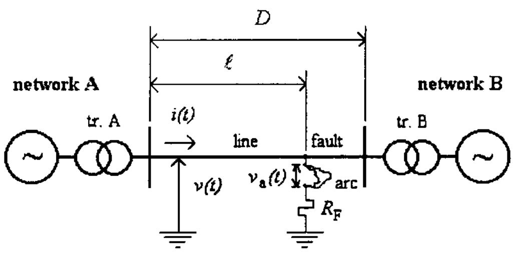

Figure 2. Test Power System

Single-phase to ground faults are simulated at different points on the transmission line. The pre-fault load was present on the line. The left line terminal voltages and currents are sampled with the sampling frequency f_s = 3840Hz. The duration of data window was equal to full cycle(T_{dw} = 16.66ms) and in second case equal to half cycle (T_{dw} = 8.33ms) of input 60Hz signal

Results obtained by processing an example of short circuit with arcing(l = 8 km, R_F = 2Ω, V_a = 3.5kV) and arc-less faults(V_a = 0 kV)will be demonstrated.

In Figs.3 and 4 voltages and currents measured by the relay before and during a single-phase line to ground arcing fault are presented, respectively. In Fig.5 estimated fault distance and estimated arc voltage amplitude for arcing and for arcless fault are presented.

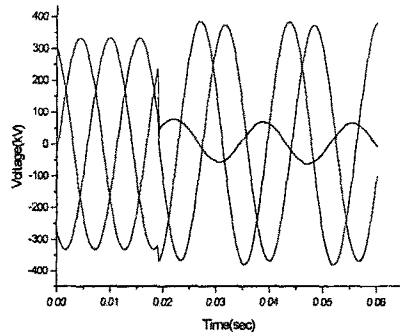

Figure 3. Input phase voltages measured by the relay

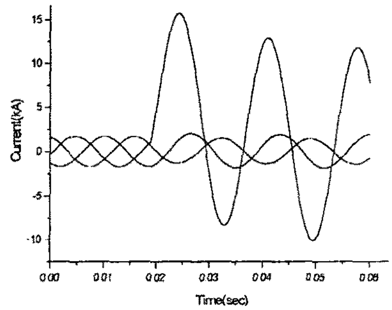

Figure 4. Input phase currents measured by the relay

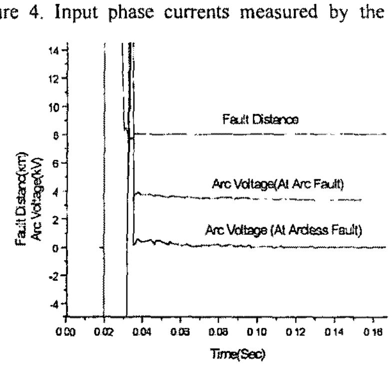

Figure 5. Estimated Fault Distance & Arc Voltage (Full-cycle window)

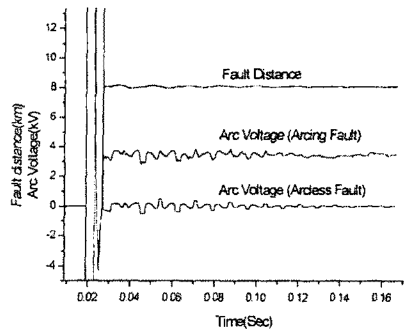

Figure 6. Estimated fault distance & arc voltage (half-cycle window)

By comparing the algorithm outputs with known shor circuit simulations input data, it was concluded that the estimated distance and arc voltage amplitude were obtained sufficiently accurate.

5. Conclusion

An efficient numerical algorithm for simultaneous estimation of the fault distance and arc voltage amplitude, as well as for blocking autoreclosure during permanent faults, is presented. The errors caused by the remote end infeed are reduced to the minimum, by using memorized prefault current. It is concluded that the algorithm is not sensitive to frequency changes and to decaying DC component existing in the fault current. The processing of data obtained through computer simulations showed that the algorithm could be applied for the protection of overhead lines.

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