ADAPTIVE DISTANCE PROTECTION BASED ON THE SYMMETRICAL COMPONENTS

Ouahdi Dris Ladjroud Rafik

e-mail: drisouahdi@hotmail.com *e-mail: rladjeroud@hotmail.com*

Boumerdes University, Faculty of Petroleum &chemistry, Department of Automatic &Electrification Engineering, Avenue de l'indépendance, 35000 Algérie

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ABSTRACT

In This paper an algorithm of fault detection with an approach which distinguishes between the faulty conditions and the effect of load flow has been developed. This algorithm is based on the negative sequence components, and it is taking into account both the effect of fault resistance and the overload situation in order to avoid the under reach and the adverse effect of load flow that cause an incorrect relay operation, and to detect the situations which can lead to the instability or even to the collapse of the system.

I. INTRODUCTION

The changing structure of the electricity supply with the emergence of independent power producers and the establishment of electrical power market may lead to an extensive exploitation of transmission lines up to their stability limit, giving rise to an overload which might have an effect on relays performance. In order to maintain the stability of the system and to ensure the continuity of the supply, the protection of transmission lines which is usually a distance protection type must be able to recognise and distinguish the situation related to a short circuit from that related to an overload. In this paper an algorithm of fault detection based on the negative sequence components is developed in order to avoid the adverse effect of load flow that causes an incorrect relay operation, and to detect the situations which can lead to the instability or even to the collapse of the system.

For technical and economical reasons, the distance protection is usually the one which is more applied to protect the transmission lines against a short circuit. Although, this protection, as compared to the other protections, used to have some disadvantages which are generally related to the design dependent on electromagnetic technology, nowadays, with the emergence of numerical and digital technology, protective relays have known a new design innovation which has brought numerous benefits in terms of performance, reliability and flexibility. With these new performances the distance protection can be conceived in such a way that it can respond to the faults and the abnormal incidents in an adaptive way, and to overcome the problems related to;

- Insensitivity to the resistant faults.
- Non-directional relay.
- Misoperation in the large overloads.

II.FAULT RESISTANCE EFFECT

Fault resistance has two components, the resistance of the arc and the resistance of the ground; in a fault between phases only the arc is involved. For a single-phase fault supplied only by one source (source S for example, Figure 1), the voltage V measured at the relay location is:

$$V = m.\ Z_{1L}.\ I_S + R_F.I_F \qquad (1)$$

Such as:

V: phase voltage (in A) at the relay location.

m: the fault distance.

Z_{1L}: positive sequence impedance of the line.

I_S: phase current (in A) at the relay location.

I_R: residual current measured from R.

R_F: fault resistance.

I_F: the total current crossing R_F is the vectorial sum of both I_S and I_R such as:

$I_S = (I_A + 3.K_0.I_0)$ and $K_0 = (Z_{0L}-Z_{1L}) / (3.Z_{1L})$.

And Z_{0L} zero sequence impedance

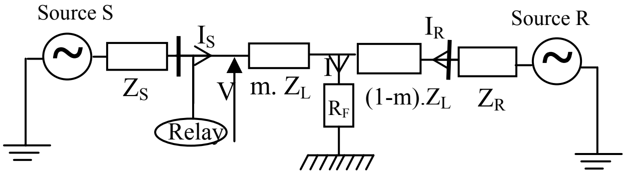

Figure 1: Line to ground fault supplied by both sides

The equation (1) can be converted into an impedance measurement as:

$$Z = \frac{V}{I} = m.Z_{L1} + R_F.\frac{I_F}{I} \qquad (2)$$

Where $I = (I_A + K_0.I_R)$.

Z includes the line impedance to the fault plus $R_F.\dfrac{I_F}{I}$.

For the radial system, $\angle I_F = \angle I$, and Z accurately measures the reactance to the fault [1].

Figure 2 shows a resistance and reactance impedance measured by the relay for this fault type. Because $R_F.\dfrac{I_F}{I}$ is all real, $\mathrm{Im}(\dfrac{V}{I})=m.|X_{1L}|$, regardless the magnitude of R_F.

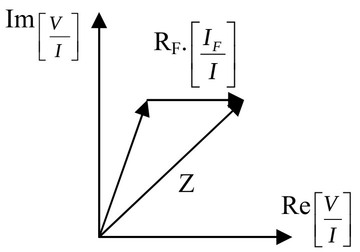

Figure2. R_F effect on the Z measurement

Thus, the use of the reactance characteristic is a better solution to overcome the problem involved in the resistive fault. If the fault is supplied only by one source, the relay measuring the reactance, cannot be induced in error related to the fault resistance (fig.2), which makes it possible to determine, with precision, the position of the fault on the line, since the reactance is proportional to the distance. On the other hand, if the fault is supplied by two sides, a measurement error can occur because of the line reactive impedance component, which causes the phase angle between the currents feeding the fault and the fault current measured by the relay($\angle I_S \neq \angle I_R \neq \angle I_F$).[1] [2] [3]

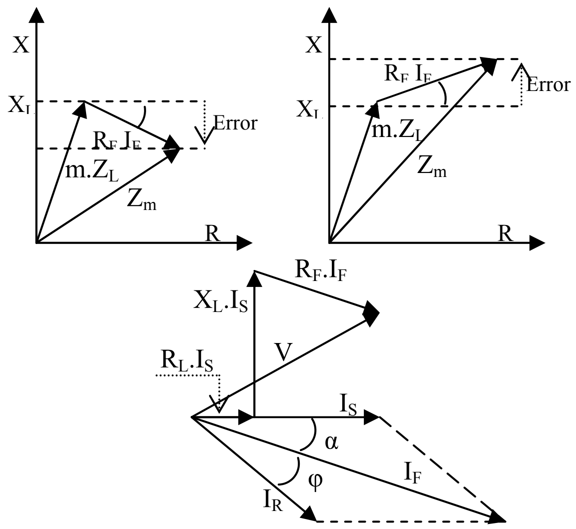

Figure3. Difference phase angle effect on the fault supplied by both sides

Figure 3 illustrates the under-reach and the overreach of the Z=V/I approach for different phase angle, the relay under-reaches for I_F leading I, and over-reaches for I_F lagging I.

III. OVERLOAD EFFECTS

In the high voltage systems, the distance relays should not include the load impedance. The traditional solution is to add the voltage constraint [4]. In an adaptive approach, the load can be supervised without interruption and when a fault occurs, and indicated by a fault detector, the load can be withdrawn in fault calculation, it's, therefore, necessary to distinguish between the faulty mode and that of the overload.

The overload is a symmetrical phenomenon. Hence no zero sequence component is present and the phase voltages and currents are symmetrical. Thus the apparent impedance; Z_r as seen by a distance relay during the overload may be written as in (3) [5]. Where, U is the line to line voltage and P and Q are the injected active and reactive powers at the location of the relay.

$$\overline{Z}_r = \frac{\overline{U}_{L1}}{\overline{I}_{L1}} = \frac{\left|\overline{U}\right|^2.(P+jQ)}{P^2+Q^2} \qquad (3)$$

In the case where Z_r is within the area of one of the pre-defined operation zones with a time duration exceeding the setting of the timer associated to this zone, the relay will operate. Low system voltages and high power flows are typical characteristics for voltage instability events. It follows from (3) that these events may cause distance relays to operate, and thus worsen the power system status which is already in a severe situation. In order to maintain the stability of the system, the voltage drop which characterizes the overload can be used as control parameter to prevent the relay operation.

IV. FAULT LOCATION

An original methodology presented by Takagi showed a way to disregard the effects of high ground fault resistance in fault location [6]. Based on this method, several other methodologies have been suggested among theme, one modified Takagi algorithm, using negative-sequence quantities have been proposed [7].

Using a single-phase arrangement of the impedances shown in Figure 1, The components of I_F are the fault currents contributed from Sources V_S and V_R, where:

$$I_F = I_{FS} + I_{FR}.$$

The component I_{FS} is related to the measured I_S current using the pre-fault (I_{SPF}) terminal current, as shown in Equation:

$$I_{FS} = I_S - I_{SPF}$$

The largest source of error in the equation (2) comes from fault resistance, which can be eliminated if both sides of the equation are multiplied by the complex conjugate of I_{FS} to get Equation;

$$V I_{FS}^* = m (Z_L I_S I_{FS}^*) + R_F (I_{FS} + I_{FR}) \quad (4)$$

Note that I_{FS} and I_{FR} have nearly the same phase [3], and if the small error resulting from this assumption can be neglected, then the term in the equation containing R_F is a real number. Therefore, if the imaginary components of the equation are isolated, we can determine the distance to the fault (m) by:

$$m = \mathrm{Im}\{V\ Ifs^*\} / \mathrm{Im}\{ZL\ Is\ Ifs^*\} \quad (5)$$

Equation (5) indicates the need to know the pre-fault current at the terminal. A modified version of this algorithm recognizes that negative-sequence currents are incremental quantities, similar to I_{FS}, where the pre-fault value is zero.

$$m = \mathrm{Im}\{V I_2^*\} / \mathrm{Im}\{Z_L I_S I_2^*\}$$

V.DIRECTIONAL ELEMENT

The directional elements are required in most applications where the lines are not radial; their objective is to indicate the direction of the power flow during a fault. The symmetrical components showed that the negative sequence network is present in all unbalanced faults, thus, the calculation of the negative-sequence impedance at the relay location allows us to determine the fault direction from the magnitude and sign of the calculated value. In Figure 4, the relay at Source S must trip for the line-to-ground fault in front of the relay at F_1 and restrain for a fault behind the relay at F_2. The negative sequence network is showed in Figure 5.

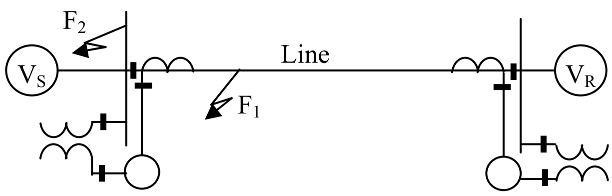

Figure 4: Forward and a reverse fault

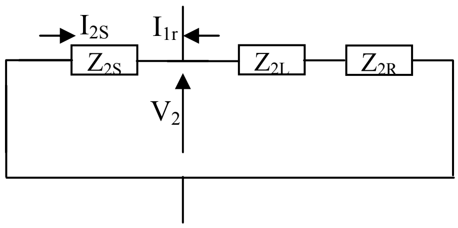

Figure 5. Negative sequence representation

Since there are no sources in the negative-sequence network, then the negative-sequence voltage V_2 is the voltage drop across the S bus source impedance Z_{2S} caused by the current I_{2S}. V_{2S} is also the voltage drop across the impedance (Z_{2L} + Z_{2R}) caused by the current I_{2R}. If the fault is in front of the relay, its voltage is $-V_{2S}$ and its current is I_{2S}. Consequently, the negative-sequence element measures the impedance ($-Z_{2S}$).

$$\frac{V_2}{I_2} = -Z_{2S} \quad (6.a)$$

However, if the fault is moved in back of the relay, the current changes abruptly to ($-I_{2R}$), and the directional element measures the impedance

$$\frac{V_2}{I_2} = +(Z_{2L} + Z_{2R}) \quad (6.b)$$

The measurement is the sum of all the impedances in front of the relay and has a positive sign. Using the sign of the V_2/I_2 measurement, a directional element can be formulated [8].

Figure 6 shows a directional element with two thresholds indicating a forward fault and a reverse fault condition. The criterion for adjustment is based on the known line impedance (Z_{1L}). For a reverse fault, the relay measures at least the line impedance. If the forward and reverse thresholds are taken close to $Z_{1L}/2$, then thresholds for the directional element are defined.

In the negative-sequence network, the angles of the impedance are highly predictable; they are basically reactance. This makes the negative-sequence directional element application simpler for all networks.

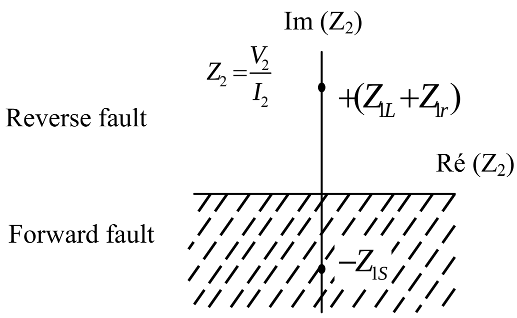

Figure 6: Negative sequence impedance for the directional element

VI. FAULT CLASSIFICATION AND PHASE SELECTION

For a single line there are 11 different types of shunt faults. Their IEC notations are: L1N, L2N, L3N, L1L2N, L2L3N, L3L1N, L1L2, L2L3, L3L1, L1L2L3, and L1L2L3N. Phase selection is primarily used to enable single pole tripping and has 7 possible outputs, namely: L1, L2, L3, L1&L2, L2&L3, L3&L1, L1&L2&L3. Fault classification plays an important role for a distance protection relay. The algorithm shall, with a high degree of probability, classify all possible realistic fault-types in order to enable single pole tripping and auto-reclosing. Knowledge about the fault type can also be used to improve reach properties of impedance zones.

Several fault classification algorithms have been presented in papers. Most of theme uses change in current and voltage, often called delta quantities, or superimposed quantities, to classify faults. [9] [10]

Since we have developed a method of unbalanced fault detection measuring the impedance "reactance" of each phase, then, this measurement can be used for the faulted phase selection and by the addition of a zero-sequence component; we can determine the fault type. This analysis can be made by using the following table:

Table 1:

Combination	Faulted Phase	Fault Type	
$X_A \le X_R + X_B \le X_R + X_C \le X_R$	A–B–C	L1L2L3 **OR** L1L2L3N	
$X_A \le X_R + X_B > X_R + X_C > X_R$	A	L1N	
$X_A > X_R + X_B \le X_R + X_C > X_R$	B	L2N	
$X_A > X_R + X_B > X_R + X_C \le X_R$	C	L3N	
$X_A \le X_R + X_B \le X_R + X_C > X_R$	A-B	$I_h > I_R$	L1L2N
		$I_h \le I_R$	L1L2
$X_A \le X_R + X_B > X_R + X_C \le X_R$	A-C	$I_h > I_R$	L1L3N
		$I_h \le I_R$	L1L3
$X_A > X_R + X_B \le X_R + X_C \le X_R$	B-C	$I_h > I_R$	L2L3N
		$I_h \le I_R$	L2L3

X_R is the reactance of adjustment.

I_R acceptable residual current

VII. RELAY ALGORITHM

The following is a description of the block functions:

Block 1: Checks if the apparent impedance is within the predefined zone.

Block 2: Checks if a resistant fault has occurred in the predefined zone.

Block 3: The directional element:

If: $\frac{V_2}{I_2} = -Z_{2S}$ Then: Forward fault

If: $\frac{V_2}{I_2} = +(Z_{2L} + Z_{2R})$ Then: Reverse fault

Block 4: Decides if a short circuit fault has occurred.
When a fault occurs ΔV/Δt will have a negative value with a high magnitude.

$\frac{\Delta V}{\Delta t} \le \frac{\Delta V}{\Delta t} f_{\max}$: A fault has occurred.

$\frac{\Delta V}{\Delta t} > \frac{\Delta V}{\Delta t} f_{\max}$: No fault has occurred.

Block 5: The timer associated to the predefined zone is started.
t_{start} = time when the predefined zone is entered.

Block 6: Decides if the fault is cleared by primary protection.
When the fault is cleared ΔV/Δt will have a positive value with a high magnitude.

$\frac{\Delta V}{\Delta t} \ge \frac{\Delta V}{\Delta t} f_{\min,\det}$: The fault has been cleared.

$\frac{\Delta V}{\Delta t} < \frac{\Delta V}{\Delta t} f_{\min,\det}$: The fault has not been cleared.

Block 7: Waits for the fault to be cleared by the primary protection.
t_{Zone} = time delay for the predefined zone to operate.

Block 8: Fault classification block.

Blocks 9 to 12 may be implemented in the algorithm when distance protection is used to protect overhead lines due to overload etc.

Block 9: Checks if the line temperature exceeds the pre-set maximum limit.
Tmax= maximum allowed temperature in the circuit.

Block 10: Timer is started for the thermal overload protection.
$t_{T,\ start}$ = time when the maximum allowed temperature is reached.
Block 11: Identical to Block 9.
Block 12: Regulates temporary overload.
$t_{T,delay}$ = time delay for the thermal overload protection to operate.

VIII. CONCLUSION

In this works, we have developed an algorithm of an adaptive impedance relay intended for the protection against short-circuits and the large overloads which occur in the electrical network, in particular the transmission lines. In order to avoid the disadvantages posed by the ordinary distance relays, we worked out this algorithm based on the symmetrical components theory to detect all unbalanced short-circuit types, and to indicate, with a certain precision, the fault location.

To prevent the operation of the relay in the overloads mode, we introduced a second test of voltage drop checking. The selectivity in this relay type is ensured by a numerical directional element based on the measurement value and the sign of the negative sequence impedance of the line. To supplement the analysis, this flow chart is equipped with a block allowing the fault classification and the faulted phase selection.

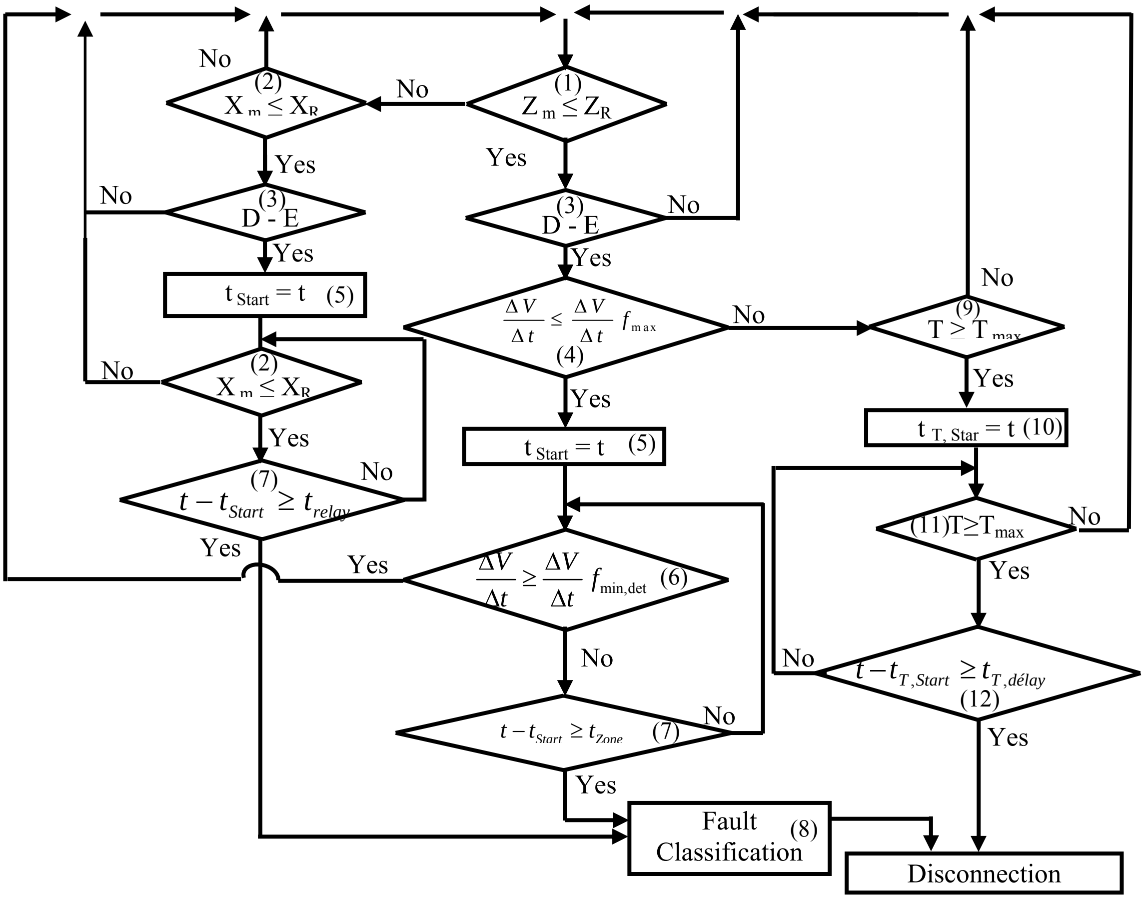

Figure 7: Relay algorithm used during abnormal operating conditions.

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