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An approach in the Improvement of the Reliability of Impedance Relay

D. Ouahdi, R. Ladjeroud, and I. Habi

***Abstract*—**The distance protection mainly the impedance relay which is considered as the main protection for transmission lines can be subjected to impedance measurement error which is, mainly, due to the fault resistance and to the power fluctuation. Thus, the impedance relay may not operate for a short circuit at the far end of the protected line (case of the under reach) or operates for a fault beyond its protected zone (case of overreach). In this paper, an approach to fault detection by a distance protection, which distinguishes between the faulty conditions and the effect of overload operation mode, has been developed. This approach is based on the symmetrical components; mainly the negative sequence, and it is taking into account both the effect of fault resistance and the overload situation which both have an effect upon the reliability of the protection in terms of dependability for the former and security for the latter.

***Keywords*—**Distance Protection, Fault Detection, negative sequence, overload, Transmission line.

I. INTRODUCTION

As the demand of electrical power grows, power systems become more complex and more difficult to manage. An essential property of any complex system is that it must continue to operate satisfactorily, even when a part of the system is subjected to random disturbance. A major objective of an electricity supply authority is to maintain continuity of supply to its customers. This is achieved by installing protection equipment capable of high speed, selective isolation of faulted sections of the power system. Rapid clearance minimizes the effect of system disturbance and provides maximum safety to the equipment and to people who may be in the vicinity of the fault. Protective relays must be capable of discriminating between healthy and faulted sections of the network, so that disruption of power supplies is kept to a minimum. For that, Distance protection systems are used in most countries of the world for the protection of high voltage transmission lines. When a fault occurs on a transmission line, it is necessary to establish the location of the fault in order to trip circuit-breakers at each end of the faulted line section, and thus isolate that section from the power system. The fault location is determined by measurement of the impedance of the faulted conductors between the relaying location and the fault. In the absence of fault resistance, this impedance is directly proportional to the corresponding "distance" from relay location to fault location. This measured impedance is influenced by a number of power system parameters and also by the fault type.

In this paper, an approach to distance protection scheme based on the negative sequence component is developed in order to avoid the undesirable effect of the load flow that causes an incorrect relay operation, and to measure the real conductor impedance.

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Rafik. Ladjroud is PhD Student, Dris Ouahdi and Idir Habi are Lecturers with the Electrical Engineering Department, Faculty of petroleum and chemistry, University of Boumerdes, Algeria.

II. IMPACT OF FAULT RESISTANCE ON FAULT LOCATION MEASURES

A fault resistance consists of two major components, arc resistance and ground resistance [1, 2]; in the phase to phase fault, only the arc is involved. [3]. the study below, shows the Impact of Fault Resistance on the Relay Measures.

A single phase line that is connected to a source at one end only and supplies no load is shown in Fig. 1, The line charging current during faults is negligible [3] and, therefore, current IS at the relay location, is equal to the current IF in the fault. The impedance seen from the relay can be mathematically expressed as:

$$Z_m = \frac{V}{I_S} = m.Z_{1L} + R_F \tag{1}$$

Such as:

V: Phase voltage at the relay location.
m: the fault distance from relay location.
Z1L: Positive sequence line impedance.
IS: Phase current flowing in the line
RF: fault resistance.
IF: the total current crossing RF.

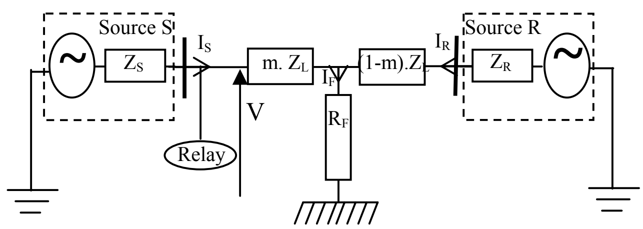

Fig. 1 Line to ground fault supplied by both sides

The fault resistance effect is shown in the R- X diagrams (Fig. 2). This figure shows that the impedance seen by the Relay is greater in magnitude than the line impedance from the relay location (at S) to fault. However, the reactive component of the apparent impedance remains equal to the reactive component of the line impedance from S to the fault.

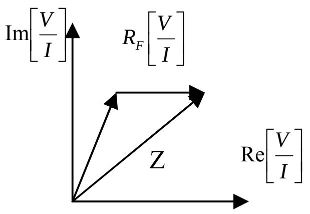

Fig. 2 R_F effect on the Z measurement

Now, if we consider that single-phase system is connected to energy sources at both terminals. The impedances measured by the distance relay can be expressed as:

$$Z = \frac{V}{I_S} = m.Z_{1L} + R_F.\frac{I_F}{I_S} \tag{2}$$

The measurement error can occur because of the line impedance reactive component and the fault current measured by the relay, which causes the phase angle between the currents feeding the fault ($\angle I_S \neq \angle I_R \neq \angle I_F$). [3] [4] [5]

Fig. 3 illustrates the under reaching and overreaching of the Z=V/I approach for different phase angle, the relay under-reaches for IF leading I, and over-reaches for IF lagging I.

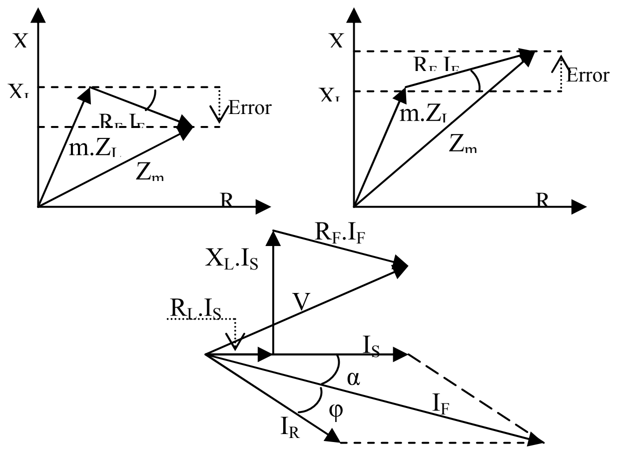

Fig. 3 Difference phase angle effect on the fault supplied by both sides

III. Overload and Voltage Instability Effects

Overload and voltage instability are phase symmetrical phenomena. Thus the apparent impedance ZR as seen by a distance relay may be written as in (3) [6]. 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.

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

Low system voltages and high power flows (reactive power increase) 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. Hence undesirable relay operations due to voltage instability will mainly be initiated by the zone with the longest reach. Normally this is the zone used for remote back-up protection; i.e. zone 3.

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 Estimation

The conventional approach for estimating the locations of transmission line shunt faults has been to measure the apparent impedance to the fault from a line terminal and to convert the reactive component of the impedance to line length. Several methods, that use the fundamental frequency voltages and currents measured at one or both line terminals, have been proposed in the past, these methods are:

1. Reactive component method. [2]
2. Takagi algorithm. [7]
3. Richards and Tan algorithm. [8]
4. Srinivasan and St-Jacques algorithm. [9]
5. Girgis algorithm. [10]

An original methodology presented by Takagi showed a way to disregard the effects of high ground fault resistance in fault location [7]. Based on this method, several other methodologies have been suggested among theme, one modified Takagi algorithm, using negative-sequence quantities have been proposed [11].

Using a single-phase scheme shown in Fig. 1, the components of IF are the fault currents contributed from Sources VS and VR, 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:

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

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;

$$VI_{FS*} = m(Z_L I_S I_{FS*}) + R_F(I_{FS} + I_{FR}) \tag{4}$$

If I_{FS} and I_{FR} have nearly the same phase [12], 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, then the distance to the fault (m) can be determined as:

$$m = \frac{\mathrm{Im}\{V.I_{FS}^{*}\}}{\mathrm{Im}\{Z_L I_S I_{FS}^{*}\}} \tag{5}$$

Equation (6) 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.

$$m = \frac{\mathrm{Im}\{V.I_2^{*}\}}{\mathrm{Im}\{Z_L I_S I_2^{*}\}} \tag{6}$$

V. Power Swing Effect

Transient instability in power systems generates power oscillations. These oscillations may cause unwanted tripping of distance relays. The brief analysis exposed bellow is taken from [13].

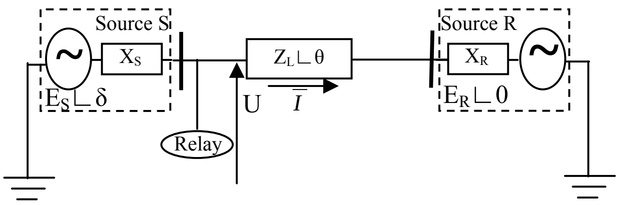

Fig. 4 Two machine system

From this figure (Fig. 4), the current and the voltage can be given as:

$$\bar{I} = \frac{E_S\angle\delta - E_R\angle 0}{jX_S + \overline{Z_L} + jX_R} \tag{7}$$

$$\overline{U} = E_S\angle\delta - jX_S.\bar{I} \tag{8}$$

$$\overline{Z_S} = \frac{\overline{U}}{\bar{I}} = \frac{E_S\angle\delta}{\bar{I}} - jX_S \tag{9}$$

During a power swing the transfer angle δ will vary. For the transfer angle δ = 0, the current $\bar{I}$ in (9) is Zero and thus Z_S is Infinite. As δ increase, Z_S moves towards and enter into operation zone.

However, to prevent these mal-trips of the distance relay, and to improve transitory stability, the amelioration of the fault critical clearing time is required. The question is how to distinguish between the symmetrical fault and the power swing.

The analysis made in [13, 14, 15] show that:

- The phase angle of the Voltage before and after the short circuit fault may considered to be the same.
- The Impedance measured by the relay changes instantaneously from a primarily resistive to primarily reactive impedance. since, the fault impedance is usually a resistance of a few ohms [16]
- The phase angle associated with the current will make a substantial change.
- For relays located at the receiving end of a transmission line the current usually will switch direction when the fault occurs and thus the phase angle will change approximately 180 degrees.

Power swings are phase symmetrical events. Accordingly the derivative of the current phase angle can be used as an additional criterion in a distance relay algorithm to distinguish symmetrical three phase faults from power swings.

VI. Relay Algorithm: (Fig. 5)

The following is a description of the block functions:

(1): Checks if an unsymmetrical resistant fault has occurred in the predefined zone.

(2): Checks if the apparent impedance is within the predefined zone.

(3): The directional element:

(4): Decides if a short circuit fault has occurred.

When a fault occurs $\frac{\Delta V}{\Delta t}$ 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.

(5): The timer associated to the predefined zone is started.

tstart = time when the predefined zone is entered.

(6): Decides if the fault is cleared by primary protection.

When the fault is cleared $\frac{\Delta V}{\Delta t}$ 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.

(7): Waits for the fault to be cleared by the primary protection.

t_{Zone} = time delay for the predefined zone to operate.

(8): Additional criterion, decides if a short circuit fault has occurred.

$\frac{\Delta\varphi_I}{\Delta t} \ge \frac{\Delta\varphi_I}{\Delta t}_{Set}$: A fault has occurred

$\frac{\Delta\varphi_I}{\Delta t} < \frac{\Delta\varphi_I}{\Delta t}_{Set}$: No fault has occurred.

(9): Fault classification block.

(10): Checks if the line temperature exceeds the pre-set maximum limit.

Tmax= maximum allowed temperature in the circuit.

(11): Timer is started for the thermal overload protection.

$t_{T,\ start}$ = time when the maximum allowed temperature is reached.

(12): Identical to Block 10.

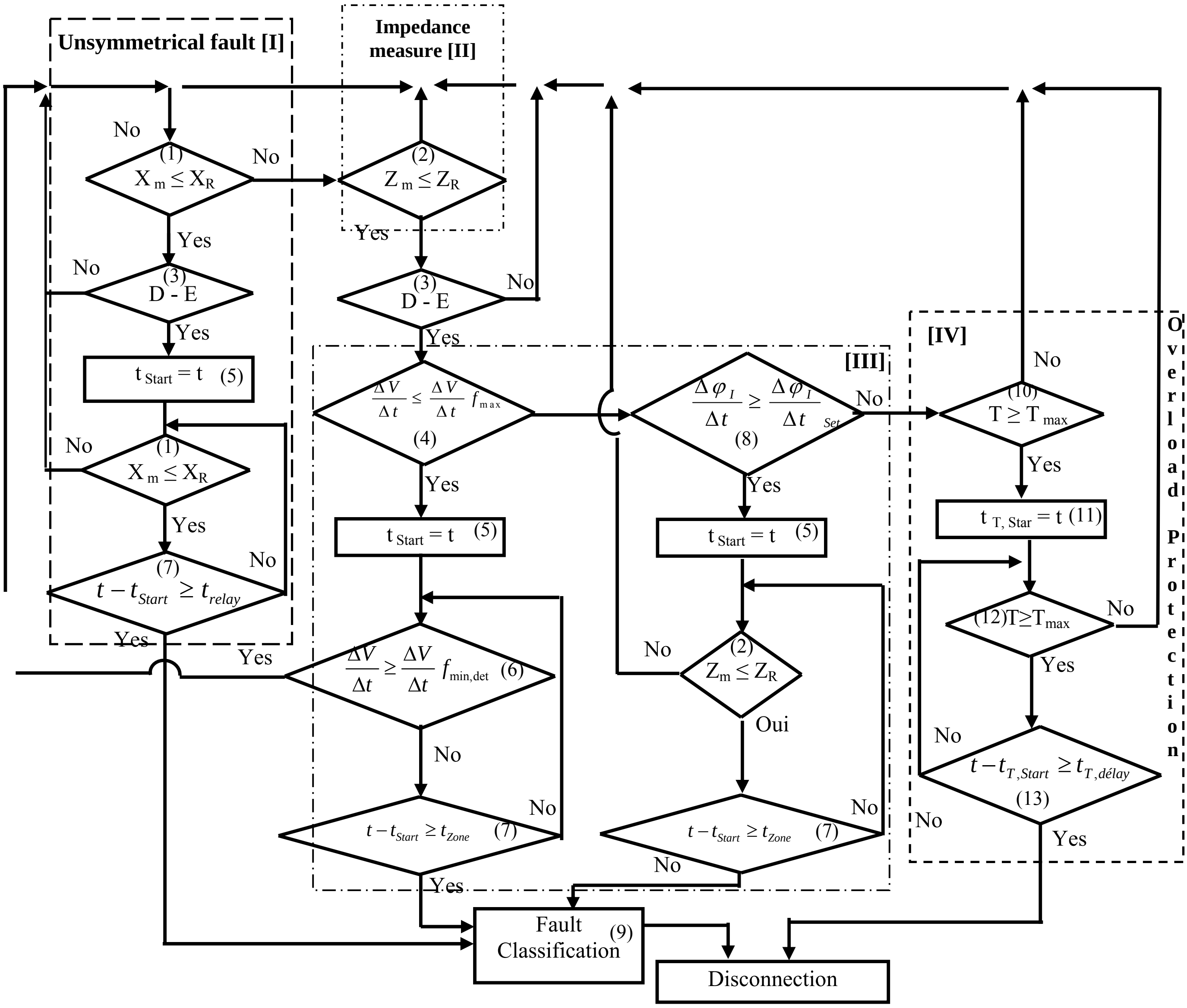

Fig. 5 Distance Relay Scheme used during abnormal operating conditions

(13): Regulates temporary overload.

$t_{T,delay}$ = time delay for the thermal overload protection to operate.

In Fig. 5, is a proposed distance relay scheme for the protection of a transmission line. This Scheme is divided into four parts; the first is intended to protect the line from the unsymmetrical short circuit fault using the negative sequence component, and estimates the distance fault. If there is no unbalanced short circuit fault, i.e. bloc (1) sends a signal to the bloc (2) in the second part, representing a traditional distance element, which tests if the apparent impedance as seen by the relay is within the operating zone, if so, then after a verification is done by the directional element, the signal passes to the third part which is intended to distinguish between the symmetrical Short-circuit faults and the other operating conditions as: voltage instability, overload and power swing.

The third part includes two testing blocks, the block (4) is based on the criterion of voltage derivation value, and for increasing degree of security, an additional block (8) is used.

VII. Conclusion

In this work, an algorithm of an impedance relay intended for the protection against short-circuits and large overloads which occur in the electrical network, in particular the transmission lines has been presented. In order to avoid the disadvantages posed by the ordinary distance relays, the algorithm is worked out based on the symmetrical components theory to detect all unbalanced short-circuit types, and to allow fault classification and the faulted phase selection with a certain precision of the fault location.

To prevent the operation of the relay in the overloads mode, a second test of voltage drop checking has been introduced. 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.

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