Locating Broken-Conductor In HV Transmission Lines

Bader A. Alkandari, Ahmad M. Al-Kandari
College of Technological Studies
Dept. Of Electrical Engineering
Kuwait

***Abstract*—This paper presents An ANN based technique for improving the performance of distance relays against open-circuit faults in transmission networks. The technique utilizes the small capacitive current measured in the open-phase plus the currents in the two healthy phases in calculating the open-circuit fault distance. The results obtained show that a distance relay with the proposed scheme will not only be able to detect the open conductor condition in HVTL but also to locate the place of this fault regardless the value of the pre-fault current loading. There is no need for especial communication schemes since the existing media could work properly for the needs of the proposed technique.**

***Keywords*—Distance relay, Open conductor, ANN, Transmission networks, fault location.**

I. Introduction

Opening a conductor in power transmission lines is one of the serious problems in the operation of power systems. This problem causes the system to operate on two phases only which badly affects system stability. It also causes many hazards to people and equipment. The transmitted power through this power transmission line will be reduced. The healthy phases may suffer from over loading. Isolators of the healthy phases will not be far from the drawbacks. The voltage upon healthy phases may increase if the system is not directly earthed.

Since open conductor is not associated with any increase in current or decrease in voltage, the measured impedance by the distance relay will not decrease in case of open conductor. In fact, the impedance measured by a distance relay on the healthy-phases increases with the occurrence of open conductor causing the distance relay to go far away from operation region.

Consequently, the case of open conductor will continue to exist until other protection scheme detects it. The protection scheme which may detect this type of fault (according to the pre-fault current value) is the earth fault relay. However, even if the line is equipped with an earth fault protection and the pre-fault current value was large enough to initiate the operation of the earth fault relay; there will be a large time delay since earth fault relays is actually a backup protection for HVTLs.

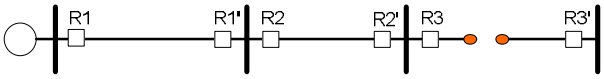


Fig. 1. Open circuit fault.

There is a lack of researches considering cases of open (downed) conductor, since most of protective relays don't respond to these types of faults. Protection engineers believe that the protective devices are not designed for open conductor fault case. Even the field experts find that no response from protective relays for case of open conductor is accepted. There aren't significant research efforts in the field of using distance relay to detect or locate the open conductor fault especially in the high voltage interconnected systems.

The only effort exerted in field of studying open conductor problems is in distribution networks [1-2]. A brief review of some open conductor fault detection techniques can be found in [3,4]. The history of the downed conductor detection is comprehensively reviewed the report of the PSRC group [5].

The objective of this paper is to modify the distance relay' algorithm to be able to estimate distance of open-circuit faults. In the next sections, the effect of open-circuit faults compared with short circuit faults is demonstrated with typical recorded case studies. The mathematical formulation of open-circuit problem and the proposed ANN-based technique are then presented.

II. Typical Problems

For an open-circuit fault occurred in a single phase of line-3 as shown in Fig. 1, the distance relays R1, R2 and R3 can easily detect such unsymmetrical fault since one of the three phases is almost zero. However, unless the settings for the three relays (as well as the settings of the associated earth fault relays) are accurately estimated, a discrimination problem between the three relays is expected and a false trip from relays R1 and R2 cannot be avoided. Usually, the open-circuit case starts with a simple problem and ends with a wide disconnected area.

III. Problem Formulation

Considering the power system shown in Fig. 2, a single-phase open-conductor fault (in *phase-a*) is assumed on line X-Y between points P and Q. The source impedances of the supplies behind the two distance relays (R_X and R_Y) are

IJSMS

represented by Z_{S-X} and Z_{S-Y}. The actual impedance between distance relay R_X and the open circuit fault place is Z_F.

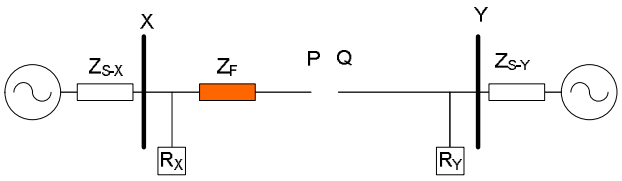


Fig. 2. System under study

The sequence voltages are given in Eq. (1):

$$\left.\begin{aligned}(V_1)_{PQ} &= \frac{1}{3}[(Va)_{PQ} + a(Vb)_{PQ} + a^2(Vc)_{PQ}]\\ (V_2)_{PQ} &= \frac{1}{3}[(Va)_{PQ} + a^2(Vb)_{PQ} + a(Vc)_{PQ}]\\ (V_0)_{PQ} &= \frac{1}{3}[(Va)_{PQ} + (Vb)_{PQ} + (Vc)_{PQ}]\end{aligned}\right\} \quad (1)$$

where $(Va)_{PQ}$, $(Vb)_{PQ}$ and $(Vc)_{PQ}$ represent the voltage drop between point P and Q in each of the three phases respectively. Since both $(Vb)_{PQ}$ and $(Vc)_{PQ}$ equal to zero, then

$$(V_1)_{PQ} = (V_2)_{PQ} = (V_0)_{PQ} = \frac{1}{3}(V_a)_{PQ} \quad (2)$$

The sequence currents can be written in terms of the sequence network impedances as follows [7]:

$$\left.\begin{aligned}I_1 &= \frac{Z_1 * I_{1PF}}{Z_1 + \left(\frac{Z_2 Z_0}{Z_2 + Z_0}\right)}\\ I_2 &= -\frac{Z_0 I_1}{Z_0 + Z_2}\\ I_0 &= -\frac{Z_2 * I_1}{Z_0 + Z_2}\end{aligned}\right\} \quad (3)$$

where I_{1PF} is the pre-fault phase current in *phase-a*.

The line impedance from the relaying point till the place of the fault in case of an open-circuit from both sides can be written as follows [7]:

$$Z_{1F} I_{1PF} = I_1 Z_{1S-X} + I_1 Z_{1F} + I_1\left(\frac{Z_0}{X+1}\right) + I_1 Z'_{1F} + I_1 Z_{1S-Y} \quad (4)$$

where

- Z_{1F} is the line impedance from the relaying point till the place of open circuit
- Z'_{1F} is the impedance of the line from the place of open circuit till the other end of the line.
- Z_{1S-X} is the positive sequence source impedance at bus X.
- Z_{1S-Y} is the positive sequence source impedance at bus Y .
- X equal to (Z_0/Z_1)

The problem is that the impedances Z_1, Z_2 and Z_0 are measured at the place of open conductor not at the relaying point, which means that they are not available for the relay and hence, it can't be used in the fault distance calculations. By rearranging Eq. (4), the positive sequence impedance Z_{1F} can be written as:

$$Z_{1F} = \frac{I_{1PF} Z_1}{I_1} + \left(\frac{Z_0}{X+1}\right) + Z'_{1F} + Z_{1S-X} + Z_{1S-Y} \quad (5)$$

Also, the zero sequence line impedance from the relaying point to the place of open circuit, Z_{0F} can be written as [7]:

$$Z_{0F} = \frac{-I_2}{I_1}\left[(Z_2 + Z_0) - (Z'_{0F} + Z_{0S-X} + Z_{0S-Y})\right] \quad (6)$$

Substituting $Z_{0F} = 3\,Z_{1F}$ and $Z'_{0F} = 3\,Z'_{1F}$, then Eq. (6) can be re-written in the form :

$$3Z_{1F} = \left(\frac{-I_2}{I_1}\right)\left[(Z_2 + Z_0) - (3Z'_{1F} + Z_{0S-X} + Z_{0S-Y})\right] \quad (7)$$

From equations (5) and (7) the positive sequence impedance from the relay point to the fault location can be written as

$$Z_{1F} = \left(\frac{I_2}{I_1 + I_2}\right)\left[Z_1\left(\frac{3I_{1PF} - I_1}{3I_1}\right) + Z_0\left(\frac{2 - X}{X+1}\right) + Z_{SX} + Z_{SY}\right] \quad (8)$$

where $Z_{SX} = [Z_{1S-X} + (1/3)\, Z_{0S-X}]$ and $Z_{SY} = [Z_{1S-Y} + (1/3)\, Z_{0S-Y}]$.

From Eq. (8), it can be seen that the line positive sequence impedance from the relaying point till the place of open conductor (Z_{1F}) is depending on the following:

- Pre- Fault loading current, I_{1PF}.
- Sequence currents I_1 and I_2.
- Source impedances at both end Z_{SX} and Z_{SY} (assumed to be constant).
- Sequence Thevinen's impedance at place of open-circuit (Z_1 and Z_0).

The last factor cannot be obtained by any distance relay since it is considered as unforeseen data. The proposed distance relay in this paper is using this equation (Eq. 8) to estimate the location of the open conductor using artificial ANN.

IV. ANN Configuration

Artificial Neural Networks (ANN) is a suitable technique to be used in this study since ANNs are prepared to work with incomplete and unforeseen data. At the same time, ANNs have a high degree of robustness and ability to learn. Different configurations (different number of hidden layers, different number of neurons in hidden layer, different transfer function for hidden and output layer(s) and different training methods) are tested in order to choose the best configuration for the proposed ANN scheme.

IJSMS

In this study, the configuration achieved minimum error goal includes two hidden layers with five neurons. The hidden layer neurons transfer function is Tansig where the output layer neuron transfer function is Puerlin. The training function was Trainscg. The MatLab is used in building and training the ANN

The values of the sequence currents versus the positive sequence impedance Z_1 are analyzed statistically to get the best formation of the training inputs .This yields the following three inputs:

$$\left.\begin{aligned} Input1 &= \left(\frac{I_{1PF}}{I_1 * I_2}\right) \\ Input2 &= \left(\frac{I_2}{I_0}\right)^2 \\ Input3 &= \left(\frac{I_1}{I_2}\right)^2 \end{aligned}\right\} \quad (9)$$

These values are the input values fed to the ANN where the output is the required positive sequence impedance of the line till the place of open conductor.

V. Simulation Results

The proposed scheme identifies the case of open conductor based on the level of current in each of the three phases. Under single phase open conductor condition, the current in one of the three phases will be below a current threshold (I_{detc}). The scheme also checks if the phase breaker is open or not (to avoid conflict with the case of segregated phase breakers). The case of open conductor is confirmed if the difference between the other two phase currents is less than an error, ε.

Different open-circuit faults were applied at different locations along the line X-Y in the power system model shown in Fig. 4. Part of the power system' specifications is presented in Table-1.

Table-2 shows a summary of test results of the proposed scheme. The maximum error recorded is less than 11%. This can be improved by training the ANN with more fault cases. The error is accepted taking into account that the ordinary distance protection is not able to even detect such kind of faults.

Table 1. Data Of Power System Model

Equipment	Data
Feeding source at side-X	2.5 GVA
Feeding source at side-X	3.05 GVA
Line length	100 km
Capacitance	3.8 x 10^{-6} F/km
Positive Sequence Reactance	0.296 Ω/km
Positive Sequence Resistance	0.04 Ω/km
Zero Sequence Reactance	0.25 Ω/km
Zero Sequence Resistance	0.95 Ω/km

Table 2. Part Of The Proposed Technique Results

Open place	*Actual Z (Ω)*	*Measured Z (Ω)*	**error %**
11%	3.25	3.22	0.92
25%	7.4	7.28	1.6
35%	10.36	10.11	2.4
45%	13.3	12.36	7.04
55%	16.28	15.16	6.8
65%	19.24	17.98	6.5
%75	22.2	22.51	-1.3
%85	25.16	26.36	-4.8

VI. Conclusions

A novel ANN based technique is proposed to improve the performance of the ordinary distance relay against open circuit faults. The maximum error in the calculated impedance is less than (7%). The results obtained show that a distance relay with the proposed scheme will not only be able to detect the open conductor condition in HVTL but also to locate the place of this fault regardless the value of the pre-fault current loading. The ANN used in the proposed scheme doesn't impose large time delay to the operation time of the distance relay as it is of simple configuration and trained off-line. There is no need for especial communication schemes as the existing media could work properly for the needs of the proposed technique.

Acknowledgement

The researchers are immensely grateful for the financial support from the Kuwait Foundation for Advancement of Science (KFAS) for supporting this project under the number 2009-1505-01.

References

[1] Eduardo Cesar Senger, "Broken Conductor Protection System Using Carrier Communication", IEEE, Transactions on Power Delivery, Vol. 15, No. 2, April 2000.

[2] D.I .Jeerings, J.R. Linders, "A Practical Protective Relay for Down-Conductor Faults", IEEE Trans. on Power Delivery, Vol. 6 , No. 2, 1991.

[3] IEEE Tutorial Course Text, "Detection of Downed Conductors on Utility Distribution Systems", 90EH0310-3-PWR, February 1990.

[4] "Downed Power Lines: Why They Can't Always Be Detected", IEEE Power Engineering Society Public Affairs Document February 1989 (Green book).

[5] "High Impedance Fault Detection Technology", report of PSRC working group D15, March 1996.

[6] ALSTOM, Technical Guide Distance Protection Relays, TG 1.1671-B, Vol. 1, pp. 441: 444.

[7] The Electricity Council, UK, Power System Protection, Volume I, 1989.

IJSMS