Ain Shams University
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Adaptive Distance Protection of a Double Circuit Line

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STATEMENT

This thesis is submitted to Ain Shams University in partial fulfillment of the requirement for the M.Sc. degree in Electrical Engineering. The included work in this thesis has been carried out by the author at the Electrical Power and machine department, Ain-Shams University. No Part of this thesis has been submitted for a degree or a qualification at other university or institute.

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ABSTRACT

Double circuit transmission lines are used more widespread as they increase the power transmission capacity and increase the reliability of the system. The classification of the fault type for various operation and switching modes on such lines using conventional techniques is difficult. The change in power systems can affect the performance of distance relays protection. In case of distance protection especially the state of parallel circuit operation depending on the power system state, a distance relay can cover from less than 50% up to far more than 100% of the total line length. The mutual magnetic coupling is one of the phenomenon affecting the precision of the distance relay.

In this thesis, an adaptive distance protection scheme of a double circuit transmission line considering the mutual magnetic coupling effect is presented. The developed distance protective relay is utilizing Artificial Intelligence (AI) technique to be adapted in both single line to ground fault (SLG) and the line to line to ground fault (LLG) in a double circuit transmission line.

An adaptive correction factor in case of single line to ground fault and line to line to ground fault for the compensation of the mutual coupling effect is verified. This is achieved using the simulation results of ATP-EMTP program before and after considering the mutual coupling effect. An Artificial Neural Network (ANN) technique is proposed in adjusting the relay decision considering the mutual coupling effect.

The adaptive protection is applied to a double circuit transmission line model and the results are satisfied.

CHAPTER TWO
POWER SYSTEM AND MUTUAL COUPLING EFFECT

2.1 GENERAL:

This chapter discusses the types of faults affecting the double circuit transmission lines, the mutual coupling effect on the D.C.T.L., also the switching modes of the line.

2.2 INTRODUCTION:

There are many types of faults affecting the T.L. such as SLG (single line to ground fault),L.L. (line to line faults),L.L.G. faults (line to line to ground fault), and L.L.L.G. fault (line to line to line to ground fault).The most popular faults in T.L. is the S.L.G. faults.

The faulted phase(s) on one circuit has an effect on the phases of the healthy circuit due to mutual coupling between the two circuits. The positive and negative sequence coupling between the two feeders is usually less than 5–7% and, hence, has negligible effect on protection. However, the zero sequence coupling can be strong and its effect cannot be ignored. The mutual impedance can be as high as 50–70% of the self-impedance. The mutual coupling particularly under earth faults, poses difficulties for conventional distance protection schemes. The protection relay may be either overreach or under reach due to the fault resistance. This coupling is not constant in nature and is dependent upon a complex interplay amongst a number of variables. Consequently, the coupled phase(s) on the healthy circuit may sometimes be wrongly diagnosed as being the faulted phase.

2.3FAULTS AFFECTING TRANSMISSION LINES:

2.3.1 S.L.G. Fault:

When a S.L.G. fault occurs, the symmetrical component representation for this fault is shown in Fig.(2.1).The voltage of the faulted phase at the measuring point is [26]:

$V= n.L.(I_a Z_1 + I_o (Z_o-Z_1)$ (2.1)

where,

I_a**:** the current of the faulted phase at the relaying point;

n: the relative fault distance;

L: the total line length;

Z_1, Z_o: the positive and zero sequence impedance of the line per unit length;

I_0: the zero sequence current of the faulted line.

$I_0 = (I_a+ I_b+ I_c)/3$

I_b, I_c: the current of phases (b)and (c) at the faulted line

The relaying current should be:

$I= (I_a + I_o. (Z_o-Z_1)/ Z_1)$ (2.2)

Thus the fault impedance seen by the relay is:

$Z_f = V / I = n.L.Z_1$ (2.3)

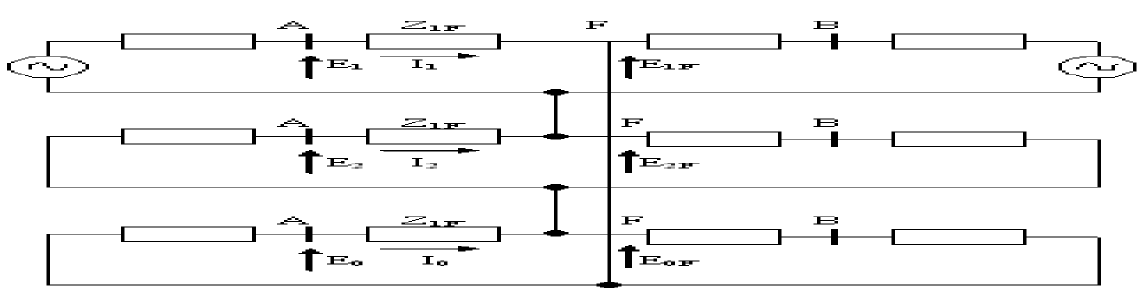

Fig.(2.1) Symmetrical components circuit for phase (a) to ground fault.

2.3.2 Phase-to-Phase Fault:

When a fault between phases (b) and (c) occurs, the symmetrical component representation for this fault is shown in Fig.(2.2).

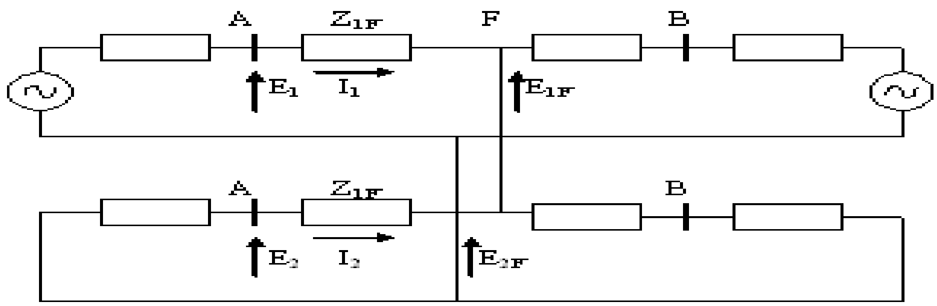

Fig.(2.2) Symmetrical components circuit for b-c fault.

The positive and negative sequence voltages at the fault bus are equal and given by:

$E_{1f} = E_{2f} = E_1 – Z_{1f}\, I_1 = E_2 – Z_{1f}\, I_2$ (2.4)

Where ;

E_1, E_2, I_1, and I_2 are the symmetrical components of voltages and currents at the relay location, and the positive and negative sequence impedance of the T.L is equal.

It follows from equation (2.4) that:

$(E_1 - E_2) / (I_1 – I_2) = Z_{1f}$ (2.5)

The phase quantities (E_b, E_c) at the relay location are given by:

$E_b = E_0 + \alpha^2 E_1 + \alpha E_2$, and $E_c = E_0 + \alpha E_1 + \alpha^2 E_2$, (2.6)

so that $(E_b - E_c) = (\alpha^2+\alpha)(E_1 - E_2)$, and $(I_b - I_c) = (\alpha^2+\alpha)(I_1 - I_2)$. (2.7)

Substituting from equation (3-8) in equation (3-6)

$[(E_b - E_c) / (I_b - I_c)] = [(E_1 - E_2) / (I_1 - I_2)] = Z_{1f}$ (2.8)

Thus, a distance relay, to which the line-to-line voltage between the phase b-c is connected, and which is supplied by the difference between the current in the two phases, will measure the positive sequence impedance (Z_{1f}) to the fault, when a fault between phases (b) and (c) occurs. Similar analysis will show that, for the other two types of phase-to-phase faults (ph-ph), when the corresponding voltage and current differences are used to energize the relays, the positive sequence impedance to the fault will be measured [3].

$[(E_a-E_b) / (I_a-I_b)] = [(E_b-E_c) / (I_b-I_c)] = [(E_c-E_a) / (I_c-I_a)] = Z_{1f}$ (2.9)

2.3.3 Three Phase Fault:

When a three phase fault occurs, the symmetrical component representation for this fault is shown in Fig.(2.3).

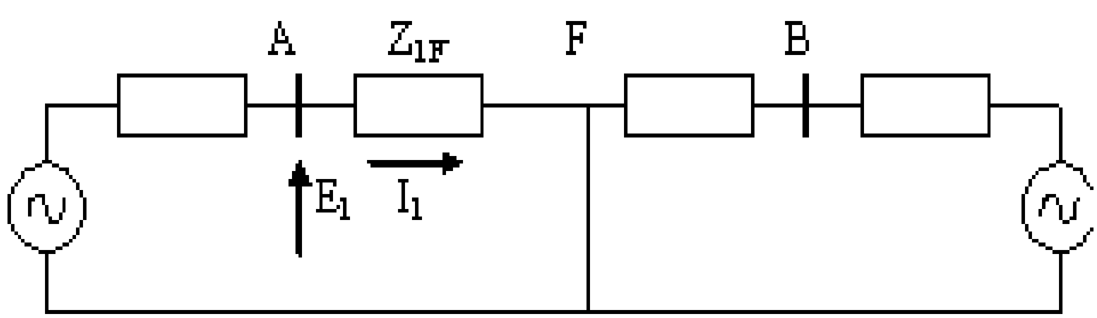

Fig.(2.3) symmetrical components circuit for L.L.L.G. fault

The positive and negative sequence voltages at the fault bus are equal and given by:

$E_1 = E_a = Z_{1f} I_1 = Z_{1f} I_a$

$E_2 = E_0 = 0$

$I_2 = I_0 = 0$ (2.17)

Also for this case,

$E_a = E_b = \alpha^2 E_1$

$E_c = \alpha E_1$, and similar relation hold for the phase current.

Consequently, for a three phase fault,

$[(E_a - E_b)/(I_a - I_b)] =$

$[(E_b - E_c) / (I_b - I_c)] =$

$[(E_c - E_a)/ (I_c - I_a)] = Z_{1f}$ (2.18)

These differences of phase voltage and current used in equation (2.18) are known as delta voltage and current. The relay energized by the delta voltage and current responds to the positive sequence impedance of a multiphase fault. A complement of three phase distance relays covers the seven multi-phase faults between them. For double phase, or double phase to ground faults, one of the three relays measures the positive sequence impedance to the fault, while, for a three phase fault(3ph-g), all three relays measure the correct impedance.

2.4 EFFECT OF FAULT RESISTANCE:

In the previous analysis, it was assumed that the fault resistance (R_f) was neglected (nearly zero). In reality for multi-phase faults, the fault arc will be between two high voltage conductors, whereas for ground faults, the fault path may consist of an electrical arc between the high voltage conductor and a grounded object such as the shield wire or the tower itself. In either case, the fault path will have a resistance in it, which may consist of an arc resistance, or an arc resistance in series with the tower footing resistance in case of a ground fault. The tower footing resistance is practically constant during the fault (and ranges between 5 ohms and 50 ohms), whereas the arc resistance changes in time as the fault current continues to flow. During the early period of the arc, in the first few milliseconds the arc resistance is negligible, and the arc channel gets elongated in time, the arc resistance increases.

The fault resistance introduces an error in the fault distance estimate, and hence may create an unreliable operation of a distance relay. The effect of fault resistance on relay operation becomes visible on R-X diagram of relay at different fault types.

The apparent impedance Z_a seen by the relay is:

$$Z_a = Z_f + R_f \cdot ((I_r/I_s) + 1) \quad (2.19)$$

I_s: the current to the fault from sending end.

I_r: the current to the fault from remote end .

If sending end current (I_s) is in phase with receiving end current (I_r), the error in the apparent impedance Z_a will be in real part only but if they are not in phase, the reactance part also is in error[4].

2.5 EFFECT OF MUTUAL COUPLING BETWEEN DOUBLE-CIRCUIT LINES:

Parallel transmission lines present unique problems to the associated line relays. The difficulty stems from the fact that the lines are mutually coupled in their zero-sequence circuits. The small amount of negative and positive sequence mutual coupling can usually be neglected. The zero-sequence coupling causes an error in the apparent impedance as calculated by equation (2.22)

When a SLG (single line to ground fault) occurs somewhere on the protected phase, the voltage of the faulty phase at the relay location is:

$$V_R = V_{Ga} = n.L.Z_1.(I_{Ga} + I_{Go}.\frac{Z_0 - Z_1}{Z_1} + I_{H0}.\frac{Z_{m0}}{Z_1}) \qquad (2.20)$$

Where;

V_R: the voltage measured by the relay;

V_{Ga}: the voltage of the faulted phase (in this case phase a of circuit G) at the relaying point;

n: the distance from the relaying point to the fault relative to the total line length;

L: the total line length;

I_{Ga}: the current of the faulty phase at the relaying point;

I_{G0}: the zero sequence current of the faulty circuit;

I_{H0}: the zero sequence current of the sound circuit.

Thus, for correct operation of the relay, and correct determination of the relative distance of the fault, the relaying current should be:

$$I_R = I_{Ga} + \frac{Z_o - Z_1}{Z_1}.\ I_{Go} + \frac{Z_{mo}}{Z_1}\ .\ I_{HO} \qquad (2.21)$$

The distance to the fault can be determined by measuring impedance that is proportional to the fault distance:

$$Z_f = \frac{V_R}{I_R} = n\,.\,L\,.\,Z_1 \qquad (2.22)$$

This relaying current requires the value of the zero sequence current of the parallel circuit. Unfortunately, measuring this current requires a high-speed communication link between the measuring equipment of both circuits, or it requires extra measuring units in the relay. Furthermore, if the parallel circuit is out of operation, the currents cannot be measured, since the measuring devices are placed between the bus and the circuit breaker. Hence, it is not possible to take into account the zero sequence current of the parallel circuit directly. Consequently, there will be an error introduced in the calculated impedance.

Nowadays, the relaying current is:

$$I_R = I_{Ga} + \frac{Z_o - Z_1}{Z_1} \cdot I_{Go} + \frac{Z_{mo}}{Z_1} \cdot I_{HO} \tag{2.23}$$

Moreover, the calculated impedance:

$$Z_f = \frac{V_R}{I_R} = n \cdot L \cdot Z_1 \cdot \left(1 + \frac{\frac{Z_{mo}}{Z_1} \cdot \frac{I_{HO}}{I_{Go}}}{\frac{I_{Ga}}{I_{Go}} + \frac{Z_o - Z_1}{Z_1}}\right) \tag{2.24}$$

$$= \alpha \cdot n \cdot L \cdot Z_1$$

α is the correction factor in the calculated impedance Z_f. This impedance is not proportional to the fault distance, since α is not constant. When α can be determined, the correct fault distance can be calculated, and the relay operates correctly. When we look at the power system model, it is possible to consider the influence of the parallel circuit mathematically. The actual influence depends on the mode of operation of the parallel circuit (Fig.(2.4)), and can be determined from the zero sequence component system.