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Adaptive distance protection of a double circuit transmission line

By

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Abstract:

The change in power systems can affect the performance of distance relays protection. In case of distance protection especially the state of double circuit operation depending on the power system state, a distance relay can cover from less than 50% up to far more than100% of the total line length. The mutual magnetic coupling is one of the phenomenon affecting the precision of the distance relay.

An adaptive distance protection scheme of a double circuit transmission line considering the mutual magnetic coupling effect is presented in this paper. The single line to ground fault (SLG) and the line to line to ground fault (LLG) in a double circuit transmission line are studied.

An adaptive correction factor in case of SLG and LLG faults for the compensation of the mutual coupling effect is suggested and calculated. It's achieved using the simulation results of ATP-EMTP program without and with considering the mutual coupling effect. The proposed adaptive protection is applied to a double circuit transmission line model and the results are reasonable.

Keywords:

Adaptive distance protection, double circuit transmission line, mutual coupling, correction factor

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1. Introduction:

Double circuit transmission lines are being used more widespread as they increase the power transmission capacity and increase the reliability of the system [1]. The classification of the fault type for various operation and switching modes on such lines using conventional techniques is difficult. 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 [2]. 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 [3].

In [3], the distance protection of a double circuit transmission line under (SLG) fault condition is formulated. To achieve correct operation, the relay does not use the measured quantities of the circuit-to-be-protected only, but also the zero sequence current of the parallel circuit. Such a relay requires extra measuring equipment and the zero sequence current of the parallel circuit cannot always be measured so a correction factor is introduced, set adaptively according to the actual power system state. In this way, the appropriate setting of the relay is provided, in relation with the actual power state.

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. The fault resistance depends upon the level of mutual coupling and/or source impedance. This coupling is not constant in nature and is dependent upon a complex interplay amongst a number of variables. As a consequence, the coupled phase(s) on the healthy circuit may sometimes be wrongly diagnosed as being the faulted phase. Although the majority of earth faults are the single phase earth type, the double line to ground fault are also considered. The conventional logical comparison techniques and linear algorithms are not well suited for such circuits. It is important to develop an alternative adaptive protection scheme for such systems [4 - 6].

In this paper SLG and LLG fault for different modes of operation of double circuit transmission line operation are studied. A correction factor has been proposed to compensate the effect of mutual coupling for relay operation improvement.

2. Distance Protection of Double Circuit Transmission Line:

Conventional distance relays have been designed for single-line distance protections [7]. When there is a single phase-to-ground fault on a single line, the measured phase impedance seen by the conventional distance relay is in proportion to the distance between the relay and the fault location. The measured impedance in phase (A) is as follows when the fault impedance is zero:

$$Z_{measured\_a} = V_{sfa} / (I_{sfa} + K_o * I_{sfo}) = mZ_{L1} \quad (1)$$

$$K_o = (Z_{Lo} - Z_{L1})/Z_{L1} \quad (2)$$

Where;

K_o	The line zero sequence current compensation factor.
Z_{Lo}, Z_{L1}	The zero and positive sequence impedance of the line respectively.
V_{sfa}, I_{sfa}	The post-fault phase voltage and current at the relay location respectively.
m	The per-unit distance between the relay and the fault location.
I_{sfo}	The post-fault zero sequence current at the relay location.

When a conventional distance relay is applied to protect a parallel line, as shown in Figure (1), errors in distance measurement will occur due to the mutual coupling between the parallel lines.

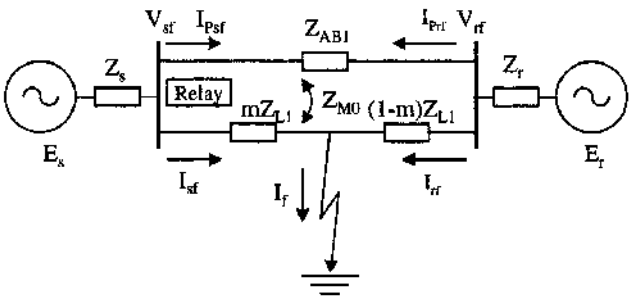

Figure (1): Typical parallel-line system.

When fault impedance is zero, the mutual coupling effect for a phase - to - ground fault can be shown as follows:

$$V_{sfa} = m_{ZL1} * (I_{sfa} + K_o * I_{sfo}) + mZ_{mo} * I_{psfo} \quad (3)$$

Where;

(Z_{mo}): The total zero sequence mutual coupling line impedance.
(I_{psfo}): The parallel line's zero sequence current.

$$Z_{m-a} = V_{sfa} / (I_{sfa} + K_o * I_{sfo}) = mZ_{L1} + \delta Z_{L1} \quad (4)$$

$$\delta = (m * (Z_{mo}/Z_{L1}) * I_{psfo}) / (I_{sfa} + K_o * I_{sfo}) \quad (5)$$

Where;

Z_{m-a}	The measured fault impedance of a distance relay using conventional zero sequence current compensation.
δ	The error in the measured impedance of the conventional distance relay.

The error may cause the relay either to overreach or under reach. It depends upon the relative direction of the parallel line's zero sequence current (I_{psfo}) versus the compensated current (I_{sfa} + K_o*I_{sfo}). If they are in opposite direction the relay will overreach other wise, it will under reach. The system impedance and line operating condition of a parallel line do not change during the normal operation. The disoperation of the conventional distance relay is caused only by the magnetic mutual coupling effect. This can be compensated by selecting proper relay settings. This could be accomplished by changing relay zone coverage setting and/or changing zero sequence compensation factor to obtaining a typical 80%–85% zone coverage corresponding to the line operating [3, 4]. The double circuit transmission line has typical 2 modes of operation which are affected by the magnetic mutual coupling as shown in Figure (2).

1- The double circuit operation as illustrated in Figure (2-a).

2- Single circuit operation (where the parallel circuit is opened and grounded from both ends) as shown in Figure (2-b).

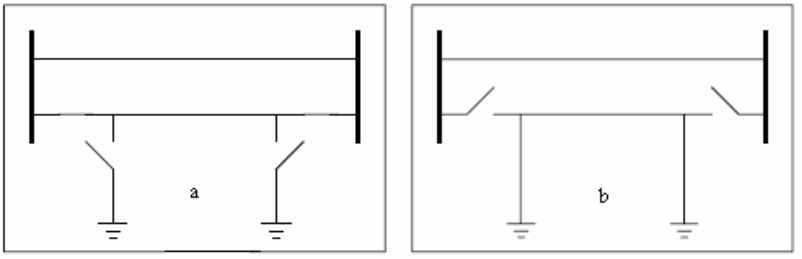

Figure (2): Double circuit transmission line switching modes.

3. Developed Adaptive Double Circuit Transmission Line Distance Protection Scheme:

In this protection scheme, each line is protected by its own relay. The three-phase voltage and current signals of the protected line are required in the adaptive relay. The scheme automatically adapts its operation based on the signal availability from the parallel lines to achieve an optimal performance by using the best available signals.

The relay will be adapted by a practical correction factor (K) which improves the relay performance.

$$K = Z_{nmc} / Z_{mc} \quad (6)$$

Where;

K The practical correction factor for the relay setting. It is the ratio between the impedance calculated before and after considering the mutual coupling effect and it's being multiplied by the relay setting impedance for its correction.

Z_{nmc} The calculated impedance for phase (a) without considering the mutual coupling effect.

Z_{mc} The calculated impedance for phase (a) on considering the mutual coupling effect.

4. Power System Network Simulation:

4.1 The studied system:

The proposed technique is applied to a studied power system. It is composed of 220 KV double-circuit transmission lines, 100 km in length, connected to a source at each end, as shown in Figure (3). All components are modeled by the ATP-EMTP toolbox. Short circuit capacity of the equivalent Thevenin sources on two sides of the line is considered to be 1.25 GVA. The transmission line is simulated using distributed parameter transposed 3 phase line (Clark's model) at frequency of 60Hz with a fault resistance of R_f =100Ω. Various double circuit transmission line parameters are shown in details in the Appendix.

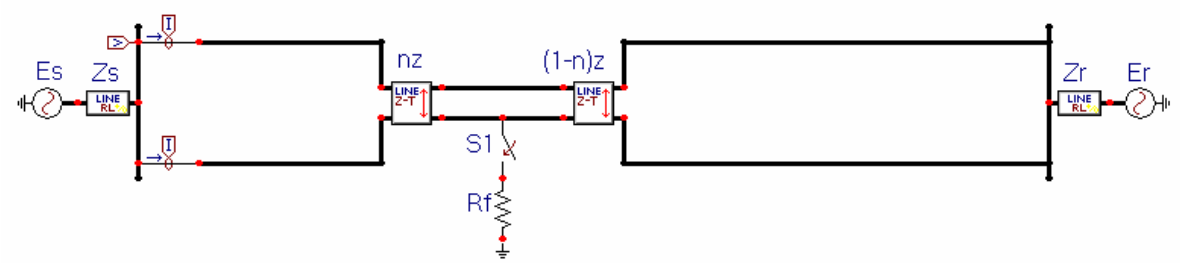

Figure (3): The studied double circuit transmission line.

4.2 ATP-EMTP simulation results:

The tested system is simulated using the ATP-EMTP program. The system is exposed to both SLG and LLG faults at different locations. The system is studied with and without considering the mutual coupling effect in each fault case.
The simulation is applied each 10 km through the whole line length of the double circuit transmission line. The samples of the simulation results are presented for both fault types at two different locations, the fault locations are selected to be at 10 km and 90 km from bus 1 (at the beginning and the end of the line). A comparison is held for the results to show the difference between considering and neglecting the mutual coupling effect in each studied case. The K factor is calculated at each fault type location.

(a) Single Line to Ground fault:

i. Double circuit operation:

- At 10 km from the sending end bus:

Samples of the simulation results for currents of phase (a), SLG fault at 10 km are illustrated at Figure (4). The three phase currents for the healthy line of the double circuit system with and without considering the mutual coupling effect are shown in Figure (4-a) and (4-b) respectively. The three phase currents for the faulted line of the double circuit system with and without considering the mutual coupling effect are shown in Figure (4-c) and (4-d) respectively.

It is observed from the simulation results that there is a slight change in the phase voltages before and after considering the mutual coupling effect when the fault occurs at 10 km. The faulted line current decreased to approximately half its value after considering the mutual coupling effect (I_{anmc}~1950A and I_{amc} ~ 950A).

- At 90 km from the sending end bus:

Simulation results samples for currents of SLG fault at 90 km are illustrated at Figure (5).

Phase (a) current for the healthy line of the double circuit system with and without considering the mutual coupling effect are shown in Figure (5-a) and (5-b) respectively.

Phase (a) current for the faulted line of the double circuit system with and without considering the mutual coupling effect are shown in Figure (5-c) and (5-d) respectively.

It is shown from the simulation figures (Figure (5)), the phase current of the faulted phase (a) changed significantly during the transient period and slightly changed at the steady state period.

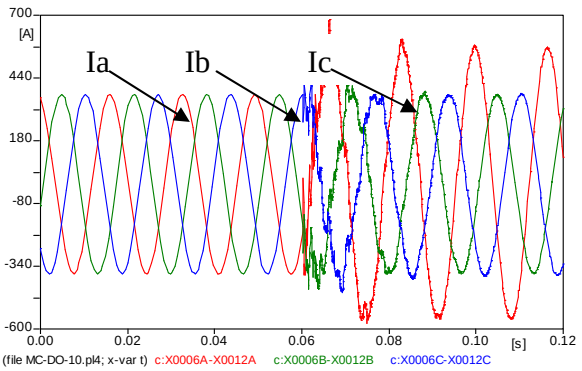

Figure (4-a): 3 phase currents of the healthy line with the mutual coupling effect.

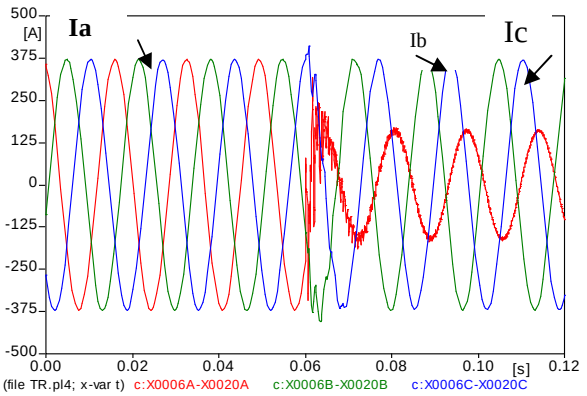

Figure (4-b): 3 phase currents of the healthy line without the mutual coupling effect.

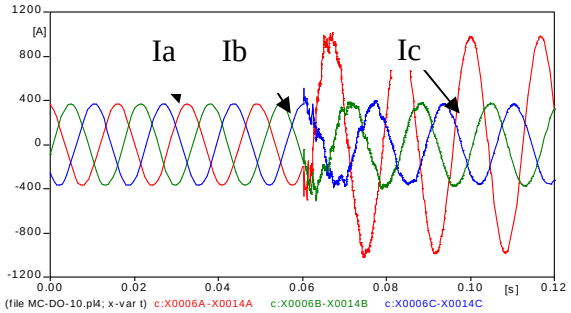

Figure (4-c): 3 phase currents of the faulted line with the mutual coupling effect.

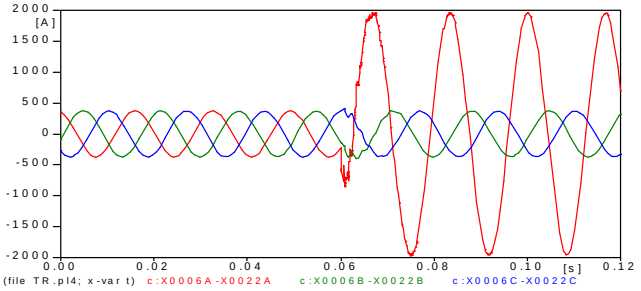

Figure (4-d): 3 phase currents of the faulted line without the mutual coupling effect.

Figure (4): Simulation results for currents of SLG fault at 10 km.

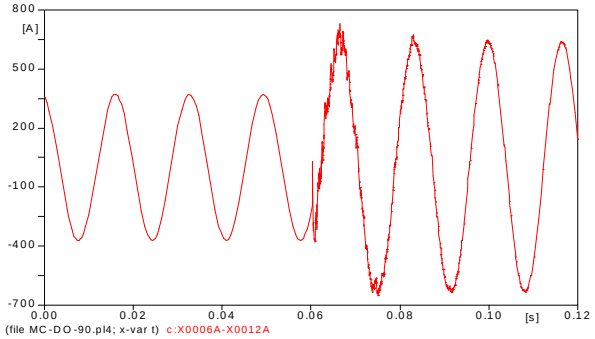

Figure (5-a): phase (a) currents of the healthy line with the mutual coupling effect.

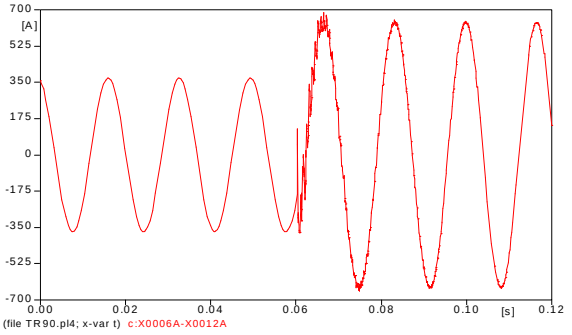

Figure (5-b): phase (a) current of the healthy line without the mutual coupling effect.

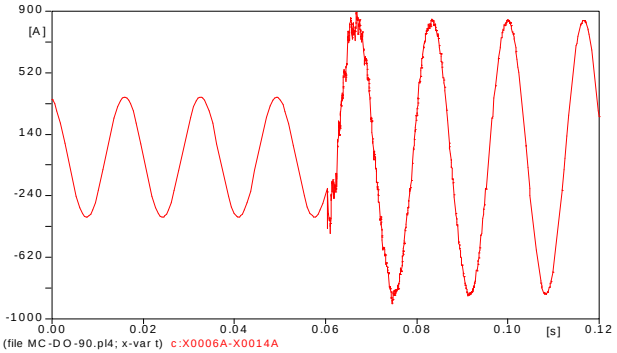

Figure (5-c): phase (a) current of the faulted line with the mutual coupling effect.

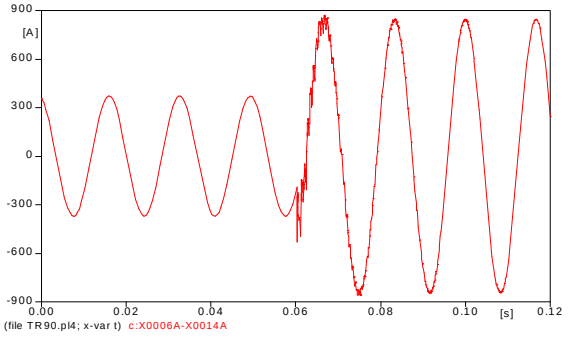

Figure (5-d): phase (a) current of the faulted line without the mutual coupling effect.

Figure (5): Simulation results for currents of SLG fault at 90 km from the sending end bus.

(ii). <u>Single circuit operation:</u>

<u>- At 10 km from the sending end bus:</u>

The simulation results for currents of SLG fault for single circuit operation at 10 km are illustrated at Figure (6). The figures are arranged and explained as in Figure (4). It is obvious that the phase voltages decreased from approximately 182KV to 173KV after considering the mutual coupling effect. The faulted line phase (a) current is slightly changed after considering the mutual coupling effect.

<u>- At 90 km from the sending end bus:</u>

Figure (7) shows the waveforms for currents of SLG fault at 90 km. The figures are arranged and illustrated as in Figure (5).
It is observed from Figure (7), the phase currents of the faulted line increased greatly from 1500A to 2500A after considering the mutual coupling effect.

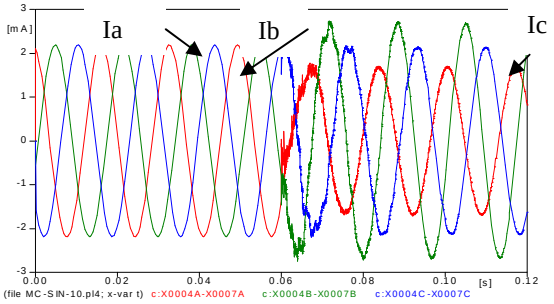

Figure (6-a): 3 phase currents of the healthy line with the mutual coupling effect.

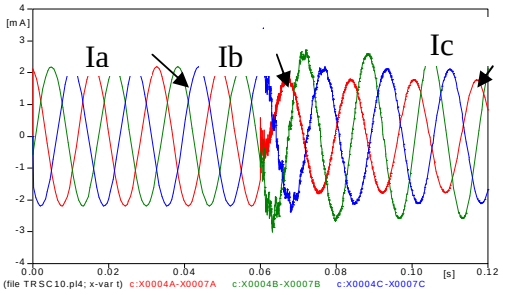

Figure (6-b): 3 phase currents of the healthy line without the mutual coupling effect.

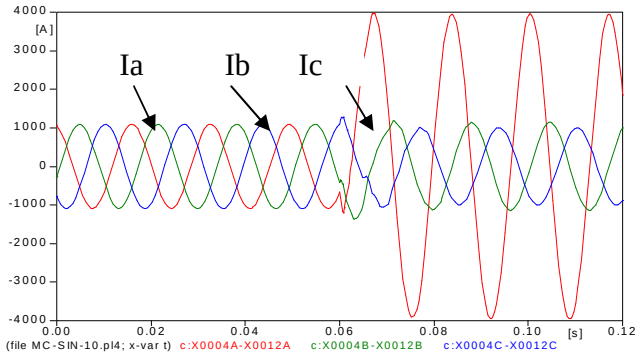

Figure (6-c): 3 phase currents of the faulted line with the mutual coupling effect.

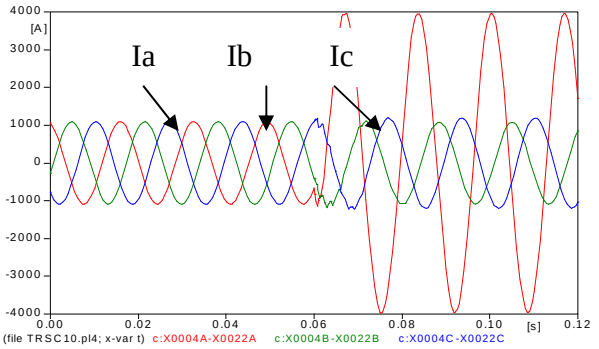

Figure (6-d): 3 phase currents of the faulted line without the mutual coupling effect.

Figure (6): Simulation results for currents of SLG fault for single circuit operation at 10 km from the sending end.

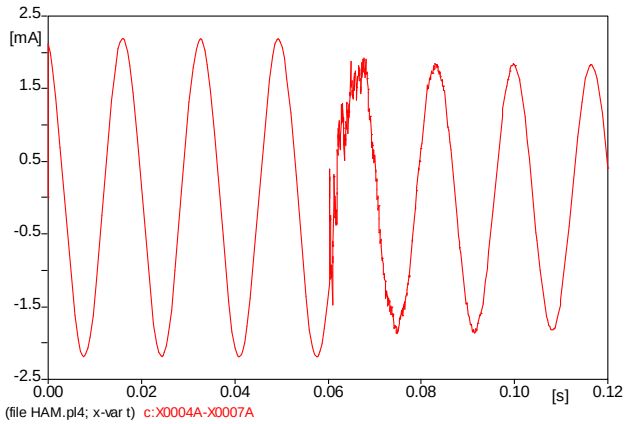

Figure (7-a): phase (a) current of the healthy line with the mutual coupling effect.

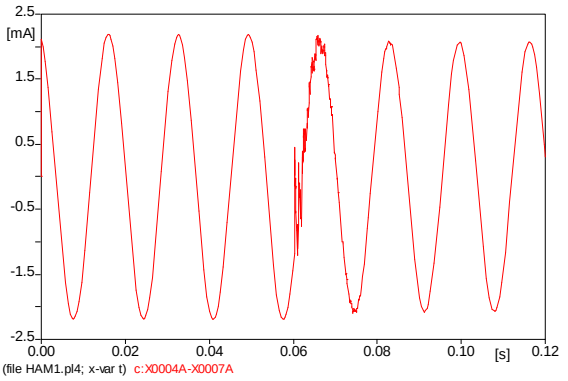

Figure (7-b): phase (a) current of the healthy line without the mutual coupling effect.

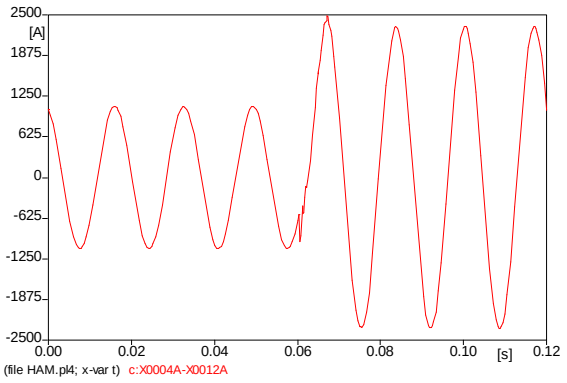

Figure (7-c): phase (a) currents of the faulted line with the mutual coupling effect.

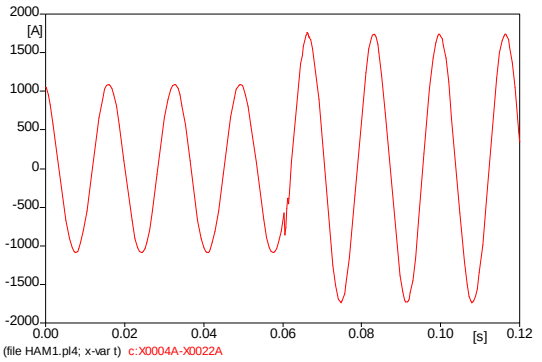

Figure (7-d): phase (a) currents of the faulted line without the mutual coupling effect.

Figure (7): Simulation results for currents of SLG fault at 90 km for single circuit operation.

(b) <u>Line to Line to Ground fault</u>

<u>(i) Double circuit operation</u>

<u>- At 10 km from the sending end bus</u>

Some of the simulation results for currents waveforms for LLG fault for double circuit operation at 10 km from the sending end bus are illustrated at Figure (8) (as explained in Figure(5)). A very slight changes in currents of both lines occurred due to mutual coupling consideration

- <u>At 90 km from the sending end bus:</u>

The group of figures in Figure (9) explains the results of the system analysis when the fault occurs at 90 km (as discussed in Figure (5)).

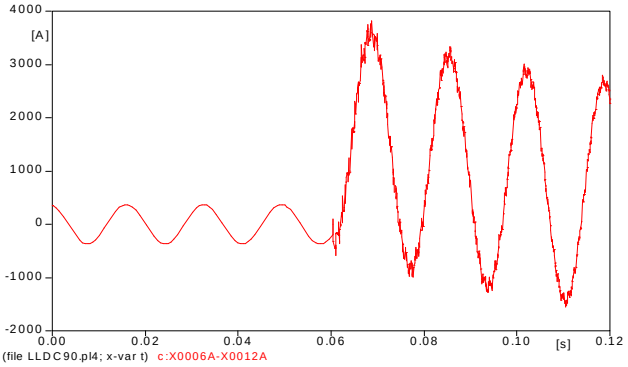

Figure (8-a): phase (a) currents of the healthy line with the mutual coupling effect.

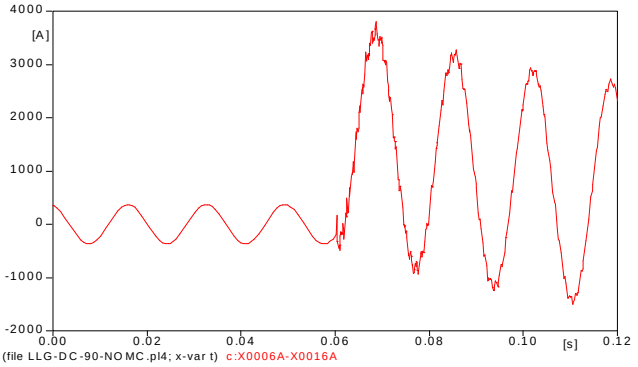

Figure (8-b): phase (a) current of the healthy line without the mutual coupling effect.

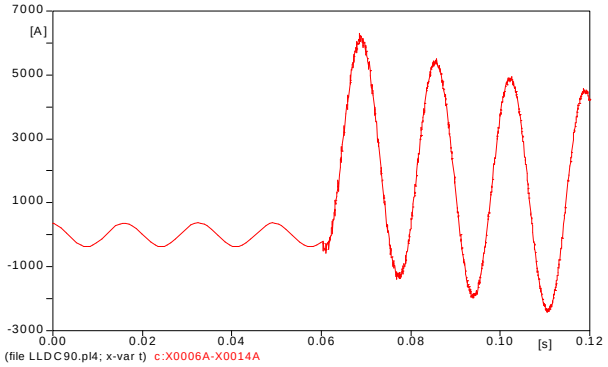

Figure (8-c): phase (a) current of the faulted line with the mutual coupling effect.

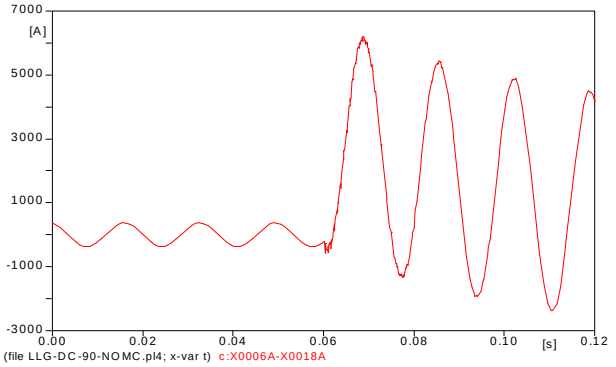

Figure (8-d): phase (a) current of the faulted line without the mutual coupling effect.

Figure (8): Simulation results for currents of LLG fault at 10 km for double circuit operation.

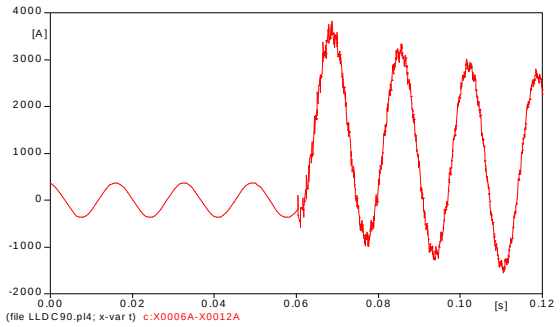

Figure (9-a): phase (a) currents of the healthy line with the mutual coupling effect.

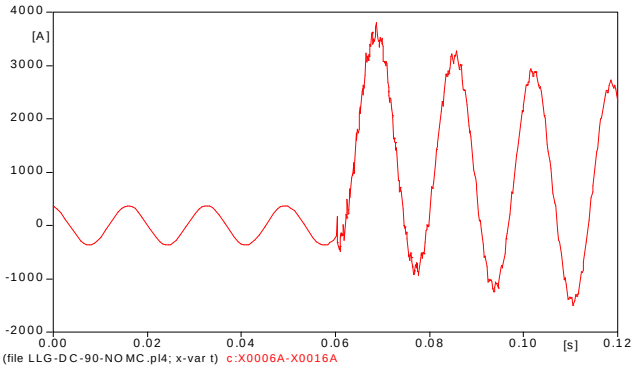

Figure (9-b): phase (a) current of the healthy line without the mutual coupling effect.

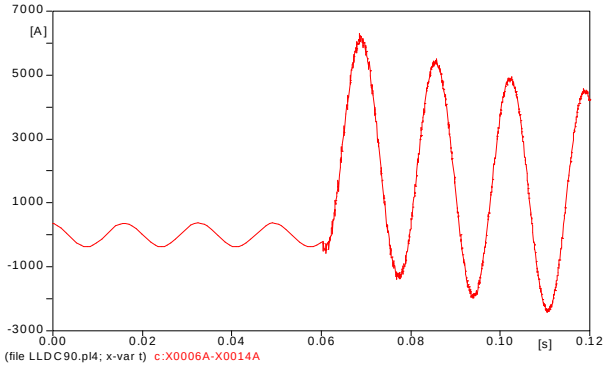

Figure (9-c): phase (a) current of the faulted line with the mutual coupling effect.

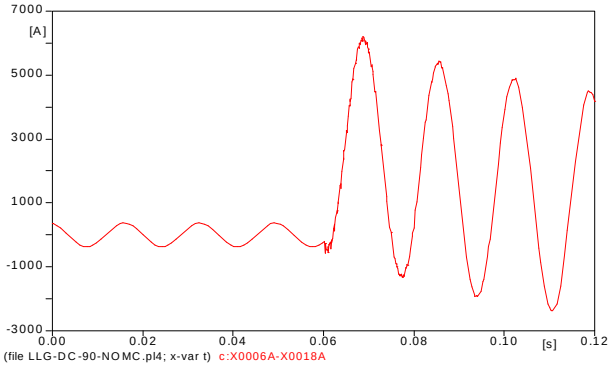

Figure (9-d): phase (a) current of the faulted line without the mutual coupling effect.

Figure (9): Simulation results for currents of LLG fault at 10 km for double circuit operation.

(ii) <u>Single circuit operation</u>

<u>- At 10 km from the sending end bus</u>

Some currents waveforms for LLG fault for single circuit operation at 10 km from the sending end bus are illustrated in Figure (10). The transient current of the healthy line varied greatly through 0.06 seconds as in Figure (10-a).

- <u>At 90 km from the sending end bus:</u>

Figure (11) shows some of the simulation results for LLG fault when fault occur at 90 km for single circuit operation (as presented in Figure (5)).

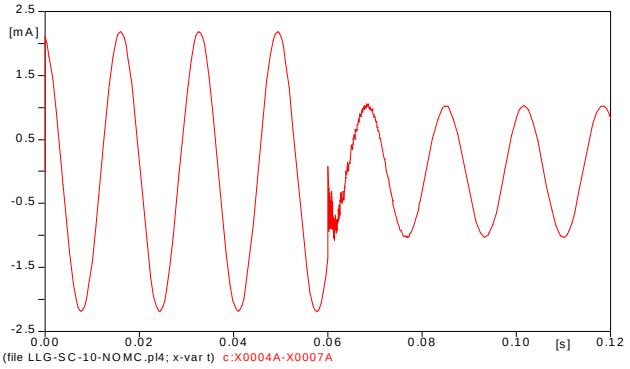

Figure (10-a): phase (a) currents of the healthy line with the mutual coupling effect.

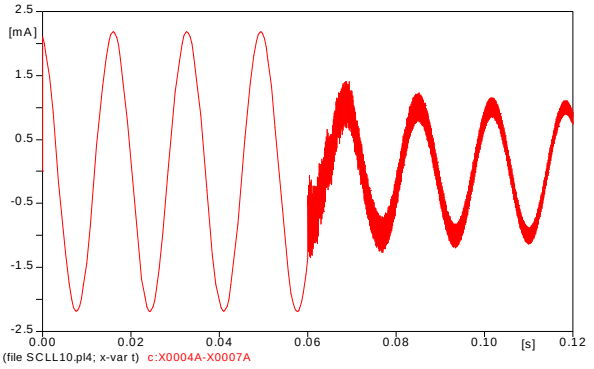

Figure (10-b): phase (a) current of the healthy line without the mutual coupling effect.

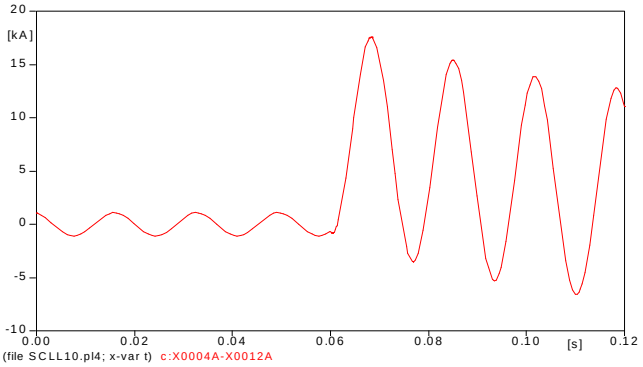

Figure (10-c): phase (a) current of the faulted line with the mutual coupling effect.

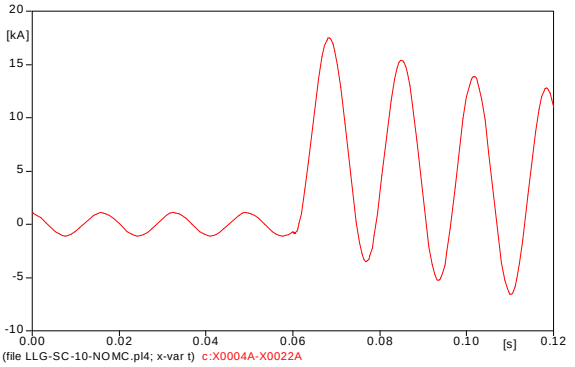

Figure (10-d): phase (a) current of the faulted line without the mutual coupling effect.

Figure (10): Simulation results for currents and voltages of LLG fault for single circuit operation at 10 km from the sending end bus.

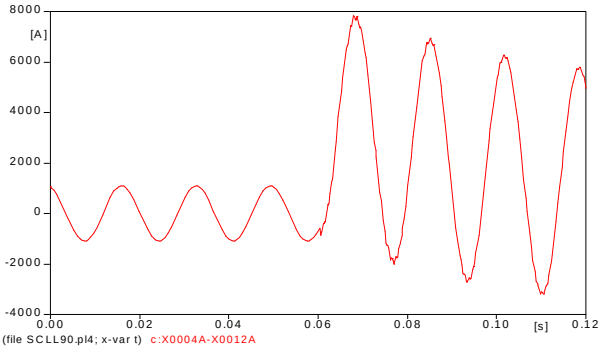

Figure (11-a): phase (a) currents of the healthy line with the mutual coupling effect.

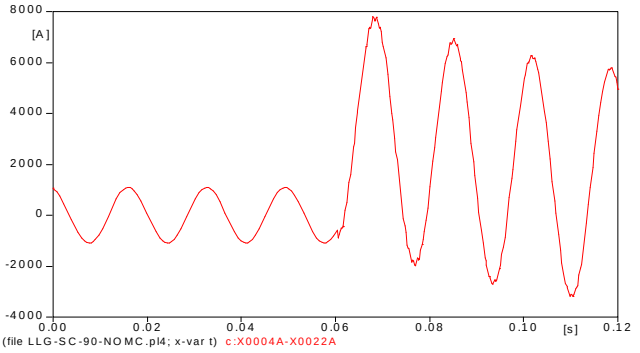

Figure (11-b): phase (a) current of the healthy line without the mutual coupling effect.

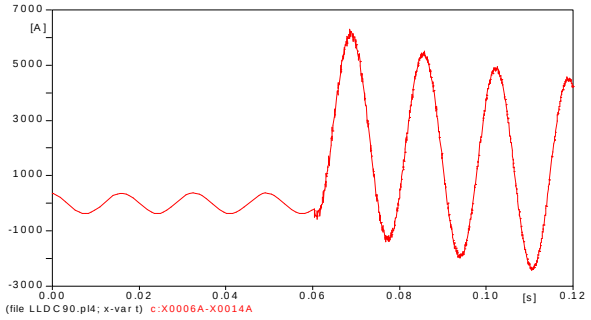

Figure (11-c): phase (a) current of the faulted line with the mutual coupling effect.

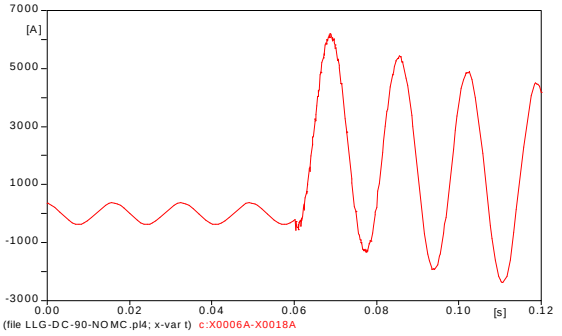

Figure (11-d): phase (a) current of the faulted line without the mutual coupling effect.

Figure (11): Simulation results for currents of LLG fault for single circuit operation when fault occur at 90 km for double circuit operation.

4.3 K Factor Calculation:

The K factor is calculated from the simulation parameters. The results are tabulated in Table (1), which shows the K factor for SLG fault at double circuit and single circuit operation modes. Table (2) illustrates the K factor for LLG fault for both modes of operation.

The correction factor (K) which presents the ratio between the relay impedance without and with considering the mutual coupling effect is introduced to adapt the relay setting to respond accurately to power system faults.

Table (1): The K factor for SLG fault

K factor (double circuit operation)	**K factor (single circuit operation)**
0.4951919	1.047693426
0.999089687	1.038199655
1.001295554	1.033145302
1.000613402	1.020680187
1.000012537	1.005095538
1.002264514	1.001402293
0.999416889	0.997119646
1.001445239	0.996015049
0.997894731	0.975719063

Table (2): The K factor for LLG fault

K_{adc}	K_{bdc}	K_{asc}	K_{bsc}
1.000278	1.000631	1.026855	1.004173
0.99876	1.000874	1.027629	1.001
1.000599	1.001392	1.024844	1.000813
1.000317	1.000761	1.021262	1.001188
1.0005	1.00134	1.017225	0.999856
1.000051	1.000584	1.013608	1.000118
1.000234	1.000527	1.009981	1.000384
1.000461	1.001068	1.005872	1.001069
1.000155	1.000391	1.001993	1.002245

K_{adc} The K factor for the faulted phase (a) in case of double circuit operation.
K_{bdc} The K factor for the faulted phase (b) in case of double circuit operation.
K_{asc} The K factor for the faulted phase (a) in case of single circuit operation.
K_{bsc} The K factor for the faulted phase (b) in case of single circuit operation.

5. Conclusion:

The mutual magnetic coupling has a great effect on the distance relay setting and operation in case of ground faults for the double circuit transmission line. Adaptive protection offers an approach to cope with the influence caused by the variable power system conditions. In this paper an adaptive distance protection technique is proposed considering the mutual coupling effect in double circuit transmission line. By adapting the relay setting, the relay responds accurately to power system faults. The adaptation mechanism has to determine the appropriate relay setting based on the actual power system readings. A practical correction factor (K) which presents the ratio between the relay impedance without and with considering the mutual coupling effect is introduced.
First the power system is simulated using ATP-EMTP program. Then, the results of the power system simulation with and without considering the mutual coupling is handled, analyzed, and processed. Then, the (K) factor is calculated.
The presented approach is applied on a 220 KV double circuit transmission line. The adaptive correction factor is calculated in case of SLG and LLG faults for different modes of operation of the double circuit transmission line. The correction factor has been proposed to compensate the effect of mutual coupling for relay operation improvement. The results are achieved and presented.

Appendix:

Positive sequence resistance R_1,Ω/km	=	0.01809
Zero sequence resistance R_0,Ω/km	=	0.2188
Zero sequence mutual resistanceR_0m, Ω/km	=	0.20052
Positive sequence inductance L_1,H/km	=	0.00092974
Zero sequence mutual inductanceL_0m, H/km	=	0.0020802
Zero sequence inductance L_0,H/KM	=	0.00092974
Positive sequence capacitance C_1,F/km	=	1.2571e-008
Zero sequence capacitance C_0,F/km	=	7.8555e-009
Zero sequence mutual capacitanceC_0m, F/km	=	2.0444e-009
Source to line impedance ratio	=	0.5
X/R	=	10

6. References:

[1] P. G. McLaren , I. Fernando, H. Liu, E. Dirks, and G.W. Swift, "Enhanced Double Circuit Line Protection", IEEE Transactions on Power Delivery, Vol. 12, No. 3, July 1997, pp. 1100-1108.

[2] Srdjan Skok, Sejid Tesnjak, and Niksa Vrkic, "Double Circuit Adaptive Protection Considering Different Operation and Switching Modes", IEEE PES Power Systems Conference and Exposition, October 2004, pp. 613-617.
[3] A. G. Jongepier and L .Van der Sluis, "Adaptive Distance Protection of Double – Circuit Line", IEEE Transactions on power delivery, Vol. 9, No. 3, July 1994, pp. 1289-1297.
[4] A. G. Phadke and S. H. Horowitz, "Adaptive Relaying", IEEE Computer Applications in Power, Vol. 3, No. 3, July 1990, pp. 47-51.
[5] Yi Hu, Damir Novosel, Murari Mohan Saha, and Volker Leitloff, "Adaptive scheme for parallel line distance protection", IEEE Transactions on Power Delivery, Vol. 17, No. 1, January 2002, pp. 105-110.
[6] S. G. Srivani, Chandrasekhar Reddy Atla and K. P. Vittal, "Comparative Evaluation of Adaptive and Conventional Distance Relay for Parallel Transmission Line with Mutual Coupling", Proceedings of world academy of Science, Engineering and Technology, Vol. 32, August 2008, pp. 542-548.
[7] M. Kezunoic, "A survey of Neural Net Application to Protective Relaying and Fault Analysis", Engineering Intelligent Systems, Vol. 5, No. 4, December 1997, pp. 185-192.

Nomenclatures:

K_o	The line zero sequence current compensation factor.
Z_{Lo}, Z_{L1}	The zero and positive sequence impedance of the line respectively.
V_{sfa}, I_{sfa}	The post-fault phase voltage and current at the relay location respectively.
m	The per-unit distance between the relay and the fault location.
I_{sfo}	The post-fault zero sequence current at the relay location.

(Z_{mo}): The total zero sequence mutual coupling line impedance.
(I_{psfo}): The parallel line's zero sequence current.

Z_{m-a}	The measured fault impedance of a distance relay using conventional zero sequence current compensation.
δ	The error in the measured impedance of the conventional distance relay.
K	The practical correction factor for the relay setting. It is the ratio between the impedance calculated before and after considering the mutual coupling effect and it's being multiplied by the relay setting impedance for its correction.
Z_{nmc}	The calculated impedance for phase (a) without considering the mutual coupling effect.
Z_{mc}	The calculated impedance for phase (a) on considering the mutual coupling effect.