Analysis of Differential Protection Response for Cross-Country Faults in Transmission Lines

Krzysztof Solak
Institute of Electrical Power Engineering
Wroclaw University of Wroclaw, WUT
Wroclaw, Poland
krzysztof.solak@pwr.wroc.pl

Waldemar Rebizant
Institute of Electrical Power Engineering
Wroclaw University of Wroclaw, WUT
Wroclaw, Poland
waldemar.rebizant@pwr.wroc.pl

Abstract—**This paper studies impact of cross-country faults in double-circuit lines on current differential relay. The protection in case of double-circuit lines should trip faults only in protected zone and not overreact for outside disturbances. The problem is when cross-country faults occur, which means that fault is incepted in the protected zone and also outside at the same time or after short break. For such a situation the differential protection may trip external faults incorrectly or may not trip internal faults. This situation should be analyzed and suggestions for protection improvement proposed. Signals for tests originated from ATP-EMTP simulations.**

Index Terms*—*ATP-EMTP simulation; cross-country fault; current differential protection; double-circuit transmission line;

I. INTRODUCTION

Current differential criterion is used with success to protect various elements in power systems, i.e. power transformers, generators, busbars and transmission lines. The basic operating principle of this criterion is to compare currents flowing into the object with the currents flowing out of the object at the other end(-s) [1, 2, 3].

Differential protection is a commonly accepted protection of single and parallel transmission lines, if only appropriate communication link connecting all line terminals is available. In standard solutions the stabilized characteristic (Fig.1) is used and the trajectory of differential/bias currents is tracked with respect to the relay characteristic to determine whether or not to trip the transmission line [2].

The standard differential relay percentage characteristic is determined by four protection settings, [2]: I_{d0}=0.3 I_n, I_{s2}=2I_n, k_1=0.3 and k_2=1.5, (I_n – load current of line). The tripping is initiated if:

$$\left|I_d\right| \geq I_{op} = k_1 \cdot \left|I_{st}\right| + I_{d0} \quad \text{for} \quad \left|I_{st}\right| \leq I_{s2} \tag{1}$$

$$\left|I_d\right| \geq I_{op} = k_2 \cdot \left|I_{st}\right| - (k_2 - k_1) \cdot I_{s2} + I_{d0} \quad \text{for} \quad \left|I_{st}\right| \geq I_{s2} \tag{2}$$

where

$$I_d = \left|\underline{i}_A + \underline{i}_B\right| \qquad I_{bias} = \frac{\left|\underline{i}_A\right| + \left|\underline{i}_B\right|}{2} \tag{3}$$

where: $\underline{i}_A$ and $\underline{i}_B$ being currents measured at line terminals, I_{bias} – amplitude of bias current, I_d – amplitude of differential current, I_{op} – relay operating current.

The zone of action of differential relay embraces only protected object which means that differential relay should trip internal faults and block all external faults. This is the main requirement differential protection must meet. The majority of external faults are usually not a big problem for the differential relay but sometimes, when external faults occur with severe CT saturation due to decaying DC in fault currents with long time constant it may lead to unwanted tripping. Generally, CT errors due to saturation should be compensated for by conventional stabilized characteristic with adequate slope setting. However, when there is a mismatch in CTs' load or they have non-identical magnetizing characteristics, a possibility still exists that one of the CTs may saturate and not the other, which may lead to unwanted protection reaction [4].

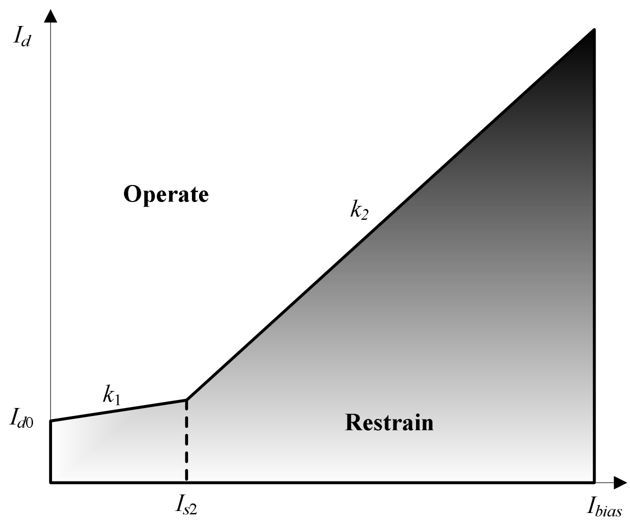

Figure 1. Stabilized characteristic of the current differential relay

A cross-country fault is another situation for which the differential protection can unnecessarily switch off protected transmission line (especially for double-circuit line). This disturbance can be defined as a fault possibly involving different phases and occurring at two different locations in power system. In this case differential protection must trip only for fault in the protected zone, but sometimes it may not trip internal faults or trip external faults incorrectly [5].

The following sections of this paper demonstrate how differential protection may response for cross-country faults. In Section 2, the ATP-EMTP model of the power system with HV parallel transmission line is described. Next (Section 3), the results of testing of current differential protection for three cases of cross-country fault are presented. Lastly, Section 4 presents the conclusions of this work.

II. ATP-EMTP Simulations Studies

To obtain the data for investigation of transmission line differential protection the ATP-EMTP model corresponding to the system shown in Figure 2 has been developed.

The overhead transmission line is modeled as transposed one with distributed parameters and mutual coupling effect taken into consideration. The line of 50 (300)km length can be divided into two sections ($d_{1(2)}$ and 1-$d_{1(2)}$, where d is length in pu), so that internal faults at almost arbitral location along the line can be simulated. The protected line is supplied from both sides, where the sending equivalent system *A* is assumed to be strong (of high short-circuit power), whereas the receiving one (*B*) is weak. The power flow can be controlled by variable angle of the receiving source, which corresponds to power flow of max 690MVA in positive or negative direction (positive direction is from the sending to the receiving terminal).

The transient response of CTs and the correct models in ATP-EMTP simulation are very important in the evaluation of high-speed relaying systems [6]. The CTs 5P30 20VA 1000/1A were modeled in ATP-EMTP using the TYPE-96 pseudo-nonlinear element. In this model there is a possibility to set the residual flux in the CT core, which is very important for studying CT saturation effects [6].

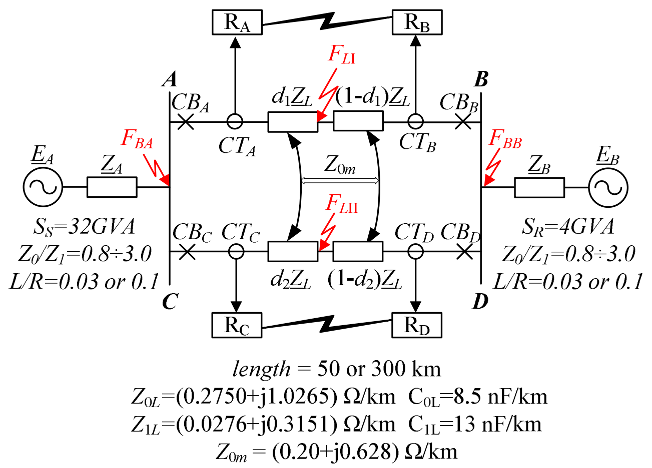

Figure 2. Model of the power system with 400kV parallel transmission line

Thorough studies have been performed by varying the 400kV power system parameters, which resulted in over 100000 different simulation cases. The parameters being changed were: length of line, fault location, systems strength, fault type, fault resistance, point on wave, residual flux, etc.

The data generated in ATP-EMTP was transferred to MATLAB, with the sampling frequency of 1600 Hz (32 samples per cycle under 50Hz system frequency). The main criteria signals (differential current I_d, bias current I_{bias},) were calculated with use of full cycle Fourier filters.

The first case of a cross-country fault is depicted in Figures 3 and Figure 4. First a *L*2-*G* fault occurs at point F_{LII} (fault location d_2 = 0.99 pu) and the second fault (*L*1-*G*) takes place

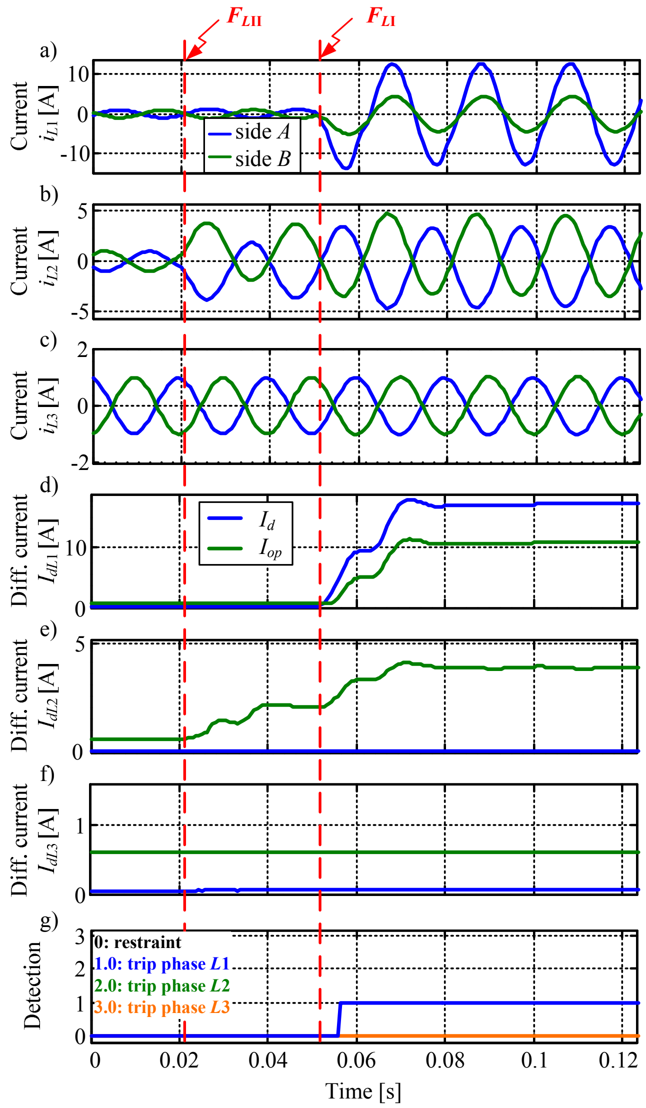

Figure 3. Example 1 – cross-country fault: a), b), c) phase currents mesured in substation *A* and *B*, d), e), f) amplitudes of differential currents and the relay settings calculated acorrding to (1) and (2), g) relay response

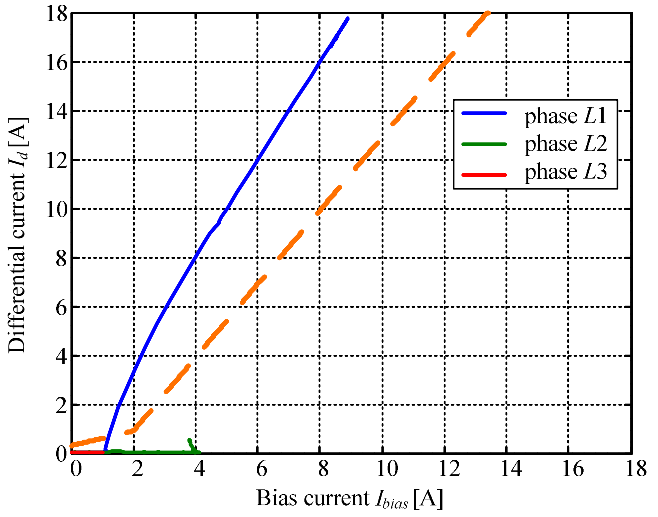

Figure 4. Example 1 – cross-country fault: stabilized characteristic and I_d-I_{bias} trajectory

in protected zone (point F_{LI}, d_1 = 0.5 pu) after a short break (about 20 ms). Operation of the relay R_A is analyzed here. One can notice that only the trajectory of phase $L1$ current enters the tripping zone (Fig. 4), which led to tripping correct protected line (Fig. 3g). For this situation differential relay behaves properly because it only detects fault at point F_{LI}. It follows that fault in parallel circuit (point F_{LII}) does not affect correct operation of differential protection.

Figures 5-6 present the second case of a cross-country fault. In this case the first fault ($L3$-G, fault resistance 0Ω) occurs at point F_{LII} (d_2 = 0.01 pu). About twenty milliseconds later the second fault ($L2$-G, fault resistance 100Ω, d_1 = 0.01 pu) occurs on protected line (point F_{LI}). Figure 6a, b, c illustrate phase currents at substations A and B. As one can see that (Figure 6c) current transformer installed in phase $L3$-G (side A) gets saturated and current transformer installed in the same phase but at opposite side (B) does not. It follows that the trajectory

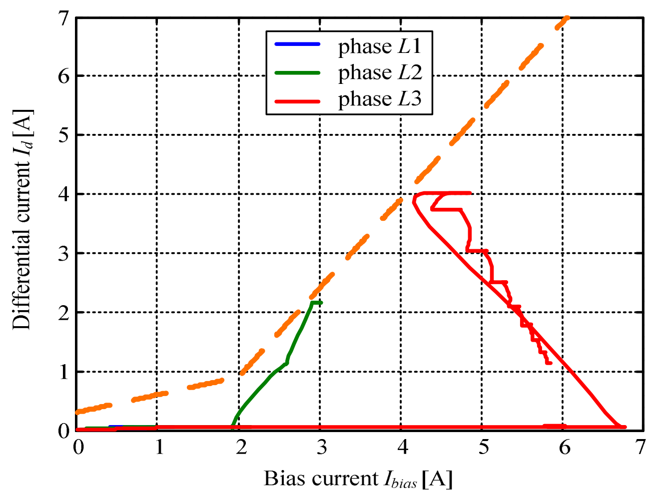

Figure 5. Example 2 – cross-country fault: stabilized characteristic and I_d-I_{bias} trajectory

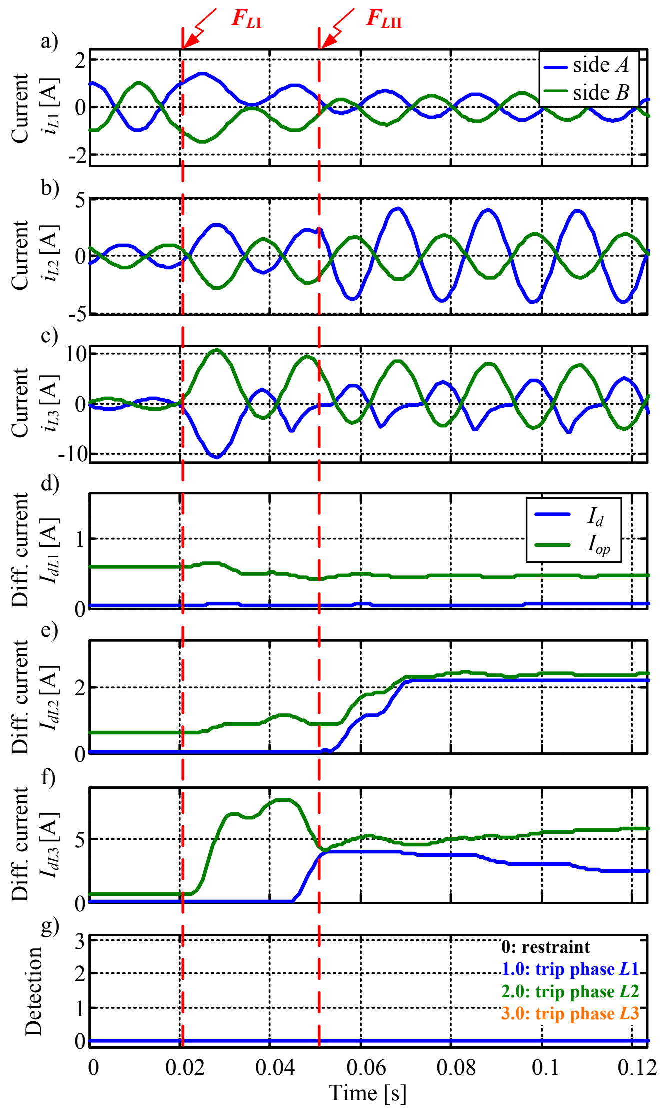

Figure 6. Example 2 – cross-country fault: a), b), c) phase currents mesured in substation A and B, d), e), f) amplitudes of differential currents and the relay settings calculated acorrding to (1) and (2), g) relay response

of phase $L3$ current is very close (Fig. 5) but does not enter the tripping zone. For this external fault ($L3$-G) with severe CT saturation differential protection remained stable without issuing false tripping command. However, the second internal fault ($L2$-G) is not switch off and that is a wrong decision. Figure 5 illustrates that the trajectory of phase $L2$ current is close to the tripping zone but does not exceed it. The sensitivity of differential protection can be improved by decreasing of the slope of stabilized characteristic (especially the second part of stabilized characteristic k_2). However, if the slope of the second part of stabilized characteristic will be decrease then differential protection may detect internal fault ($L2$-G) and also react to external fault ($L3$-G). Analysis of this case leads to the conclusion that it is very difficult to ensure detection all internal faults and also blocking all external faults by using traditional stabilized characteristic.

In Figures 7 and 8 the third case of a cross-country fault is presented. First, an external fault ($L2$-G) with severe CT saturation at point F_{LII} (d_2 = 0.01pu, fault resistance 0Ω) and then, after about 20 ms, the second internal fault ($L1$-G, d_1 = 0.5pu, fault resistance 10Ω) at point F_{LI} occur, which is depicted in Figure 7a,b. Differential protection detected the internal fault ($L1$-G) within less than 5ms after fault inception (Fig. 7g). Unfortunately, the protection detected also external fault because the trajectory of phase $L2$ current entered the tripping zone (Fig. 8). In such a case differential protection recognized faults both in phase $L1$ and $L2$, which is incorrect because internal fault occurred only in phase $L1$. Such a decision of differential protection (detection of faults in phase $L1$ correctly and also in phase $L2$ incorrectly) may lead to wrong operation of autoreclosing function. In this case single-pole autoreclosing function should be used, which means that breaker poles in phase $L1$ must be opened and reclosed. As a result of wrong decision of differential protection three-pole autoreclosing function is used which means that breaker poles in all phases will be opened and reclosed. Such a behavior influences unfavourably reliability of consumers supply.

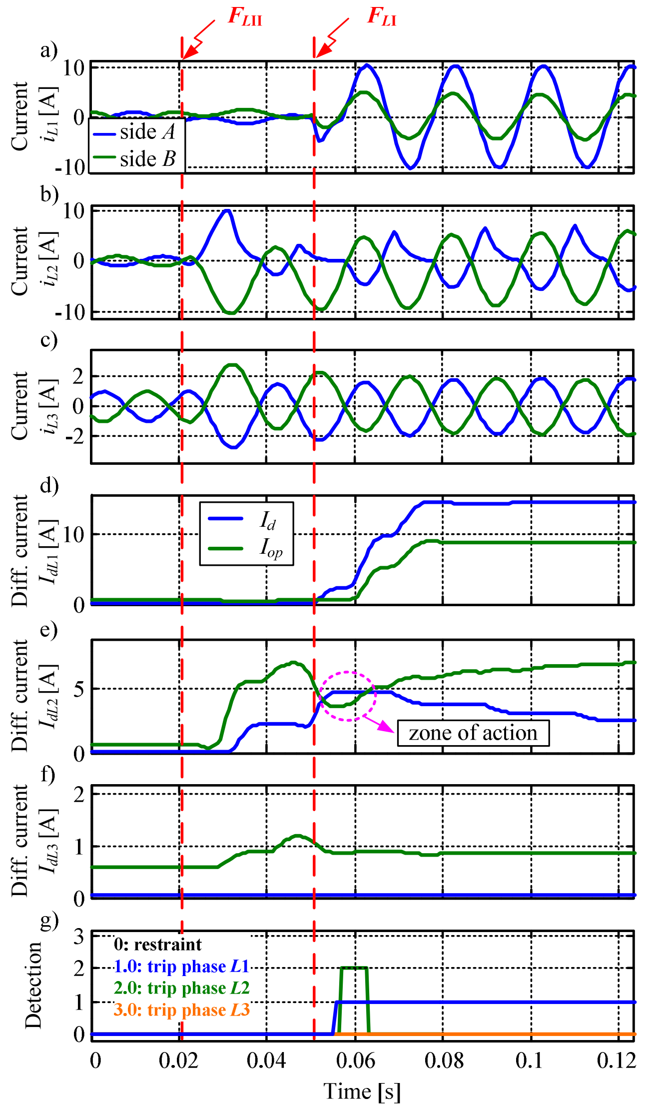

Figure 7. Example 3 – cross-country fault: a), b), c) phase currents mesured in substation A and B, d), e), f) amplitudes of differential currents and the relay settings calculated acorrding to (1) and (2), g) relay response

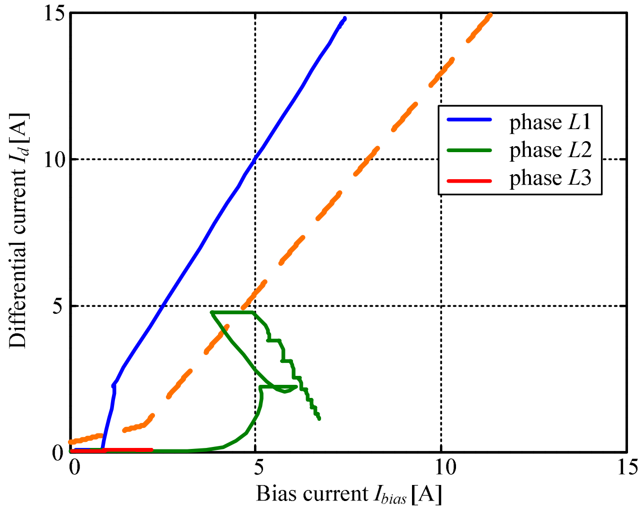

Figure 8. Example 3 – cross-country fault: stabilized characteristic and I_d-I_{bias} trajectory

III. Conclusions

The results of testing of current differential protection for cross-country faults are shown in this paper. Generally, differential protection works properly when cross-country fault taken place. However, for some cross-country faults differential protection may mal-/misoperate, especially when internal fault via high resistance or external fault with severe CTs saturation occurred. Therefore, there is a need for an improved differential principle for transmission lines with the aim of achieving better stabilization and sensitivity, reliability and speed of operation for cross-country fault cases. Other criteria and adaptive solutions are to be developed for the purpose.

References

[1] M.K. Adamiak, W. Premerlani, "A New Approach to Current Differential Protection for Transmission Lines", GE publication GER-3981, (1998).

[2] AREVA, "P54x Application Guide", (2005).

[3] S. Ward, T. Erwin, "Current Differential Line Protection Setting Considerations", RFL Electronics Inc, (2005).

[4] W. Rebizant, K. Solak, A. Wiszniewski, A. Klimek, "Fuzzy Inference Supported Current Diffetential Protection for HV Transmission Lines", Proceedings of the DPSP 2010 Conference, 29.03-01.04.2010, Manchester, UK, paper 5.

[5] B. Kasztenny, B. Campbell, J. Mazereeuw, "Phase selection for single–pole tripping – weak infeed conditions and cross–country faults", 27th Annual Western Protective Relay Conference Proceedings, Spoken, 24–26 October 2000.

[6] N. Villamagna, P.A. Crossley, "A CT Saturation Detection Algorithm Using Symmetrical Components for Current Differential Protection", IEEE Transactions on Power Delivery, vol. 21, No. 1, pp. 38-45, (January 2006).