Improved Transverse Current Differential Protection Resistant to Power Swing

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Abstract Power swing phenomenon is a complex situation for relaying schemes protecting transmission system including double circuit transmission line. Transverse differential techniques based on superimposed current have limitation during power swing due to signal modulation. In this paper, an improved transverse differential protection using one cycle moving sum of superimposed current is proposed. The moving sum technique minimizes the residual value of the superimposed current present during power swing and provides significant index during faults. Proposed method is tested for a double circuit line for different fault conditions and compared with available technique.

Keywords Double circuit line · Moving sum · Power swing · Superimposed current · Transverse current differential protection

Introduction

In case of a fault in a double circuit transmission system, corresponding line should be isolated quickly to maintain reliability of power system. Different techniques such as longitudinal current differential, distance relaying and

transverse current differential protection schemes are being used for protection of double circuit line (Apostolov et al. 2007). Power swing leading to large variation in voltage and current signals, is a critical situation while protecting such lines. Longitudinal current differential protection using information from both ends is reliable and immune to power swing but requires synchronized phasors and abundant communication channel. The performance of such a technique depends on communication channel and the fault clearing time depends on reporting rate of the phasors and communication delay.

Distance relays are widely used for protection of double circuit line because of the advantages of better selectivity and coordination. Performance of distance relay is affected by mutual coupling between the lines and power swing. The effect of mutual coupling can be avoided by using proper compensation factor (Apostolov et al. 2007). Different techniques are available in distance relays to deal with power swing (IEEE Power System Relaying Committee of the IEEE Power Engineering Society 2005). However, if a fault occurs during power swing it should be detected and the faulty line should be isolated quickly. Detection of balanced fault in such a situation is more difficult due to symmetric variation of prefault signals during power swing. For this purpose, fault detection technique based on decaying DC component of the current waveform is proposed in Lotfifard et al. (2010). A differential power based fault detection technique is available in Rao and Pradhan (2012).

Further, for a double circuit system distance relay has zone selection problem during power swing (Tziouvaras and Hou 2004). Difficulty in faulty phase identification during power swing is also addressed therein. To accelerate the fault clearing time, distance relay decision transfer tripping schemes are implemented with communication facility. These techniques are also susceptible to power

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swing because of the distance relay as an integral component therein.

Transverse differential protection compares the current signals of both the lines at a bus to identify the faulty line. Transverse differential protection scheme based on average current is proposed in Gilany et al. (1995). This method has limitation for far end fault. A reliable transverse differential protection using incremental current signals is proposed in Eissa and Malik (1996) to overcome the blind spot. This method is immune to mutual coupling and able to identify the faulty line along with faulty phase utilizing few samples. Cross differential protection using superimposed currents is proposed in IEEE Power System Relaying Committee of the IEEE Power Engineering Society (2005) and Wang et al. (2005). These methods work well for fault during normal operating condition, but have limitation to identify faulty line during power swing because of modulated current signals. These methods also have problem for high resistance fault at far end and in such cases, sequential tripping is useful which may delay fault clearance. This problem can be avoided by using pilot protection schemes (Behrendt 1998). A combined cross differential and distance relay protection is proposed in Pasand and Jafarian (2011). For this method also power swing is a critical situation.

In this paper, transverse current difference is obtained from the absolute value of one cycle sum of superimposed current of both lines. One cycle sum filter minimizes the residuals in superimposed currents during power swing. It provides an improvement in the detection process compared to conventional superimposed method and able to identify faulty line along with faulty phase even during power swing. Proposed method is tested for a 400 kV double circuit line under different faults and power swing simulated using PSCAD/EMTDC software and compared with available method.

Proposed Method

In a double circuit line, the change in current signal of faulty line is higher than the healthy line for an internal fault and equal in case of an external fault. Conventional

transverse differential protection compares the superimposed currents of both the lines to identify the faulty line (Eissa and Malik 1996). The method provides satisfactory result for fault during normal operating condition when the pre-fault current signals are sinusoidal. During power swing, the signals are not stationary and modulated with two frequency components. The modulated current waveform during power swing for a two-machine system can be expressed as (Lotfifard et al. 2010),

$$i(t) = I_s \sin(2\pi f_s t + \varphi_s) + I_r \sin(2\pi f_r t + \varphi_r), \quad (1)$$

where I_s and I_r are the amplitudes of the current signals of frequencies f_s and f_r close to nominal frequency f_0 and, φ_s and φ_r are corresponding initial phase angles. The current signal significantly varies with the swing frequency $((f_s - f_r)/2)$. The superimposed current becomes substantial during power swing and this may leads to incorrect protection decision during power swing.

In the proposed method, one cycle moving sum of superimposed currents are used to attenuate the frequency components close to f_0 present in the current signal during power swing for reliable trip decision.

One Cycle Moving Sum Filter

Moving sum filter is widely used in power system protection for fault detection, direction estimation and faulty phase identification (Pradhan et al. 2006). Frequency response of the filter for a window length of T_0 can be written as follows:

$$\bar{X}(j\omega) = e^{-\frac{j\omega T_0}{2}} \left[\frac{2}{\omega} \sin\left(\frac{\omega T_0}{2}\right) \right]. \quad (2)$$

Magnitude response of the filter is given in Fig. 1. It shows that the filter rejects the nominal frequency component f_0 completely and significantly attenuates the frequency components f_s and f_r during power swing. The filter completely allows the DC component and provides less attenuation to low frequency components appear during fault condition. This filter is suitable to minimize residual value of the superimposed current present during power swing and to provide significant index during faults.

Fig. 1 Frequency response of the moving sum filter

Further, such a fault detection technique is insensitive to noise (Pradhan et al. 2006).

Proposed Transverse Differential Protection

One cycle sum of the superimposed current for each line is computed as,

$$\Delta i_{sum1}(k) = \sum_{p=k-N+1}^k [i_1(p) - i_1(p-N)] \quad (3)$$

$$\Delta i_{sum2}(k) = \sum_{p=k-N+1}^k [i_2(p) - i_2(p-N)], \quad (4)$$

where i_1 is the line-1 current sample, i_2 is the line-2 current sample and N is the number of samples per cycle. To identify the faulty line accurately cumulative sum of the differential current is calculated as,

$$\Delta i_{sum12}(k) = \Delta i_{sum12}(k-1) + |\Delta i_{sum1}(k)| - |\Delta i_{sum2}(k)|. \quad (5)$$

If Δi_{sum12} is positive the algorithm declares line-1 as faulty and for a negative value, line-2 is identified as faulty. To have proper discrimination during all possible conditions threshold values should be selected for both positive and negative sides of the index Δi_{sum12} . Guidelines available in Eissa and Malik (1996) are considered while selecting such threshold values. In addition, noise and harmonics are considered for testing the algorithm as the method being based on sample values. Fast power swing condition should be taken into account while selecting the threshold and thereby the method would be able to identify the faulty line for all swing conditions.

The transverse differential protection is applicable only when both the lines are in service hence this method cannot be used independently. The proposed method can be implemented with distance relaying schemes (Pasand and Jafarian 2011). This will help to provide reliable decision during power swing condition when the distance relays have limitation to identify faulty line and phase.

Results

To test proposed method a 400 kV double circuit transmission system as shown in Fig. 2 is considered (Brahma 2007). The system data are provided in “Appendix”. The system is simulated in PSCAD/EMTDC software with distributed line model. For protection of line MN, transverse differential relays R_1 and R_2 are used at bus M and N respectively. Current signals are availed by the relays through current transformer of 800:5. Current samples are collected at a rate of 1 kHz. To simulate power swing, a

Fig. 2 400 kV double circuit transmission line

three-phase fault is created in line-4 at 0.5 s and cleared by opening breakers B7 and B8. As a result, power swing is observed in both line-1 and 2. Different faults are simulated in line-1 and 2 during this period and Δi_{sum12} is calculated using (5) for both the relays. Based on the discussion in “Proposed Method”, the threshold value to detect faulty line using (5) is chosen as 100 A, considering maximum swing frequency of 6 Hz. Proposed technique is compared with the available transverse differential technique based on superimposed current (Eissa and Malik 1996).

Line-to-Ground Fault on Line-1 During Power Swing

To demonstrate the performance of conventional and proposed methods during power swing, phase-A to ground fault is created on line-1 at 4.54 s, $\delta = 150^\circ$ and 120 km away from bus-M. Results for transverse differential current computed by relay R_2 at bus-N for phase-A current are shown in Fig. 3. At large angle of δ , the line current becomes significantly high and increase in current due to fault is small as observed in Fig. 3a. In addition to that, the superimposed current of healthy line is substantial due to power swing. Therefore, simple superimposed current technique is not sufficient to identify the faulty line. As a result, the index value Δi_{12} is growing from positive to negative as in Fig. 3b. Thus, for this case the conventional method fails to identify the faulty line (line-1).

With the proposed method, the residual superimposed current present due to power swing is filtered using moving sum approach and as a result, the Δi_{sum1} of healthy line current is negligible. The index Δi_{sum12} of the proposed method is consistently positive and identifying the faulty line correctly as shown in Fig. 3c. This case clearly shows the strength of proposed method over conventional method.

Three-Phase Fault During Power Swing

A three-phase fault is created on line-2 at 3.305 s, $\delta = 100^\circ$ and 180 km away from bus-M and results are shown in Fig. 4. It is observed from Fig. 4a that the index

Fig. 3 Results of relay R_2 at bus-N for line-to-ground fault in *line-1* at 4.54 s, 120 km from bus-M during power swing. **a** Line-current signals at bus-N. **b** Δi_{12} of conventional method (Eissa and Malik 1996). **c** Δi_{sum12} of proposed method

Δi_{12} of phase-A current computed by the relay R_1 at bus-M is positive (as high as 8 A) during the initial transient period and negative afterwards. Thus, to detect the faulty line correctly, a higher value should be selected as a threshold, which may reduce the sensitivity of the conventional fault detection technique. The threshold of Δi_{12} is chosen as 10 A for the conventional method. Index Δi_{12} computed by relay R_2 at bus-N is consistently negative and ensuring a fault in line-2. On the other hand, indices Δi_{sum12} computed by both the relays are consistently negative during fault period and confirming line-2 is faulty as in as shown in Fig. 4b. This case clearly shows the advantage of the proposed method.

Cross-Country Fault During Power Swing

Cross country fault is critical for any protection scheme. To check the performance of the proposed method, a cross country fault is created in phase-A of line-1 and phase-B of line-2 with arc resistance of 70Ω at 2.2 s, $\delta = 70^\circ$ and 200 km away from bus-M and corresponding results are

Fig. 4 Results for three-phase fault in *line-2* at 3.305 s, 180 km from bus-M during power swing. **a** Conventional method. **b** Proposed method

Fig. 5 Results for cross country fault at 2.2 s, 200 km from bus-M with an arc resistance of 70 Ω . **a** Conventional method. **b** Proposed method

shown in Fig. 5. It is observed that the index Δi_{12} seen by both relays R_1 and R_2 are oscillating as in Fig. 5a and R_1 decision at bus-M may be incorrect. This is due to significant superimposed component of healthy line current, because of power swing. On the other hand, the index Δi_{sum12} seen by both the relays is consistent and correct as shown in Fig. 5b. Index Δi_{sum12} of relays R_1 and R_2 are with high positive values for phase-A and high negative values for phase-B. The result clearly shows the faulty phases of respective lines involved in the fault.

Conclusion

Power swing is a critical situation for any line protection scheme. A transverse differential transfer trip scheme for protection of double circuit line is proposed in this paper to identify faulty line and faulty phase even during power swing. In this method, residue in superimposed current during power swing is filtered using moving sum approach. The proposed method

tested for different faults during power swing and compared with conventional method. Results show better performance of the proposed method compared to available techniques during power swing. The proposed transverse differential can be implemented along with distance relaying schemes. This will help to provide reliable decision during power swing condition when the distance relays have limitation.

Appendix

The parameters of the 400 kV system.

Generator: 600 MVA, 22 kV, 50 Hz, inertia constant = 4.4 MW/MVA. $X_d = 1.81$ p.u., $X'_d = 0.3$ p.u., $X''_d = 0.23$ p.u., $T'_{do} = 8$ s., $T''_{do} = 0.03$ s., $X_q = 1.76$ p.u., $X'_q = 0.25$ p.u., $T'_{q0} = 0.03$ s., $R_a = 0.003$ p.u., X_p (Potier reactance) = 0.15 p.u.

Transformer: 600 MVA, 22/400 kV, 50 Hz, Δ/Δ , $X = 0.163$ p.u., $X_{core} = 0.33$ p.u., $R_{core} = 0.0$ p.u., $P_{copper} = 0.00177$ p.u.

Transmission lines: line lengths of line-1 and 2 = 280 km, line lengths of line-3 and 4 = 100 km.

$Z_1 = 0.12 + j0.88 \Omega/\text{km}$, $Z_0 = 0.309 + j1.297 \Omega/\text{km}$

$C_1 = 1.0876 \times 10^{-8} \text{F/km}$, $C_0 = 0.768 \times 10^{-8} \text{F/km}$.

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