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An efficient power differential scheme for power transformer protection

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Abstract:

This paper proposes and develops a Power-based Differential Scheme (PDS) for power transformer protection. The proposed PDS for power transformer is based on computing the active and reactive power loci during normal operation, switching, normal power swing, and internal and external faults. The proposed PDS concept based on monitoring and comparing the transformers primary and secondary active and reactive powers. The dynamic response of the proposed PDS is tested and modeled using Matlab/Simulink software a step up transformer fed from single alternator system from one end versus the utility busbar at the other end. The test results confirm the superiority of the proposed scheme to distinguish internal and external faults as well as magnetizing inrush currents with good selectivity, high speed, sensitivity, stability limits and high accuracy response of the power differential scheme.

Keywords:

Power differential Scheme, Transformer differential protection, Inrush current, Fault current, Criterion function, High impedance fault.

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1. Introduction:

Power transformers are very important and central components of electric power systems. Protection of power transformers is very vital mission of protection engineers. This protection should be fast, economic and reliable. Consequently, high anticipations are imposed on power transformer protective Schemes. Expectations from these Schemes incorporate dependability, security, speed of operation (minimum clearing fault time) and stability.

Current-based Differential scheme (CDS) as a concept is used for protecting medium and large power transformers. This concept is based on monitoring and comparing the transformers primary and secondary currents. The value of current difference between both primary and secondary sides indicates an abnormal operation or internal fault. Some problems occurred during application of the CDS scheme on the power transformer. One of these problems is the large magnetizing inrush current (MIC) which leads to transformer saturated and mal-operation of protection relays. The avoiding these effects are still rich field of research with respect to protection engineers. The MIC leads and occurs in transformer at the following conditions:

- The time of large change in voltages are occurred such as sudden change in the input terminal voltage transformer
- Due to switching-in or due to recovery from external fault. As a result, a large inrush current is drawn by the transformer from supply
- When transformer is energized in parallel with a transformer that is already in service, known as "sympathetic inrush" condition [1].

The difference current which accomplished the magnetizing inrush currents may be of the order (8-12) times of full load [2]. Therefore, the discrimination between magnetizing inrush current and fault current is greatly important issue. *The MIC is affected by the following issues* [3]:

- The switching angle which is defined as point on the voltage wave at the instant the transformer is energized,
- The supplying circuit impedance to the transformer which measures stiffness/weakness of supply systems,
- The value and sign of the residual flux linkage in the transformer core,
- The nonlinear magnetic saturation characteristics of the transformer core, and
- Switching in the case of close or open secondary.

While, the fault current is affected by load condition and the fault boundaries as:

- Fault incipient time instant,
- Fault impedance,
- Fault type {Single-line-to-ground (SLG), Double- line-to-ground (DLG), Line-to-line (LL) and Three-phase to ground (3 -G)},

In literature, many researchers proposed several approaches to solve the MIC problem. The most common technique used to prevent false trips during the initial energization is harmonic restraint scheme [4]. Harmonic restrain principle based techniques often encounter problems when second harmonic generates in other operating conditions and the magnitude exceeds the predefined threshold. This may be due to current transformer saturation, system resonant conditions, presence of a shunt capacitor, or presence of nonlinear loads or distribution capacitance in a long extra high voltage (EHV) transmission line connected to the protected transformer [5, 6]. However, the second order harmonic component may also be generated during internal faults in the power transformer. To avoid the tripping operation dependency on such a threshold case, Guocai presented a criteria based on the bus voltages. The second harmonic restraint is cancelled when the voltage of a bus is less than 70% of its rated voltage [7]. Another scheme based on the similarity between the voltage waveform and current waveform was been employed for inrush identification [8]. Neural networks, wavelet transform and fuzzy logic have been proposed to differentiate inrush and internal fault current [9-11]. The Wavelet Transform based methods have better ability of time frequency location but its limitations are that need long data window and also sensitive to noise and unexpected disturbances, these drawbacks may limit their application in sensitive protection. Artificial neural networks can classify patterns perfectly but the results do not determine the classification accuracy. Some of priori methods suffer from being dependant on parameters of protected transformer, protective algorithm calculative cost, and some from voltage transformers requirements and so on. Some are affected in a noisy environment or current distortions such as CT saturation. Not of all these schemes succeeded except under restrictions to discriminate fault current and inrush current.

The PDS has been proposed for differential protection of transmission lines [12-14]. It is based on computing the active and reactive power loci during normal operation, switching, normal power swing, and internal and external faults. From these loci, discrimination of internal faults can be achieved via efficient algorithm supported by logical functions [13]. Determination of the appropriate setting is exhaustively investigated and the most appropriate setting functions are obtained. The distinguished behavior of the PDS and its remarkable sensitivity has been verified via intensive real-time test cases [3, 12-14]. The test results show that the differential power algorithm is really a promising concept as it is perfectly immune to inrush current. Thus, further enhancement and testing of the PDS are really appreciated.

In this paper, the performance of PDS for power transformer is introduced. A simplified setting expression is derived to ease scheme adjustment for different power system. Universality of the enhanced scheme algorithm is proven via steady state and real-time test cases. The suitable performance of this scheme is demonstrated by simulation of different faults and switching conditions on power transformers.

2. Power Differential Scheme (PDS)

Referring to the reported PDS, the union action of the active and reactive power detectors is considered [12-14]. This provides a complement in addition to some overlapping as far as the type of fault, the range of fault resistance, and power angle swings are concerned. The PDS can be described with the help of Figure 1. With reference to Figure 1, the current and voltage signals are measured, sampled with 32 samples/cycle. Then, the fundamental active and reactive powers are computed from the complex product of the current and voltage. The power is computed for the active power at both primary and secondary ends on sample-by-sample basis.

The $P=P_p -P_s$ and $P = (P_p+P_s)/2$ are computed where P_p and P_s are the primary and secondary ends power transformer, respectively. Similarly, the reactive power algorithm is processed considering the reactive power at the sending (Q_p) and receiving (Q_s) ends. The difference average (ΔQ) and reactive power through (Q) are then computed. Values of P, P, Q and Q are employed to feed the overall fault detector scheme.



and average extraction diagram for phase a.

3. Improved PDS Settings

The active power and reactive settings of the power differential Scheme have been proposed to fulfill the maximum internal fault sensitivity and external fault stability under the probable worst conditions. It is proposed that the setting of the differential power is altered to the following two line segments as shown by Figure 2. The first line segment is plotted and given by the straight line segment AB and expressed by the equation:

$$\Delta P_{set} = K_{\perp} \Delta P_{max} + \frac{\Delta P_{max}}{P_{max}} \left(\frac{1 - K_{\perp}}{K_{\perp}} \right) \times P \qquad for \quad P \le K_{\perp} P_{(max)} \tag{1}$$

Where ΔP_{max} is the difference power and P_{max} is the maximum through power. *P* is the measured quantity of the through active power at scheme location. K_1 is a multiplier

constant determines the maximum value of ΔP_{set} . A value of K_I =1.75 is adopted. It can be concluded that a wide range of high impedance internal fault loci up to 1700 Ω can be detected or come above the threshold. The second segment is expressed by the equation:

$$\Delta P_{set} = \frac{K_{2} \Delta P_{max}}{(K_{2} - K_{1})} + \frac{\Delta P_{max}}{P_{max} (K_{1} - K_{2})} \times P \qquad for \quad K_{1} P_{max} < P \le K_{2} P_{max}$$
(2)

Where K_2 is the power through multiplier, which determine the horizontal setting limit of *P*. It is set at a value of 1.9. This segment is plotted as a dashed straight line *BC* tangent to the first curved segment at "*B*" and intersects the horizontal axis at "*C*". The active power detector algorithm is started with calculations of the average values ΔP and *P*. The measured value of *P* is compared with the value of $K_1 P_{max}$, if it is less; ΔP_{set} is computed from (1). If $K_1 P_{max} < P_{av} \le K_2 P_{max}$, the value of ΔP_{set} is computed from (2). If the measured value of ΔP is greater than the obtained ΔP_{set} from (1) or (2), a trip





Figure 2: Power differential Scheme characteristic & Power Swing locus

Figure 3: Model of SIMULINK system of PDS transformer protection

4. Performance Evaluation via Real-Time Cases

The results in the paper context will be given for a typical 300 MVA, 220/66 kV, transformer and is simulated using MATLAB/ SIMULINK software. The performance of the power differential scheme with the proposed setting is evaluated via real time response tests under different operating and fault conditions. Responses are computed for active and reactive power detectors at different internal and external fault cases with different resistance fault.

From Figure 3 it can be shown the model of the simulating system. Passing through subsystem 1 will illustrate the synchronous machine associated with the Hydraulic Turbine and Governor "HTG" and excitation system blocks. By the use of subsystem 5 it can be implement power transformer model. Also, via subsystems 3&4 can be measured the voltage and current at both ends Primary & Secondary by putting the voltage and current measurements on any phase. Then these signals are input of the active and reactive power measurement block. This block measure active and reactive power associated with a periodic set of voltage and current which may contain

harmonics. P&Q are calculated by averaging the (I-V product with a running window over a complete cycle of the fundamental frequency so that the powers are evaluated at fundamental frequency. The out values in subsystem 3&4 are the P&P and Q&Qto workspace and it can comparison between these value and the out algorithm's values from subsystem 6. It can compute the difference of active and reactive power vales from the input values (P&Q) at both ends of power transformer. The recorded responses are as given in the following subsequent sections.

4.1 Real Time Responses of P detector during internal faults:

The active power detector response is computed for sudden application of solid (through $R_f = 0.2$) internal single L-G fault at primary & secondary sides, the power angle $\delta = 30^{\circ} \& 15^{\circ}$, respectively and fault inception angle $\alpha = 0^{\circ}$. The result is recorded in conjunction with the proposed active power setting as shown in Figure 4. This figure shows the remarkable sensitivity of the power differential scheme for detection of solid fault. On the other hand, the response of the conventional current differential scheme is excellent under that condition as shown in Figure 5.



The results presented in Figures 6-12 demonstrate the difference of sensitivity between the PDS and CDS schemes. Figures 6 and 7 shows sensitivity of the two protection schemes when the resistance fault is increased to 10 and 100 , respectively. The two schemes are sensitive for this fault type with these values of resistance fault. The same action is considered for the proposed power differential Scheme which is shown in Figures 8 and 9, respectively. If the fault impedance is increased gradually up to 200 which is the maximum sensitivity for the conventional current differential scheme as shown in Figure 10. In the proposed PDS, the sensitivity is reached to 1700 as shown in Figure11. Also, the trip action which is demonstrated in Figure 12 it vanishes at both pre- and post- fault occurence and equals one during fault until the end of fault duration



Figure 6: Current detector response at Figure 7: Current detector response at internal solid SLG fault at secondary side, $\delta = 60^{\circ}$ and $R_f = 10\Omega$.



Figure 8: Active power detector response at internal SLG fault at secondary side, $\delta = 30^{\circ}$ and $R_f = 10\Omega$.



Figure 10: Current diff., Scheme c/s response under internal SLG fault at secondary side, $\delta = 30^{\circ}$ and $R_f = 200\Omega$



internal solid SLG fault at secondary side, $\delta = 60^{\circ}$ and $R_f = 100 \Omega$.



Figure 9: Active power detector response at internal SLG fault at secondary side, $\delta = 60^{\circ}$ and $R_f = 100 \Omega$.



Figure 11: Active power detector response at internal SLG fault at secondary side, δ $=30^{\circ}$ and $R_f = 1700\Omega$

4.2 Real Time Responses of P detector during external faults:

The loci from Figures 13-16 represented the external L-G fault pattern at secondary side of power transformer with high resistance fault (up to 1700) and without resistance fault. These figs are revealing the excellent stability of power

differential scheme under any conditions of external fault and at any location as primary or secondary side of power transformer. Also, the current differential scheme is robust under these conditions as shown in Figures 17 and 18.

4.3 <u>Real Time Responses of Power and Current- Detectors During Inrush Current:</u>

The active power detector response is computed for initial inrush, recovery inrush and sympathetic inrush current and the power angle $\delta = 30^{\circ}$. The result is recorded in conjunction with the proposed active power setting as shown in Figure 19. It can be seen that for inrush condition the value of P_{dif} remains under the setting threshold by a large margin as shown by the solid line. However, for the current detector response the value of current difference I_{dif} exceeds the setting threshold and detects this case as a fault case although it is not. These results are shown in Figures 20 and 21.



Figure 12: Trip signal under internal LG fault at secondary side, $\delta = 30^{\circ}$



Figure 14: Active power detector response at external L-G fault at secondary side, $\delta = 30^{\circ} \& R_f = 100 \Omega$.



Figure 13: Active power detector response at external solid L-G fault at secondary side, $\delta = 30^{\circ}$.



Figure 15: Active power detector response at external L-G fault at secondary side, $\delta = 30^{\circ}$ & $R_f = 1700\Omega$



Figure 16: Active power detector response at external L-G fault at Primary side, δ =30° & R_f=1700 Ω



Figure 18: Current detector response at external L-G fault at secondary side, with $R_F=200$ & $\delta=30^\circ$



Figure 20: Three- phase current response during sympathetic inrush case, $\delta = 30^{\circ}$.



Figure 17: Current detector response at external solid L-G fault at secondary side, $\delta = 30^{\circ}$





Figure 21: Response of PDS vs. CDS during initial inrush current.

5. Conclusions:

In this paper, a power differential scheme has been examined to protect the power transformer using SIMULINK/MATLAB model. The evaluation has been accomplished at different fault conditions and at different power swings. To help the protection engineer adjust the scheme setting. The scheme setting algorithms have been tested under external fault and internal fault. Also, the Scheme algorithm has been evaluated under all cases of inrush current which accomplished the power transformer and it can be discriminated between inrush case and internal fault case. Ascertaining sensitive and secure differential power Scheme has been verified.

<u>References:</u>

- [1] M. Tripathy, R. P. Maheshwari and H. K. Verma, "Power transformer differential protection based on optimal probabilistic neural network," IEEE Transactions on Power Delivery 25 (2010) 102-112.
- [2] M. Tripathy, R. P. Maheshwari and H. K. Verma, "Advances in transformer protection: A review," Electric Power Component Systems, 33 (2005) 1203– 1209.
- [3] S. Jazebi, B. Vahidi, S.H. Hosseinian, J. Faiz "Magnetizing inrush current identification using wavelet based Gaussian mixture models" Simulation Modeling Practice and Theory 17 (2009) 991–1010.
- [4] H. Zhang, P. Liu, O.P. Malik, "A new scheme for inrush identification in transformer protection", Electric Power Systems Research 63 (2002) 81–86.
- [5] J. Faiz, S. Lotfi-Fard, "A novel wavelet based algorithm for discrimination of internal faults from magnetizing inrush currents in power transformers," IEEE Transactions on Power Delivery 21 (2006) 1989–1996.
- [6] L. Pei, M. OP, et al., "Improved operation of differential protection of power transformer for internal faults," IEEE Transactions on Power Delivery 7 (1992) 1912-1919.
- [7] S. Guocai, Y. Dachuan." Identifying internal faults of transformers through the similarity degree between voltage and current" Proceeding, IEEE PES 2000 Winter Meeting, Singapore.
- [8] Y. Kuniaki. "Power differential method for discrimination between fault and magnetizing inrush current in transformers," IEEE Transactions on Power Delivery 12 (1997) 1109-1118.
- [9] J. Pihler, B. Grear, D. Dolinar, "Improved operation of power transformer protection using artificial neural network" IEEE Transactions on Power Delivery 12 (1997) 1128-1136.

- [10] F. Jiang, Z.Q Bo., "Power transformer protection based on transient detection using discrete wavelet transform (DWT),"Proceeding, IEEE PES 2000 Winter Meeting, Singapore.
- [11] B. Kasztenny, E. Rosolowski et al." A self-organizing fuzzy logic based protective Scheme-an application to power transformer protection" IEEE Transactions on Power Delivery 12 (1997) 1119-1127
- [12] H.A. Darwish, A.I. Taalab, and E.S. Ahmed, "Investigation of power differential concept for line protection," IEEE Transactions on Power Delivery 20 (2005) 617-624.
- [13] A. I. Taalab, H. A. Darwish and E. S. Ahmed, "Performance of power differential scheme with adaptive setting for line protection," IEEE Transactions on Power Delivery, 22 (2007) 50-58.
- [14] H. A. Darwish, A. I. Taalab, and E.S. Ahmed, "A novel power differential concept for line protection," Middle East Power Systems Journal, 1 (2004) 41-49.