Rate of Rise of Differential Current Based Protection of Power Transformer

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***Abstract*— This paper proposes a new algorithm for the protection of power transformer depending on the rate of rise of differential currents. In which, all the winding currents of all the phases of power transformer are sensed through current transformer and based on the phasor difference between currents, differential currents of all phases are computed. Based on the value of differential current, abnormal condition is detected and rate of rise of differential currents (RRDC) is calculated. Further peak of the sum of derivative of RRDC function (SDRRDC) of all three phases is calculated and which is used to distinguish between external disturbances (magnetic inrush) and internal faults of transformer. For the validation of proposed protection algorithm, internal faults (symmetrical and asymmetrical) like line-to-ground (LG), line-to-line (LL), line-to-line-to-ground (LLG), line-to-line-to-line (LLL) and line-to-line-to-line-ground (LLLG), magnetic inrush as external disturbance and energisation of faulted transformer events are considered. Several test cases are generated, simulated and verified using PSCAD/EMTDC and MATALB software packages. The proposed scheme precisely discriminates between magnetic inrush and internal faults condition with less response time than the conventional biased differential current protection scheme.**

Keywords— Power transformer, differential protection, magnetic inrush and internal fault

I. Introduction

Power transformers are the one of the costliest equipment in the electrical power generation and transmission networks. The configuration in which they are used is totally depends on the application or the power transmission level. Depending upon the application, they can be turned ON/OFF irregularly (occasionally) or regularly (frequently). Nowadays to reduce the transmission losses, the power is transmitted at very high voltage levels of 1.2 MV, 765 kV and 400 kV. The energisation of power transformer at this much higher voltage level cause higher value of magnetic inrush currents. Consequently, an adaptive protection system is required for the power transformers which can successfully differentiate between faulty condition and magnetic inrush condition.

Conservatively, biased percentage differential current based protection scheme along with second harmonic restrain algorithm is used to avoid mal-operation of protecting device during magnetising inrush currents [1]-[3]. Nowadays it is hard to attain accurate differentiation between internal transformer fault and magnetising inrush condition in a power transformer because, the most of transformer manufacturers are utilizing better-quality magnetic material due to which 2^{nd} harmonic components of the magnetic inrush is considerably reduced [4]. Furthermore, depending on the 5^{th} harmonic component-based blocking is also used in case of grid voltage goes high which may result into saturation of the magnetic core of transformer and hence, the 5^{th} harmonic component will increase. So conventionally, biased differential current based protection algorithm along with some extra added features is used to differentiate between the fault and external disturbances. Additionally, for Extra High Voltage levels, the X/R ratio of the transformer is found to be very high and hence, the decaying dc component will be large in the inrush and fault current. The response time of protection algorithm may be need to delayed in the event of fault which is having large decaying dc component and also at the time of energisation of faulted transformer [5]. Moreover, unwanted operation of the commercial relays due to CT ratio errors and different tap position, the operating value of the biased differential relay is kept higher by increasing the slope of the differential characteristics [6]-[7]. This has adverse result on the sensitivity of the relay in event of faults in the power transformer.

Few resources available which account higher accuracy without compromising the sensitivity of the relay [8]-[14]. Some authors proposed a power transformer protection technique which requires additional potential transformer [15]-[17] along with current transformer which adds extra cost in the protection equipment. Afterwards, protection scheme based on Artificial Neural Network [18]-[20], Fuzzy logic [21]-[22] and Wavelet and S- transform [23]-[25] is proposed by many authors. Further, Principle Component Analysis (PCA) and Mathematical Morphology (MM) based methods are proposed [26]-[27]. ANN and Fuzzy logic-based method have practical implementation limitation. Afterwards, Wavelet transform based method requires very high number of samples and fails to perform noise assist analysis of the data. Conversely, S-transform based method is not able to include all signals in its window and have high computation time than the other methods. Equally, method based on PCA and MM requires multiple threshold and in practical it is difficult to decide so many numbers of thresholds.[28] suggests the method based on the random forest technique for power transformer protection.

In this paper, the proposed method detects abnormal condition by doing phasor comparison of primary and secondary winding currents of power transformer using Discrete Fourier Transform (DFT) algorithm. If abnormal condition is detected, further rate of rise of differential current (RRDC) and peak of the sum of derivative of RRDC of all three phases (SDRRDC) is computed. Based on the sum of SDRRDC external disturbance condition and fault is detected. The proposed methods accurately discriminate between external disturbance (magnetic inrush) condition and internal fault of power transformer as well as electrical event like energisation of faulted transformer. During energisation of faulted power transformer event, fault current may have value equal or less than magnetic inrush current, though proposed protection scheme is able to distinguish that event. The response time of proposed method is also less compared to conventional method. The proposed method and simulation results and advantages of the proposed method are discussed in further section II and III.

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II. PROPOSED METHOD

Fig 1. shows the basic flowchart of the proposed algorithm. First, instantaneous values of all CT secondary currents of both primary (I_{pa}, I_{pb}, I_{pc}) and secondary (I_{sa}, I_{sb}, I_{sc}) are acquired. Depending on the configuration of power transformer phase compensation is done. Estimation of phase for all currents (I_{pa}, I_{pb}, I_{pc}, I_{sa}, I_{sb}, I_{sc}) is done using phasor estimation algorithm. Differential current for all three phases $Id_{(a,b,c)}$ are computed by doing phase comparison of all winding currents and abnormal condition is checked. After detecting abnormal condition rate of rise of differential current (RRDC) is computed using eq 1.

$$RRDC_{(a/b/c)}(t) = \frac{abs\,(Id_{(a/b/c)}(t) - Id_{(a/b/c)}(t-1))}{\Delta t} \quad (1)$$

Where, $RRDC_{(a/b/c)}$ is the RRDC of individual phases.

Further, sum of the derivative of RRDC (SDRRDC) of all three phases is calculated using following equation,

$$SDRRDC(t) = \sum[abs(k * \frac{(RRDC_{(a/b/c)}(t) - RRDC_{(a/b/c)}(t-1))}{\Delta t})] \quad (2)$$

Where, Δt is the time difference between each sample and k is multiplication constant which is set to 10^{-4}.

Here, Th is the threshold used to decide abnormal condition depending upon the magnitude of differential currents ($Id_{(a/b/c)}$). Th_{final} threshold used to differentiate between external disturbance (magnetic inrush) and internal fault condition. The peak value of SDRRDC should be non-zero and lies above Th_{final} for the magnetic inrush and should lies below Th_{final} for internal fault. The set value of threshold Th_{final} is kept 5. Selection of the threshold and k is important and purely system dependent.

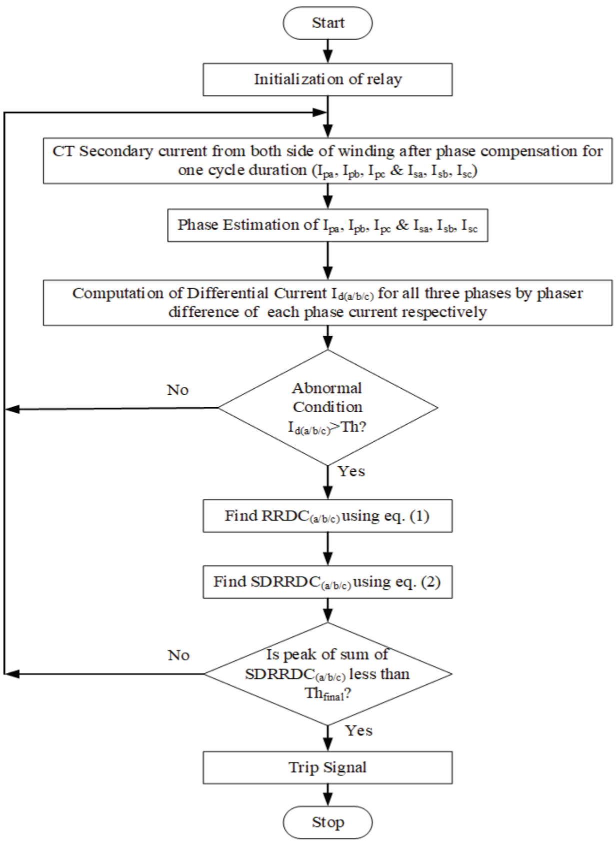

Fig. 1. Flowchart of Proposed Protection Algorithm

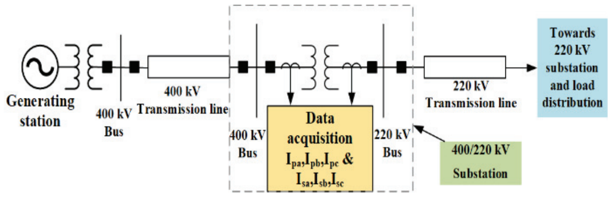

Fig. 2. Single line diagram of current power system network

III. SIMULATION AND RESULS

This section discusses about the simulation model used to carry out performance of proposed algorithm, number of test cases generated and discuss the result in the following sub-sections.

A. Simulation model

Fig. 2. Shows the single line diagram of a portion of an current power system transmission grid situated in Gujarat, India which is established and managed by Gujarat Electricity Transmission and Corporation (GETCO) limited. As shown in fig. 2. Power is generated and it is transmitted at 400 kV transmission line. At 400 kV substation, which is stepped down to 220 kV voltage level using power transformer. Power transformer located at 400 kV substation. The specification of Power transformer is tabled in Appendix. Data acquisition of currents (I_{pa}, I_{pb}, I_{pc}, I_{sa}, I_{sb}, I_{sc}) is done at sampling frequency of 4 kHz. This model of current power system is developed in PSCAD/EMTDC software. The Proposed method is established in MATLAB environment and verified for all the test cases considered as per table I.

B. Test Cases

A large number of test cases, as depicted in table I, have been generated, simulated and performed on the established simulation model of transformer. Internal faults such as LG LL, LLG, LLL and LLLG are generated by varying fault location (FL) by 5%,25%,50%,75% and 95% from the terminal of the winding as well as varying fault inception angle (FIA) by 0˚, 30˚, 60˚, 90˚, and 120˚ from phase a voltage is considered. Magnetic inrush currents are generated with considering residual flux (0%, ±20%, ±50%, and ±80% of rated value), varying load (0% to 100% in a step of 20%) and varying switching instances (SI) (0˚, 30˚, 60˚, 90˚, and 120˚ from phase a voltage). System impedance is also considered variable by 80%,100% and 120% of rated value. Considering above variations, 1650 cases are generated for winding faults (LG, LL, LLG, LLL and LLLG), 525 cases are generated for magnetic inrush current and 1650 cases are generated for energisation of faulted transformer, as total number of cases considered are 3825.

TABLE I. TEST CASES GENERATED

Sr. No.	Electrical Event	Parametric Variation	Test cases
1	Winding faults	Combination of internal faults (11) × winding (2) × Impedance (3) × FIA (5) × FL (5)	1650
2	Magnetizing inrush	Residual magnetism (7) × Impedance (3) × SI (5) × Load (5)	525
3	Energisation of faulted Transformer	Combination of internal faults (11) × winding (2) × Impedance (3) × SI (5) × FL (5)	1650
Total numbers of test cases generated			**3825**

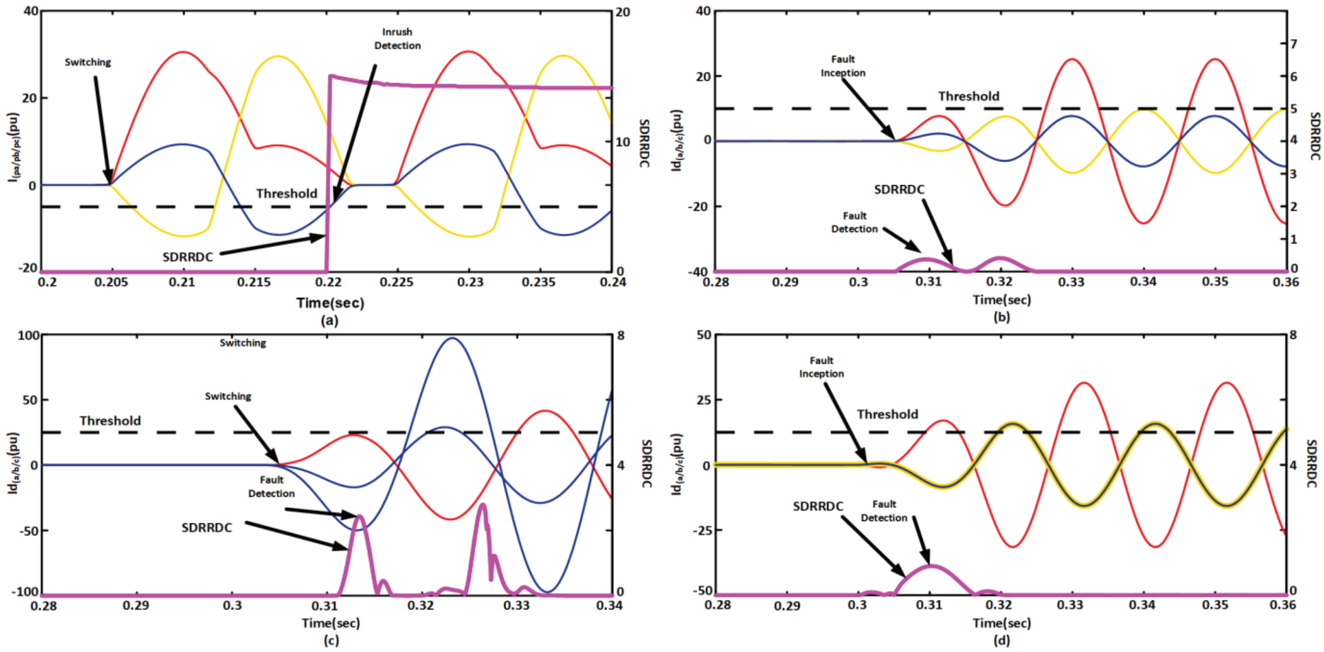

Fig. 3. Primary currents and SDRRDC during (a) Magnetic inrush and differential current and SDRRDC during (b) LG fault (c) Energisation of faulted transformer (having LG fault) (d) LL fault

C. Results

Fig. 3. Shows the performance of proposed protection scheme for conditions in magnetic inrush, LG fault, LL fault and energisation of faulted transformer condition. As show in fig. 3(a) Power transformer is energised at 60° with +80% of residual flux, the peak value of SDRRDC function is 16 which is higher than the threshold so that algorithm detects as the external disturbance (magnetic inrush) and avoid nuisance tripping of protective device. During LG and LL fault as shown in fig. 3. (b) and (d), fault is occurred on 50% of winding on A phase-ground and between AC phase at 90° and 0°, respectively. The peak value of SDRRDC function in this case is 0.5 and 1 which is below threshold value, so that proposed algorithm detects event as internal fault with response time of 4.5 and 7.7ms, respectively. When power transformer having LG fault, is energized as shown in fig. 3. (c), the proposed algorithm detects that event with the response time of 8.3 ms. Fig. 4 shows the LLL internal fault condition in which fault is incepted at 120° on secondary windings of the power transformer. The peak value of SDRRDC is 3.2 and proposed scheme detect fault within 2.2 ms. The performance of proposed method is carried out on all the 3825 cases defined in the table I.

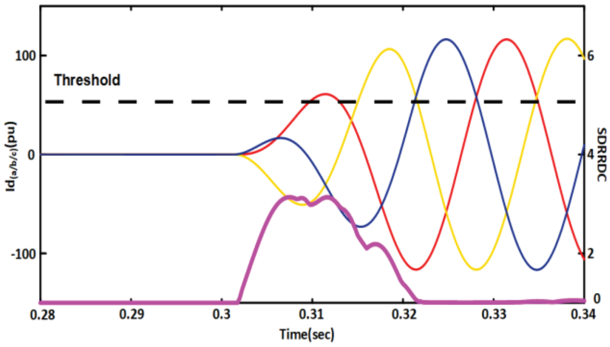

Fig. 4. Differential current and SDRRDC during LLL fault

D. Advantages of proposed method

- Conventional biased-differential protection used 2nd harmonic restrain method to detect magnetic inrush which may fail if improved magnetic material is used in power transformer [4]. This proposed scheme detects magnetic inrush accurately.
- Conventional biased differential protection cannot detect energization of faulted transformer when value of fault current is equal or less than inrush current, but proposed method detects that electrical event with less response time.
- The proposed method can easily be implemented without any additional hardware requirement in the existing electric power system network.
- This method completely works fine with low sampling frequency. The sampling frequency selected is 4 kHz which is standard sampling frequency used in the actual power system network [6]-[7].
- The average response time achieved by this method is 10 ms (half cycle) which is lower than the conventional biased differential protection scheme which have response time of 20 ms (cycle).

IV. Conclusion

A new rate of rise of differential current based method, which distinguishes internal faults in the power transformer with external disturbances. The suggested technique has been tested by exhibiting a part of present power system network using PSCAD/EMTDC software package. Different electrical events containing winding faults, energisation of faulted transformer and external disturbances (magnatising inrush) are generated. Out of total 3825 test cases, the proposed scheme is capable to sense all cases of winding faults as an internal fault, at same time, it is also able to discriminate the magnetising inrush condition as an external event. The average response time achieved by this method is 10 ms (half cycle) which is lower than conventional method.

APPENDIX

Source Impedance	Z_1	0.8715 + j9.9615 Ω
	Z_0	1.743 + j19.923 Ω
Power Transformer	Rating	3-phase, 315 MVA, 400 kV/220 kV, 50 Hz
	Connection	YΔ11
	Reactance (per phase)	12.5%
	Magnetizing Current	0.1%
Current Transformer	Ratio	1/433
	Leakage Inductance	0.8 mH
	Burden Resistance	0.5 Ω

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