Three State Kalman Filter based Directional Protection of Power Transformer

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Abstract— **Due to interconnection, power system complexity is increasing day by day. So, reliable operation under fault conditions in power system is a major concern. As a heart of power system, transformer involves self importance with highest efficiency. Saturation of current transformer and magnetizing inrush are major issues for reliability of transformer protection. This paper presents detection of internal fault against external abnormalities on the basis of direction of primary and secondary current with respect to its voltages. Various fault and inrush case studies are generated on power transformer in PSCAD™ software. Three state Kalman filter is utilized to analyze current and voltage signals of primary and secondary side of power transformer. The algorithm is validated on MATLAB software after collecting data from PSCAD™ model. Various inrush, internal fault and external fault cases are authenticated using the projected scheme. It is observed that the proposed scheme effectively issue trip commands for all internal faults and remain inoperative for inrush and all external fault conditions.**

Keywords— Power transformer, directional protection, Inrush, Fault, CT Saturation, Three state Kalman Filter, Phasor difference.

I. INTRODUCTION

As an importance of power transformer in power system, it required continuous monitoring and most reliable protective scheme. In fact 10 % faults occur in transformer among whole power system and among them 70 % faults are belongs to winding faults [1]. Traditionally, percentage biased differential protection is mainly used with harmonic restrain or blocking techniques. Mainly harmonics are generated in transformer due to its core saturation [2]. Fault current is getting disturbed by inrush & CT saturation conditions. Even in the case of core saturation, 2nd harmonic value is more than 10 % [3]. This harmonic restrain based transformer protective schemes will fail in the cases of, inrush and CT saturation conditions as both will generate 2nd harmonic component. So it is necessary to discriminate CT saturation and inrush conditions to avoid mal operation in transformer protection.

If internal fault is followed by inrush and if the case is of internal fault with CT saturation then system must trip and under external fault with CT saturation conditions trip signal must be blocked. Percentage bias differential protection is provided in power transformer with slope to bias differential characteristics [3]. But, under heavy CT saturation condition, percentage biased protection may mal operate. Effect of harmonics in power transformer differential protection [4] is major issue to discuss and implement proper scheme. Even-Harmonic Restraint, Fifth-Harmonic Blocking is also explained in [5] but under internal fault with CT saturation condition, signal is blocked and system is not isolated. Virtual third harmonic theory [6] based analysis in transformer differential protection is also mal-operates under external fault with CT saturation. Harmonic restrain with V/f technique [7] is also utilized. Scheme of conventional second harmonic and DC decaying time with the ratio between the fundamental component and first peak magnitude [8] are also utilized for transformer protection. However, saturation followed by internal fault case is not concentrated. Time-frequency analysis [9] for transformer protection is also affected by noise signal. Impact of CT saturation [10] with degree of saturation and harmonic blocking during external fault, cross blocking with other phases are also one of the advance scheme for transformer protection. Full cycle Fourier algorithm and LES [11] based transformer fault detection with compromise of sharpness of filtering is proposed with limited validations. Half cycle Fourier transform [12] data window used for transformer protection with 97% efficiency. However, the scheme fails for CT saturates after first half cycle during external fault.

Recently many schemes related to transformer protection based on classifier and decomposing techniques are proposed. Support Vector Machine (SVM) [13] based classifier schemes are discussed in past without clearing how to collect training data in an actual field. Also PNN [14] based classifier techniques takes considerable time for testing and issue delayed trip signal. Also decomposing technique like Discrete Wavelet Transform (DWT) [15] with spectrum comparison technique used to discriminate internal and external abnormalities in transformer, however DWT increase waveform discrimination complexity. Two state Kalman filtering [16] technique used for adaptive differential protection of power transformer and also discriminate fault and abnormal conditions with very short duration. E. Esmile *et al.* [17] used Kalman filtering techniques to detect partial saturation of Current Transformers effectively to extract the phasor quantities of the unsaturated current.

Main problem in Fourier based algorithm is noise, which is overcome by Kalman filter based technique. In the proposed algorithm, three state Kalman filtering based techniques [18] is used to estimate phasors of current and voltage signals. It also calculates the angle between voltage and current of primary/secondary side of power transformer. Based on the

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direction of current from primary and secondary, the proposed algorithm, discriminates between internal fault and external abnormalities. Various test cases are simulated and validated to observe the effectiveness of the algorithm. Proposed technique and schematic diagram is elaborated in Section-II. Projected Kalman filtering process with mathematical formulation and its advantages are detailed in section III. Section-IV reveals simulation modeling and section-V presents result discussion and validation.

II. PROPOSED MATHODOLOGY

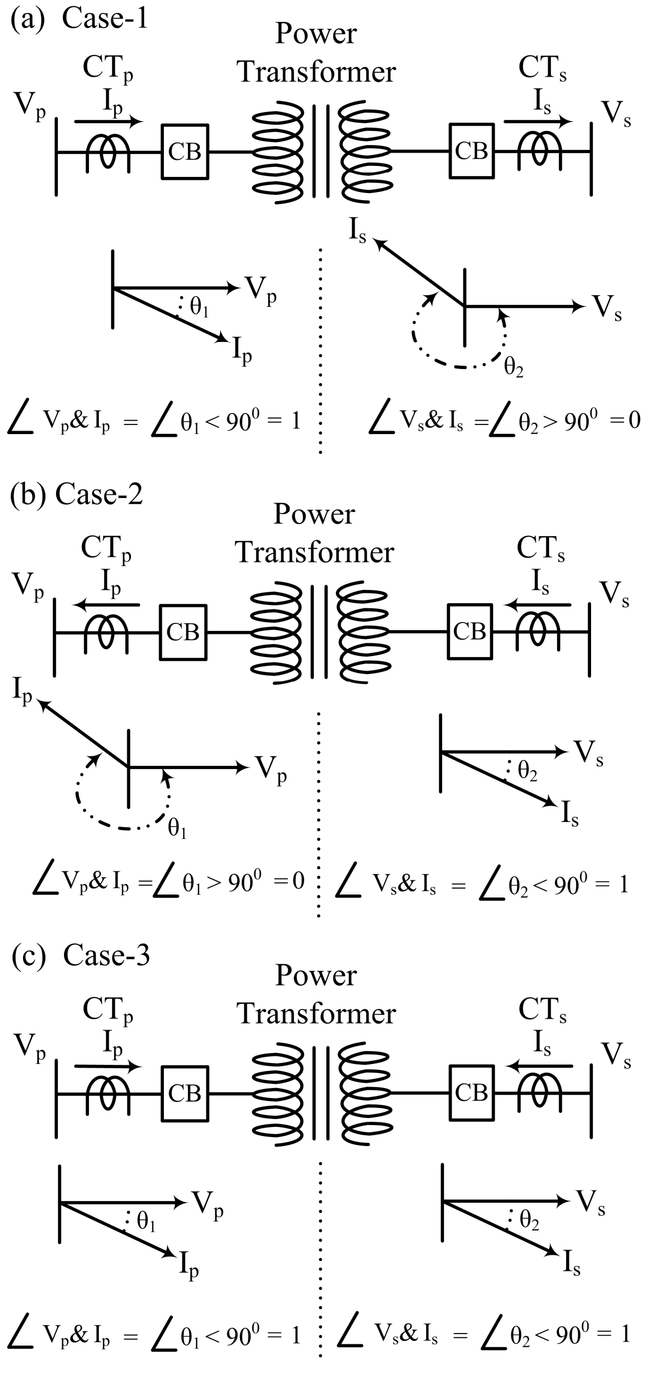


Figure 1: (a) External fault on line-2 (secondary side) (b) External fault on line-1 (primary side) (c) Internal Fault

Initially, the direction of current i.e. phasor angle are measured with the help of three state Kalman filter technique, which estimates phase angle of the actual current quantity with its referred voltage signal. The three state Kalman filter is tuned to fundamental frequency, hence it extract correct phase angle, out of given transient signal by eliminating DC component and unwanted harmonics. CTs and PTs are connected on both sides of the transformer to acquire the current and voltage signals for proposed relaying scheme. In connection to the proposed methodology, three possible cases are involved as shown in Fig.1. Here, the current direction is considered as positive (i.e.$-90^0 > \theta < 90^0$, relaying region) with respect to reference bus voltage, if current flowing towards transformer winding and away from bus then it generates ‘1’ (high signal). Contradictory, current flowing away from transformer winding and towards bus ($-90^0 < \theta > 90^0$, blocking region) then it generates ‘0’ (low signal). In Fig.1(a),Case-1 elaborates the condition of normal operation or external fault, as the current at the primary side is in positive direction and hence it generates ‘1’ but on the secondary side the current direction is negative side and hence it generates ‘0’. Similarly for Fig.1 (b), case-2, where primary side generates ‘0’ and secondary side generate ‘1’. Hence in both the cases 1 & 2, no trip signal is generated at the end of decision logic (AND logic) due to one low signal (0) at each time. If the current direction from both buses are positive i.e. toward transformer from both buses then trip signal generated due to both high (1) signals. This condition is treated as internal fault condition of the transformer as shown Fig.1(c), case-3.

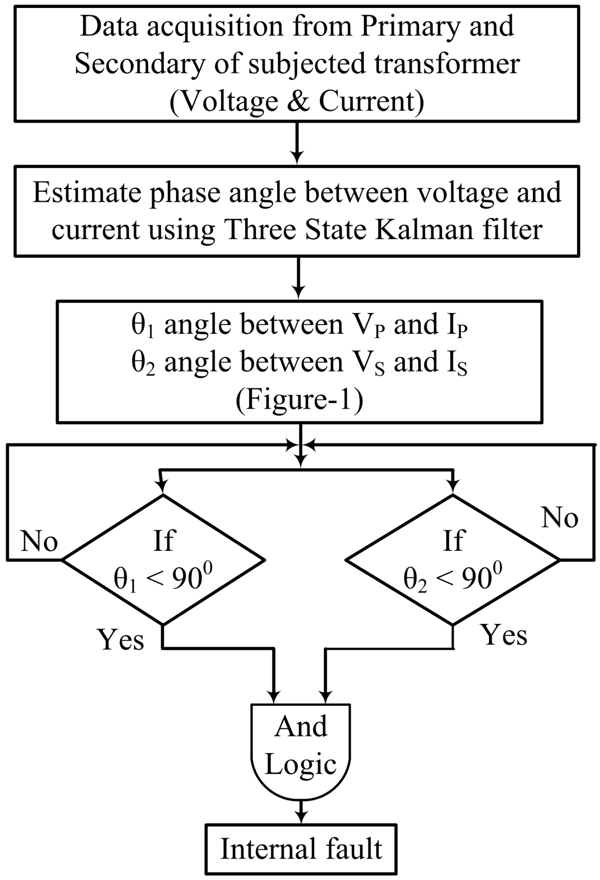


Figure 2: Proposed transformer protection algorithm

Fig.2 shows the block diagram of the anticipated directional protection scheme. The CTs & PTs secondary signals of transformer primary and secondary side are given as the input to the proposed algorithm. In case of different transformer connection such as delta-star connection the compensation of the phase angle is done by connecting star-delta CT respectively and vice versa. CT secondary currents and PT secondary voltages for one cycle duration is continuously fetching from the primary and secondary of the power transformer. From the given input the phasor angle of primary side current (θ_1) and secondary side current (θ_2) are calculated with the help of three states Kalman filtering technique as explained in the section III. It is good to note that the phasor angle is measured by taking bus voltages of both sides of transformer as the reference quantity. Only in the case if both signals of primary and secondary side current are positive then trip signal generated with AND decision logic.

At the time of inrush condition, the primary side phasor angle is in the relaying region and send high signal (1) but at that time the secondary side phasor angle is in the blocking region and send low signal (0) so the condition will not satisfied and hence the algorithm will not check any further condition and return back to fetch next current sample. This shows the effectiveness and computational simplicity of the proposed scheme.

An additional case of the worst condition can be considered as; if the bolted fault occurs on the transformer buses on either side then system cannot use the bus voltages for calculation of the phasor angle, at that instant the whole algorithm may not work because of unavailability of input. Hence, the proposed work acquires one cycle pre fault sample data of voltage signal from the stored buffer memory. With the help of this additional facility of buffering the data in memory, the scheme performs well in the case of unavailability of the voltage data.

III. Kalman Filtering Techniques and Its Advantage

Kalman filtering process is best option with respect to Fourier transform in terms of reliability, flexibility, mathematical ability, adaptive capability and also compatible with new transducers. Nowadays, due to high speed of computer execution, proposed filtering process gives better results than DFT [16].

State model for Kalman filtering process is

$$X_{k+1} = \emptyset_k X_k + W_k \tag{1}$$

Where, X_k is the state vector at time t_k, $\emptyset_k$ is transition matrix, W_k is uncorrelated vector sequence with known co-variance structure

$$V_{abc}(x,s) = AV_{012}(x,s)$$
$$I_{abc}(x,s) = AI_{012}(x,s) \tag{2}$$

Where, $A = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}$; $a = 1 \angle 120^0$

Transformer primary and secondary voltage equation with complex frequency domain $\begin{bmatrix} V_{PR} \\ V_{PY} \\ V_{PB} \\ I_{PR} \\ I_{PY} \\ I_{PB} \end{bmatrix} = [K] \begin{bmatrix} V_{SR} \\ V_{SY} \\ V_{SB} \\ I_{SR} \\ I_{SY} \\ I_{SB} \end{bmatrix}$ (3)

Where R, Y, B phase sequence, P & S refers Primary and secondary of Transformer respectively, K referred transferred resistance

And similarly symmetrical components are

$$\begin{bmatrix} Vs_{012} \\ Is_{012} \end{bmatrix} = \begin{bmatrix} U & -Z_T(s) \\ 0 & U \end{bmatrix} \begin{bmatrix} Vp_{012} \\ Ip_{012} \end{bmatrix} \tag{4}$$

Here, 0, 1, 2 refer zero, positive & negative sequence components sequentially.

Inversion process

$$f(t) = \frac{1}{2\pi} \int_{-\Omega}^{\Omega} F(\alpha + j\omega)(\sigma(\omega) \exp((\alpha + j\omega)t) d\omega \tag{4}$$

With discrete sample at

$$s = \alpha \pm j\frac{\Delta\omega}{2}, \alpha \pm j\frac{3}{2}\Delta\omega, etc \ldots.$$

And sigma factor $\sigma(\omega) = \frac{\sin(\frac{\omega\pi}{\Omega})}{\frac{\omega\pi}{\Omega}}$

Where α is convergence parameter, ω is step and $\Delta\omega$ is step length, range is defined as Ω.

State model to measure phasor component:

Two state Kalman filter is sufficient to estimate voltage but due to decaying component in current, three states Kalman filter is necessary for current and voltage angle measurement. Even due to adaptive capability, scheme allows high speed operation for terminal fault.

(1) State equation

$$\begin{bmatrix} X1_{k+1} \\ X2_{k+1} \\ X3_{k+1} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & e^{-\beta\Delta t} \end{bmatrix} \begin{bmatrix} X1_k \\ X2_k \\ X3_k \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ W_k \end{bmatrix} \tag{5}$$

(2) Measurement Equation

$$Z_k = [\cos\omega_0 k\Delta t \quad -\sin\omega_0 k\Delta t \quad 1] \begin{bmatrix} X1_k \\ X2_k \\ X3_k \end{bmatrix} + V_k \tag{6}$$

(3) The initial covariance matrix

$$\begin{bmatrix} \sigma_i^2 & 0 & 0 \\ 0 & \sigma_i^2 & 0 \\ 0 & 0 & \sigma_i^2 \end{bmatrix}$$

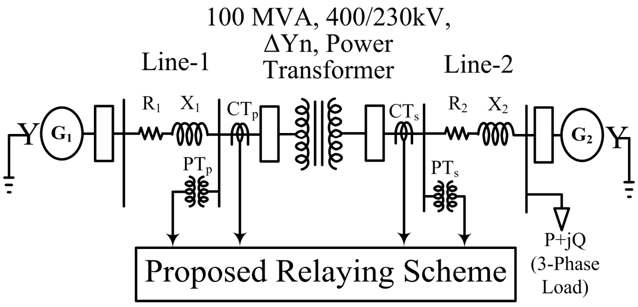
Advantages of Kalman filtering process with respect to Discrete Fourier Transforms (DFT) are as under [18]:

- It has autocorrelation function for noise signal, so remains stable against noise signal.
- Converge faster than DFT to estimate phasor quantities of voltage and current.
- Converge exact post fault values with steady state 1 percentage error after half cycle and 0.2 percentages error after full cycle, while DFT shown 5 percentages error after full cycle.
- Low computational burden.
- Feasibility to store off line computed past covariance data to reuse data from memory.

IV. Simulation Modelling

Recently, many researchers proposed various techniques to protect transformer but they all have some inherent limitations which is discussed in section I. Here, in this article authors have proposed directional based protection scheme using three state Kalman filters which can identify the direction of the flow of current from both side of power transformer. The direction of the current is measured by taking voltage as the reference quantity. The single line diagram of the considered power system is shown in Fig. 3.

100MVA, 400/230kV, 3 phase, power transformer is simulated in this study. Source (G1) has capacity of 100MVA, 400kV; 50 Hz is connected with a 50 km transmission line (Line 1) which fed the power transformer. The secondary side of the power transformer connected to another transmission line (Line 2) of 30 km and the Line 2 is terminated at bus 2. A load of 100MW, 25MVAR and another source (G2) of 100 MVA, 230kV, 50 Hz are connected on bus 2. Bus PTs and CTs of Primary and secondary side of power transformer fed voltage and current signals respectively, to the data acquisition system of the relaying scheme. The detailed ratings of each equipment of fig. 3 are given in Appendix-A. JA (Jiles-Atherton) model of CT is utilized to carry out precise simulation in PSCAD software [19] for accurate measurement of magnetic characteristics in power transformer protection.



P, S refer Primary and secondary
CT & PT refer current and potential transformer
1,2 refer line 1 and line 2 parameter

Figure 3: System Diagram

Model is simulated in PSCAD™ software and collected sampled data is used to find current direction and angle with respect to reference voltage by three states Kalman filtering in MATLAB coding.

V. RESULT ANALYSIS

A. *Magnetic Inrush*

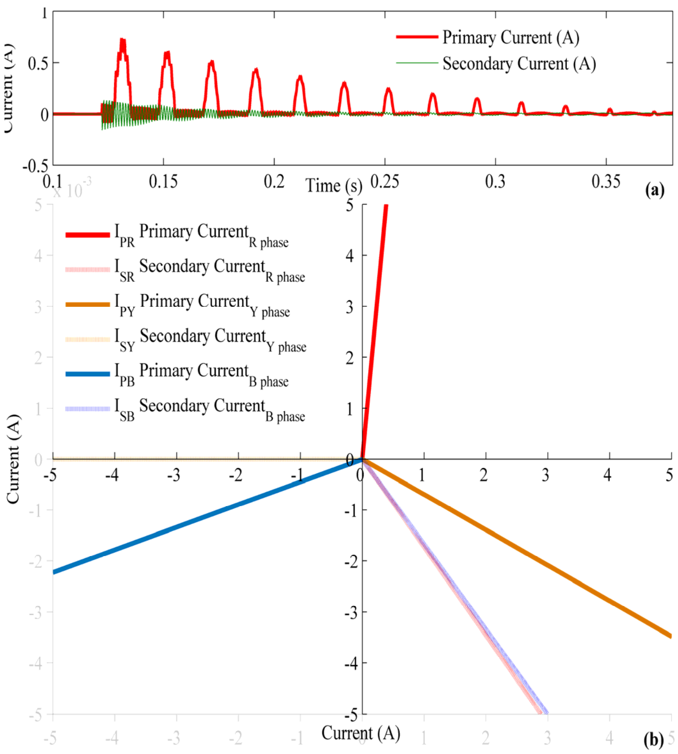


Figure 4 Magnetic inrush (a) Primary and secondary current waveform (b) Primary & Secondary current phasor

Under secondary open circuited condition, inrush generated in primary of transformer due to core saturation. Figure 4(a) shows current waveform of inrush conditions simulated in this work. Figure 4(b) shows primary and secondary current phasors with its voltage assessment.

Table-I Algorithm operation for various test conditions

Sr. No.	Various test conditions		Primary		Secondary		Final signal
			High(1) /Low(0)	Θ_1	High(1)/ Low(0)	Θ_2	Trip(1)/ Block(0)
1.1	Inrush	R	1	85.55	0	-59.98	0
		Y	1	-34.84	0	-180	
		B	0	-156.0	1	59.1	
2.1	Internal Fault (L-G)	R	1	-83.19	1	-88.29	1
		Y	1	-88.42	0	-173.1	
		B	1	-89.19	0	90.77	
2.2	Internal Fault (L-L-G)	R	1	-69.97	1	-59.88	1
		Y	0	140.3	0	134.8	
		B	0	-142.2	0	104.8	
2.3	Internal Fault (L-L-L-G)	R	1	-84.9	1	-59.02	1
		Y	0	155	1	-59.02	
		B	1	34.22	1	59.65	
2.4	High Resi. Internal Fault (L-G)	R	1	-22.61	1	2.635	1
		Y	0	-142.6	0	-117.4	
		B	0	96.49	0	121.7	
2.5	CT Satu. In Internal Fault (L-G)	R	1	-83.18	1	-87.74	1
		Y	1	-87.86	0	-175.5	
		B	1	-88.58	0	91.37	
3.1	External Fault (L-G)	R	0	90.5	1	-89.49	0
		Y	1	-59.57	0	-182.8	
		B	0	-90.36	1	89.55	
3.2	External Fault (L-L-G)	R	0	115	1	-60.05	0
		Y	1	-55.16	0	134.6	
		B	0	-147.3	0	104.7	
3.3	External Fault (L-L-L-G)	R	0	90.73	1	-59.07	0
		Y	1	-29.39	0	-179.6	
		B	0	-150.6	1	59.56	
3.4	High Resi. External Fault (L-G)	R	0	153.7	1	3.667	0
		Y	1	33.69	0	-116.4	
		B	1	-87.22	0	122.8	
3.5	CT Saturation in External Fault(L-L-G)	R	1	115.9	0	-10.09	0
		Y	0	-54.35	0	135.3	
		B	1	-147.1	0	105.7	

Table-I shows the result analysis of the proposed scheme for the simulation model shown in the Fig. 3. Various test cases are considered here in the article and the same were simulated on the PSCAD™ software to thoroughly validate the proposed three state Kalman filtering process based directional protection scheme.

From the Table-I It can be seen that in the case of inrush condition the primary and secondary side phasor angle did not generate high signal (1) simultaneously and hence the relay will not generate the trip signal. Similarly, in the case of any internal fault condition as shown from the table, if any like phase signals of both side are high (1) simultaneously then it generates trip signal. On the other hand, in the external fault cases as shown in Table-I, no like phase of both sides of transformer generates high signal (1) simultaneously and hence relay did not generate trip signal and consequently the system will remain in the stable condition.

B. *Internal fault(L-L-G)*

As per the protection scheme, if phasor angle of current signal of like phase from primary and secondary side is less than 90 degree then it produce high signal for decision logic. This mean, the direction of the primary side current and secondary side current are opposite (applicable only in the case of interconnected system or the system having the source which also fed from the secondary side of the transformer) which generates a trip signal and operates the circuit breaker.

Fig.5 (a & b) shows results of internal fault with phasor angle. Fig. 5(a) shows primary and secondary current waveform. It is clear from Table-I and Fig. 5 (b) that for each internal fault cases the relay gives consistent operation.

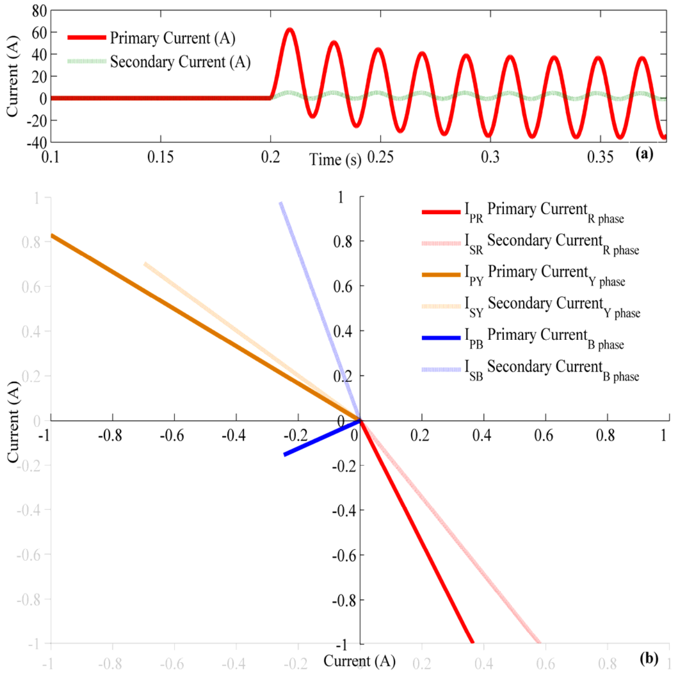


Figure 5 Internal fault (a) Primary and secondary current waveform (b) Primary & Secondary current phasor

C. External fault(LL_G)

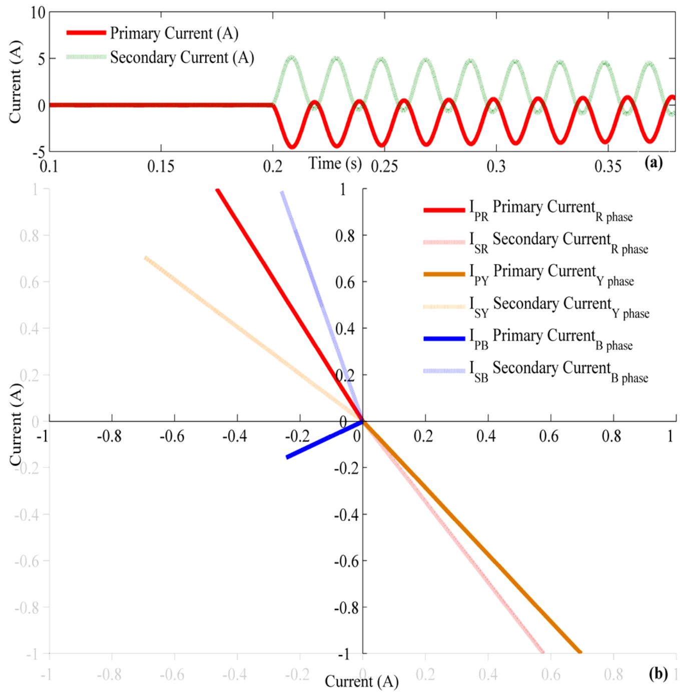


Figure 6 External fault (a) Primary and secondary current waveform (b) Primary & Secondary current phasor

Conversely, if the external fault occurs on any side of the transformer (outside CT location) or in the case of the inrush condition the direction of the current will remain same and hence the condition will not satisfied and algorithm will fetch next current sample. Algorithm validation is carried out as per Figure-6 and Table-I.

During external LL-G fault simulated on line-1, phasor angle with respect to its concern voltage of primary and secondary current are as shown in Fig. 6 (b). From result analysis with various external fault test conditions, it is clear that no high signal generated from any phase simultaneously. Finally relay remains in its inoperative condition and no trip signal is generated as per algorithm.

D. CT saturation during external fault(LL-G External Fault with CT saturation)

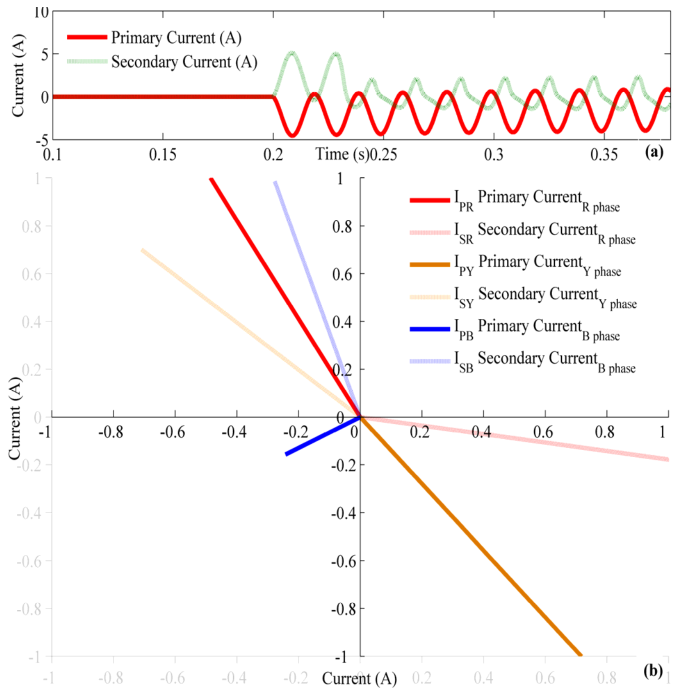


Figure 7 External fault with CT saturation (a) Primary and secondary current waveform (b) Primary & Secondary current phasor

In case of external fault condition with CT saturation, current direction of primary and secondary side is same because fault is external and hence as per algorithm, relay didn't get high signal and doesn't issue trip signal. Magnitude based relay may mal-operate in case of external fault with CT saturation condition.

Also, as shown in Fig.7(a&b) that the phasor angle difference of the currents are not fall in the tripping category which maintain the block condition of the relay.

VI. CONCLUSION

This article presents a new directional protection scheme for power transformer based on three state Kalman filter. To authenticate the proposed scheme, a power system is simulated in PSCAD^{TM} software and validated in MATLAB software. Various internal fault, inrush condition and external fault with CT saturation cases are considered with variation in parameters. It is to be noted that, during internal fault condition the direction of current with respect to reference voltage from both buses are towards the transformer and contradictory for normal and external fault situation. Hence, in the case of normal, inrush and external fault conditions the direction of the current of both the sides of transformer remains same while in the case of internal fault condition the current direction will be opposite to each other which intimates that the condition is of internal fault. Authors also considered the worst case of unavailability of the voltage reference quantity; in that case the scheme used the buffer data which works as backup to provide complete protection of the transformer. CT saturation condition and High resistance internal fault cases are also validated in the software.

The result analysis carried out in this work proves the efficacy of the proposed scheme in respect to other magnitude or pattern recognition based protection scheme in terms of the accuracy, computational simplicity and resistant to external disturbances.

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References

[1] J. L. Blackburn and T. J. Domin, *Protective Relaying Principles and Applications*. 2006.

[2] Y. G. Paithankar and S. R. Bhide, *Fundamentals of power system protection*. PHI Learning Pvt. Ltd., 2010.

[3] B. Bhalja, R. P. Maheshwari, and N. G. Chothani, *Protection and switchgear*, Second edi. New Delhi, India: Oxford university press, 2017.

[4] E. Madzikanda and M. Negnevitsky, "A practical look at harmonics in power transformer differential protection," in *2012 IEEE International Conference on Power System Technology (POWERCON)*, 2012, pp. 1–6.

[5] A. Guzman, S. Zocholl, G. Benmouyal, and H. J. Altuve, "A Current-Based Solution for Transformer Differential Protection Part II: Relay Description and Evaluation," *IEEE Power Eng. Rev.*, vol. 22, no. 7, p. 60, Jul. 2002.

[6] D. Chen, W. Chen, X. Yin, Z. Zhang, and Y. Hu, "The analysis of operation characteristic of transformer differential protection based on virtual third harmonic theory," in *Proceedings. International Conference on Power System Technology*, 2002, vol. 2, pp. 720–722 vol.2.

[7] C. J. Mozina, "Protection and Commissioning of Multifunction Digital Transformer Relays at Medium Voltage Industrial Facilities," in *2006 IEEE Industrial and Commercial Power Systems Technical Conference - Conference Record*, 2006, pp. 1–11.

[8] A. K. Al-Othman and K. M. El-Naggar, "A New Digital Dynamic Algorithm for Detection of Magnetizing Inrush Current in Transformers," *Electr. Power Components Syst.*, vol. 37, no. 4, pp. 355–372, 2009.

[9] Z. Moravej, A. A. Abdoos, and M. Sanaye-Pasand, "Power transformer protection scheme based on time-frequency analysis," *Int. Trans. Electr. Energy Syst.*, vol. 23, no. 4, pp. 473–493, 2013.

[10] M. Stanbury and Z. Djekic, "The impact of current transformer saturation on transformer differential protection," *IEEE Trans. Power Deliv.*, 2015.

[11] H. Abniki and M. Sanaye-Pasand, "A novel technique for internal fault detection of power transformers based on moving windows," *Int. Trans. Electr. Energy Syst.*, vol. 24, no. 9, pp. 1263–1278, 2014.

[12] B. Khalkhali and J. Sadeh, "Transformer Differential Protection by Online Core Modeling and Orthogonal Polynomials," *IEEE Trans. Power Deliv.*, vol. 30, no. 5, pp. 2146–2153, Oct. 2015.

[13] A. M. Shah and B. R. Bhalja, "Discrimination Between Internal Faults and Other Disturbances in Transformer Using the Support Vector Machine-Based Protection Scheme," *IEEE Trans. Power Deliv.*, vol. 28, no. 3, pp. 1508–1515, Jul. 2013.

[14] Z. Moravej, A. A. Abdoos, and M. Sanaye-Pasand, "A New Approach Based on S-transform for Discrimination and Classification of Inrush Current from Internal Fault Currents Using Probabilistic Neural Network," *Electr. Power Components Syst.*, vol. 38, no. 10, pp. 1194–1210, 2010.

[15] C. Jettanasen and A. Ngaopitakkul, "The Spectrum Comparison Technique of DWT for Discriminating between External Fault and Internal Fault in Power Transformer," *J. Int. Counc. Electr. Eng.*, vol. 2, no. 3, pp. 302–308, 2012.

[16] A. A. Girgis, D. G. Hart, and W. B. Chang, "An adaptive scheme for digital protection of power transformers," in *[Proceedings] Conference Papers 1991 Power Industry Computer Application Conference*, 1991, pp. 2–9.

[17] E. M. Esmail, N. I. Elkalashy, T. A. Kawady, A. I. Taalab, and M. Lehtonen, "Detection of Partial Saturation and Waveform Compensation of Current Transformers," *IEEE Trans. Power Deliv.*, vol. 30, no. 3, pp. 1620–1622, Jun. 2015.

[18] A. A. Girgis, "Application of Kalman filtering in computer relaying of power systems," 1981.

[19] PSCAD Research Center, *EMTDC-Transient Analysis for PSCAD Power System Simulation*. Winnipeg, MB, Canada, 2005.

Appendix-A

Equipment Rating	G1	G2
MVA	100 MVA	100 MVA
KV	400 KV	230 KV
Frequency	50 Hz	50 Hz
Positive sequence impedance	0.2	0.2
Positive sequence phase angle	85 degree	85 degree
Zero sequence impedance	0.05 ohm	0.05 ohm
Zero sequence phase angle	85 degree	85 degree
Phase	30 degree	0 degree

Transmission Line:

$R = 0.162 \times 10^{-5}$ ohm/m, $X_L = 0.124 \times 10^{-2}$ ohm/m, $X_C = 374.34$ Mohm/m

Load: P = 100 MW, Q = 25 MVAR