# Current Differential Protection of Alternator Stator Winding

N.W.Kinhekar, Sangeeta Daingade, and Ajayshree Kinhekar

***Abstract*—This paper describes a digital technique for detecting internal faults in stator windings of alternator. The technique uses current phasors measured at both ends of stator windings and implements differential protection. These current phasors at both ends are calculated using recursive DFT algorithm. ATP-EMTP package has been used for simulations and generation of fault data which is then processed in MATLAB to get fundamental frequency current phasors and to implement relay logic. Results of case studies of single line to ground and line to line fault are presented.**

***Keywords*: Current differential protection, alternator, internal faults, ATP-EMTP.**

## I. Introduction

SYNCHRONOUS generator is the most important element of power system. Generators do experience short circuits and abnormal electrical conditions. In many cases, equipment damage due to these events can be reduced or prevented by proper generator protection. Generators, unlike some other power system components, need to be protected not only from short circuits, but also from abnormal operating conditions. Examples of such abnormal conditions are over-load, over-excitation, over-voltage, and loss of field, unbalanced currents, reverse power, and abnormal frequency. When subjected to these conditions, damage or complete failure can occur within seconds, thus requiring automatic detection and tripping. All faults associated with synchronous generators may be classified as either insulation failures or abnormal running conditions [1], [2]. An insulation failure in the stator winding will result in either an interturn fault, a phase fault or a ground fault, but most commonly the latter since most insulation failures eventually bring the winding into direct contact with the core [1]. Differential relays, in particular the digital ones, are used to detect stator faults of generators.

Electric power utilities and industrial plants tradionally use electromechanical and solid-state relays for protecting synchronous generators [3]. With the advent of digital technology, researchers and designers have made significant progress in developing protection systems based on digital and microprocessor techniques [4], [5]. Several microprocessor based algorithms for detecting stator winding faults have been proposed. Sachdev and Wind [6] developed an algorithm that uses instantaneous differences between line and neutral end currents for detecting phase faults. Tao and Morrison [7] have used the discrete Fourier transform and Walsh functions to calculate the phasors of the fundamental frequency and third-harmonic voltages. An on-line digital computer technique for protection of a generator against internal asymmetrical faults is described by P. K. Dash and O. P. Malik [8], [9] in which the discrimination against external faults is achieved by monitoring the direction of the negative sequence power flow at the machine terminals. In this paper, we are proposing digital differential technique in which currents at the both ends of stator windings are measured and calculated fundamental frequency phasors of this currents using DFT.

The paper is organized as follows. Section II presents a general introduction of ATP and the simulation model of synchronous generator. Section III demonstrates and discusses the proposed technique and DFT algorithm used to calculate phasors. Section IV presents the results of case studies for internal and external fault and tripping logic for differential relay. Finally the conclusion is given in Section V.

## II. ATP-EMTP Modelling of Synchronous Generator

The alternative transient program (ATP) provides the graphical interface to electromagnetic transient program (EMTP) on the MS-Windows platform. It can solve any single and multiphase network which consists of interconnections of linear and non-linear components. ATP library has many in built models including rotating machines, transformers, surge arrestors, MOV, transmission lines and cables [10]. The model SM-59 provides detail dynamic modeling of synchronous machine. In addition to rated voltage, current and frequency, the model needs d and q axis steady state, transient and sub-transient reactances. It also needs value of moment of inertia, damping coefficient and number of poles. When dynamics of the machine is not required, sinusoidal voltage source model Type-14 can be used. Thus the package is preferred for modeling of synchronous generator to study the differential protection scheme. Figure 1 represents synchronous machine model in ATP-EMTP used to do fault analysis. Single line to ground fault is created at the mid point of stator winding. Currents at the both ends of stator windings are measured and stored in a file and used for phasor estimation in MATLAB. Current phasors at the both ends of stator windings are

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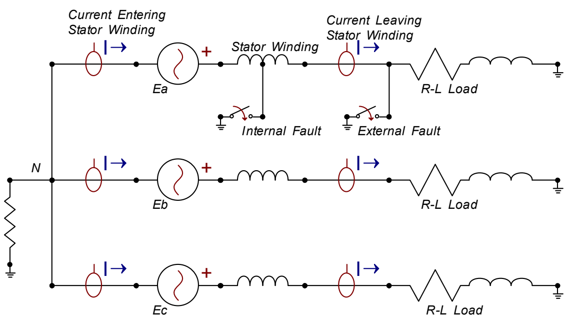


Fig. 1. Synchronous Machine Model

obtained using DFT algorithm which is explained in section III. Difference of these current phasors at both ends is taken and differential relay logic is used.

## III. PROPOSED TECHNIQUE

In this paper, ATP-EMTP software is used to produce reliable fault data. Fault is created on the stator winding. On the both sides of stator winding current meters are connected which represents current transformers. These current meter measures current entering into stator windings, which are called starting end currents represented as IaS, IbS, and IcS for three phases a, b, c respectively as shown in figure 2.

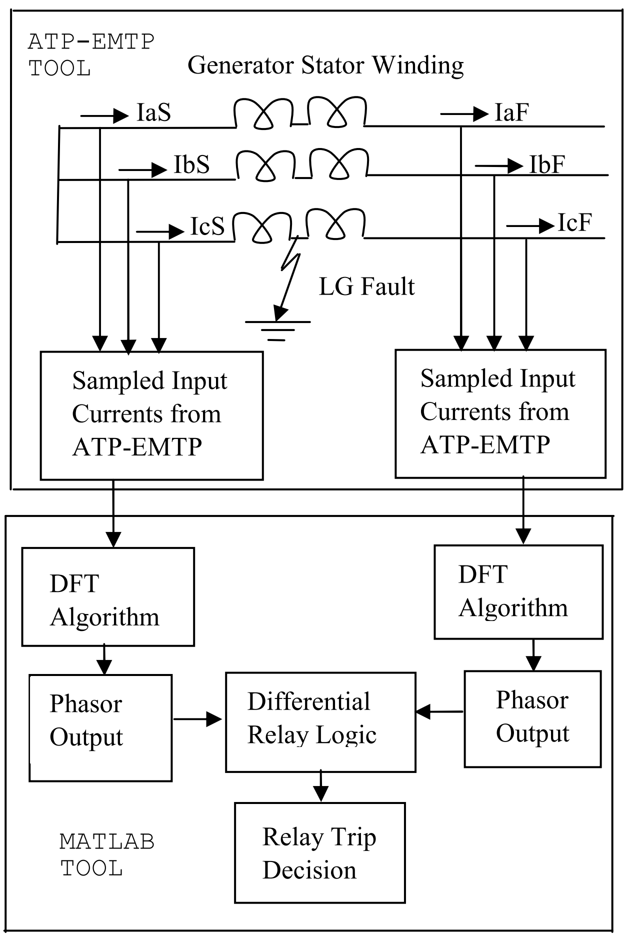


Fig.2. Block diagram of proposed scheme

Similarly, currents at the other end of stator winding called as finishing end currents are represented as IaF, IbF and IcF are measured by current meters at that end. Ground fault is created at the midpoint of stator winding of one of the phase. Fault data measured by current meters at both end of stator windings is stored in a file. This fault data is in the discrete sampled form. Thus, simulation in ATP-EMTP gives discrete samples of currents at both ends of stator winding. These current samples are then processed in MATLAB to produce fundamental frequency current phasors using recursive DFT algorithm [11]. Real and imaginary components of these current phasors at both ends of stator winding are compared. It is observed that, under no fault condition, difference of real and imaginary components of current at the both end is zero and under fault condition, it is greater than zero. Based on this analysis, differential relay logic is applied and relay trip or no-trip decision is taken. Single line to ground fault and line to line fault, internal and external to the stator winding are simulated and results are discussed as a case study in next section.

## IV. CASE STUDY

Single line to ground and line to line faults are simulated on synchronous machine stator winding in ATP-EMTP. Analysis of these faults is illustrated below.

### *A. Internal Fault*

Single line to ground fault is simulated at the midpoint of phase ‘a’ stator winding as shown in figure 1. Currents entering stator windings are shown in figure 3 below.

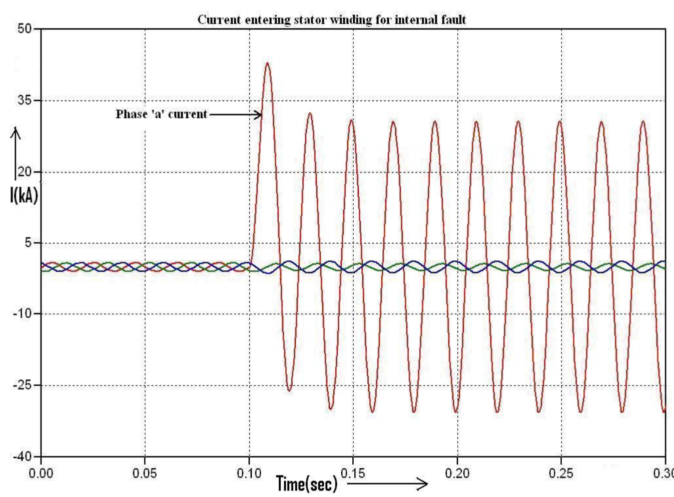


Fig.3. Current entering stator winding

Currents leaving stator winding are as shown in figure 4 below. It is observed that current leaving the stator winding of phase ‘a’ is zero for internal fault.

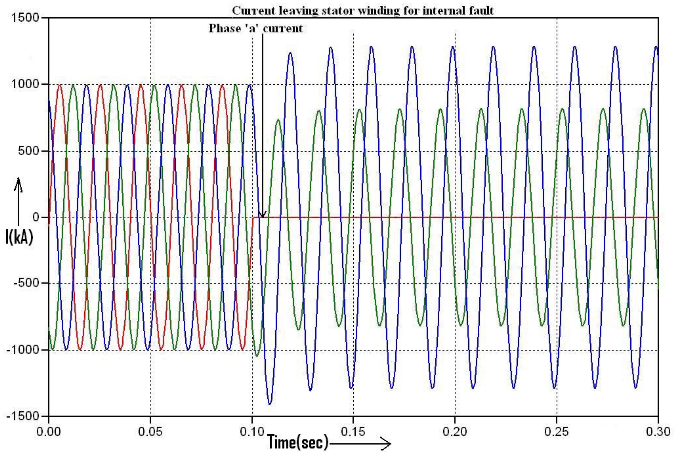


Fig.4. Current leaving stator winding

Similarly line to line fault is simulated at the midpoint of phase ‘a’ and phase ‘b’ of stator winding. Currents entering stator windings are shown in figure 5 below.

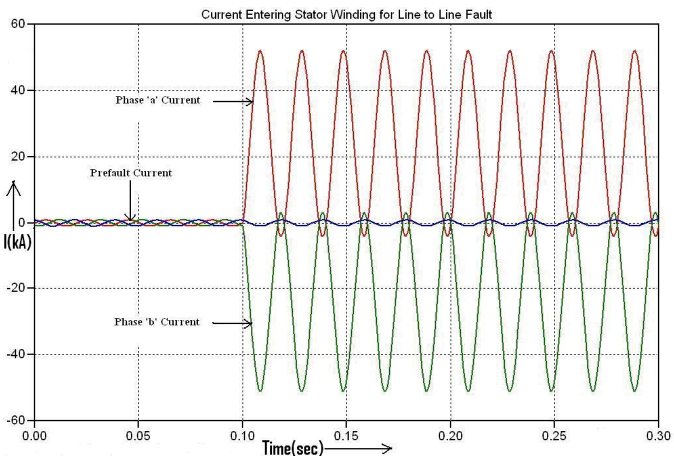


Fig.5. Current entering stator winding

Currents leaving stator winding for line to line fault are as shown in figure 6 below.

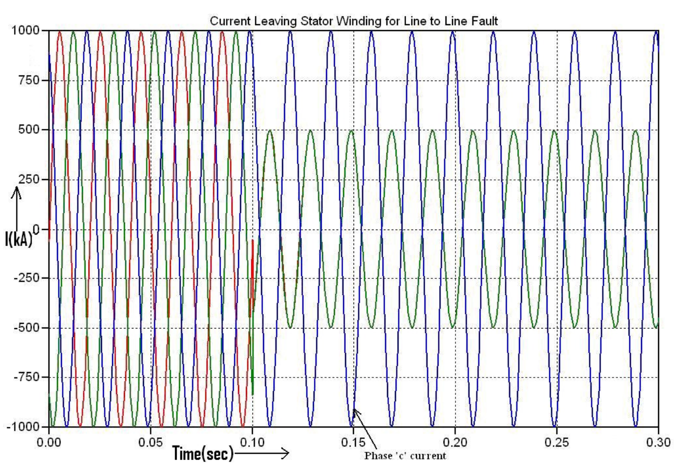


Fig.6. Current leaving stator winding

These currents at starting end and at finishing end of stator windings are stored in a file and processed in MATLAB. Currents at both ends are in sampled form and recursive DFT algorithm is applied to calculate fundamental frequency phasor. Both magnitude and phase angles are calculated.

Magnitudes of currents at both ends of stator windings for single line to ground fault are as shown in figure 7 (a) and (b) below.

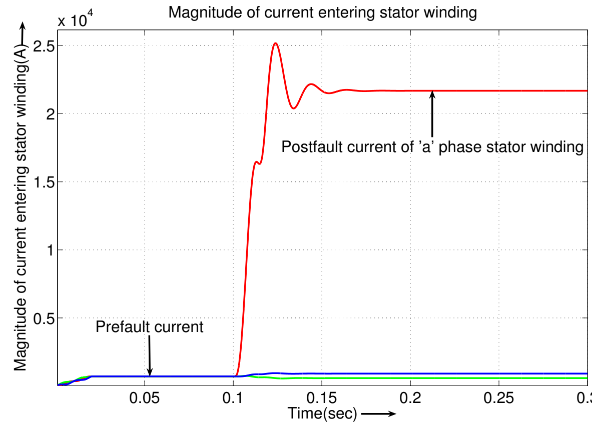


Fig.7 (a) Magnitude of current entering stator winding

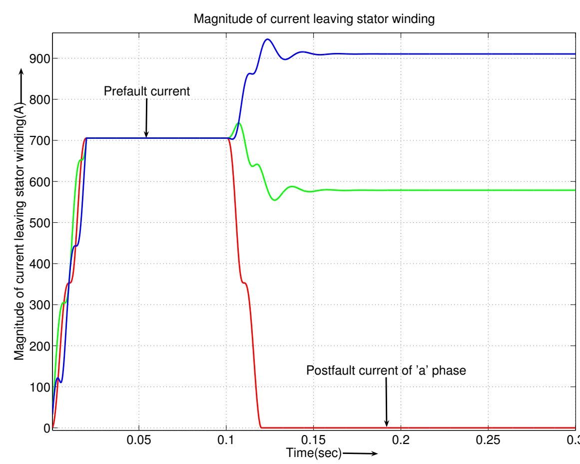


Fig.7 (b) Magnitude of current leaving stator winding

Magnitudes of currents at both ends of stator windings for line to line fault are as shown in figure 8 (a) and (b) below.

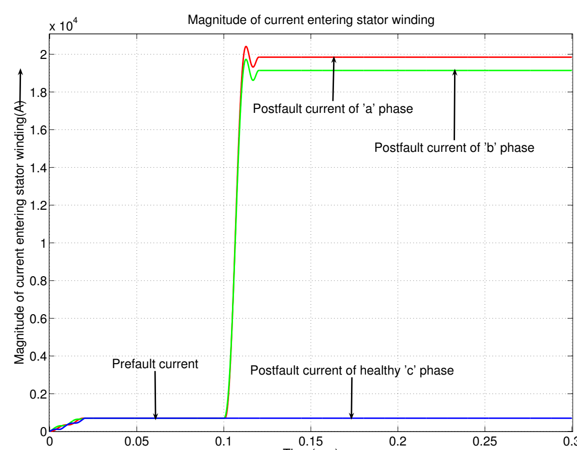


Fig.8 (a) Magnitude of current entering stator winding

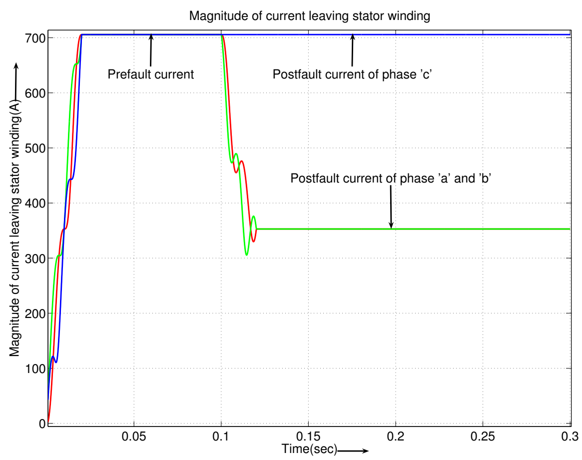


Fig.8 (b) Magnitude of current leaving stator winding

Phase angles of currents at both ends of stator windings for single line to ground fault are as shown in figure 9 (a) and 9 (b) below.

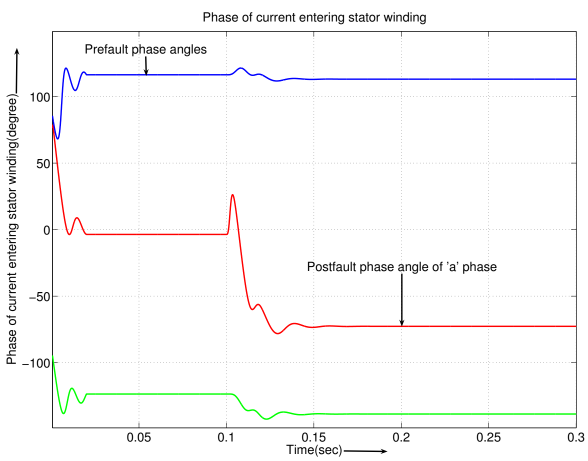


Fig.9 (a) Phase angle of current entering stator winding

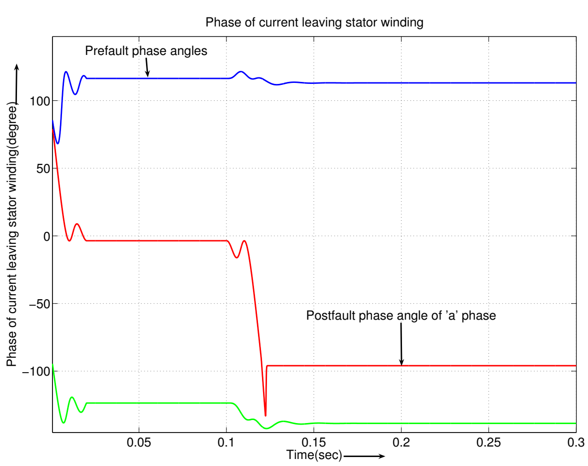


Fig.9 (b) Phase angle of current leaving stator winding

From above figure 7 (a) and (b), it is observed that after fault inception on phase ‘a’ stator winding at 0.1s, current at starting end rises to high value and current at finishing end becomes zero. From figure 9 (a) and (b), it is observed that after fault inception, there is unbalance in the phase angles of currents at both ends. Similarly, unbalance in the phase angles is also observed in case of line to line fault.

After calculating magnitude and phase angle of currents at both ends of stator windings, there real and imaginary components are calculated. For single line to ground fault, the difference of real and imaginary components of currents at both ends is taken and is as shown in figure 10 (a) and 10 (b) below.

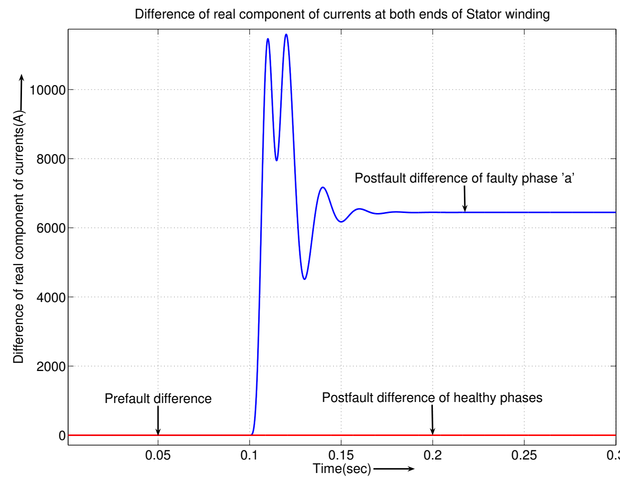


Fig.10 (a) Difference of real component of currents at both ends

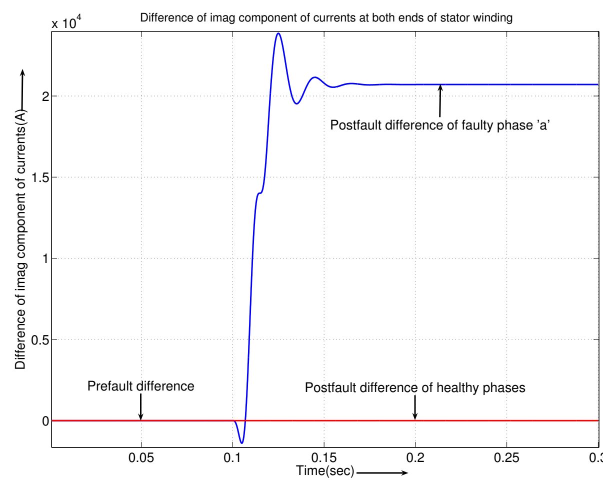


Fig.10 (b) Difference of imaginary component of currents at both ends

From figure 10 (a) and (b), it is observed that, during prefault condition, difference of currents at both ends is zero for both faulty as well as healthy phases. After fault inception, this difference rises to very high value for faulty phase. This change in difference of currents at both ends is used for fault discrimination and also to generate the trip signal for circuit breaker.

Differential relay logic is developed based on the change in difference of real and imaginary components of currents at both ends of stator winding. Figure 11 shows the trip signal. It is observed that at 0.1s relay issues trip signal.

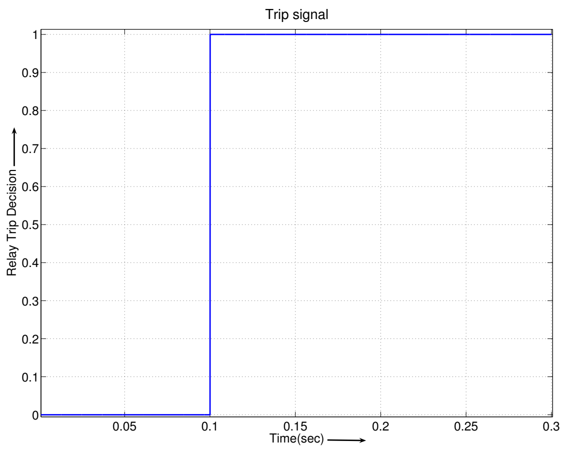


Fig.11 Trip signal

Similar analysis is carried out for line to line fault and generates the trip signal.

### B. External Fault

Single line to ground fault is simulated at the terminal of phase ‘a’ stator winding as shown in figure 1. If single-line to ground fault occurs on terminal of synchronous generator that is external to the stator winding, then currents at both ends of stator windings remains same as shown in figure 12 (a) and (b) below.

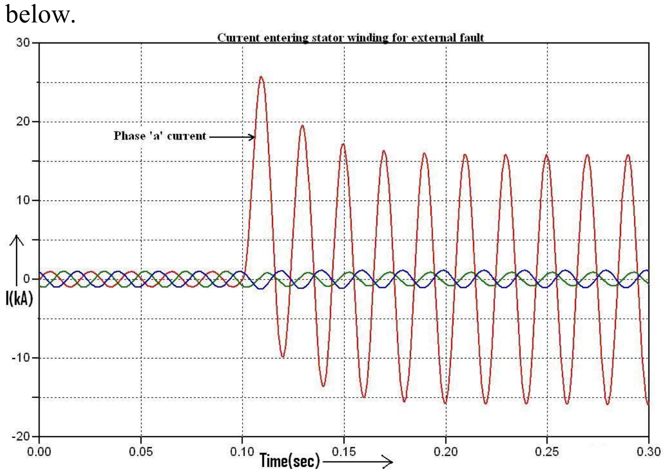


Fig.12 (a) Currents entering stator winding for external line to ground fault

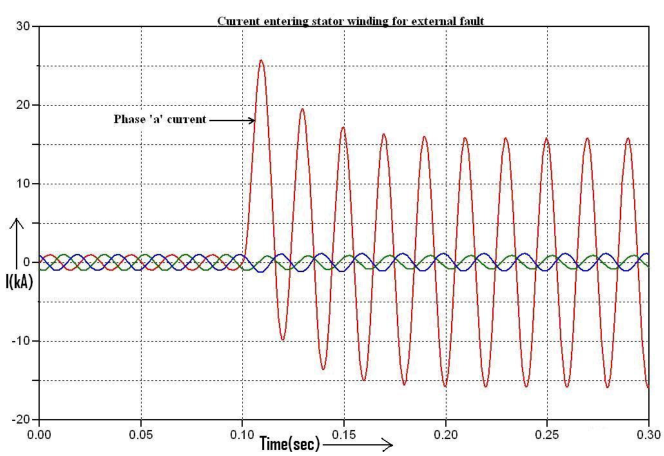


Fig.12 (b) Currents leaving stator winding for external line to ground fault

If line to line fault occurs on terminal of synchronous generator that is external to the stator winding, then currents at both ends of stator windings remains same as shown in figure 13 (a) and (b) below.

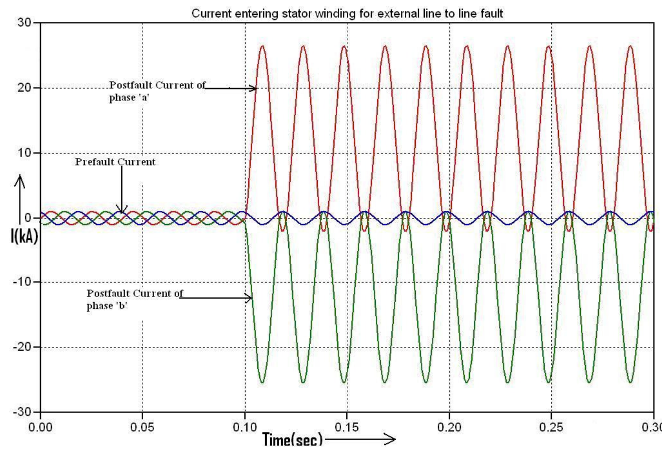


Fig.13 (a) Currents entering stator winding for external line to line fault

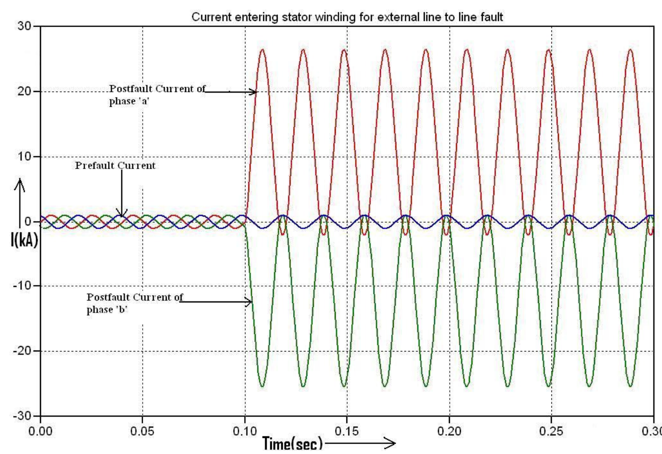


Fig.13 (b) Currents leaving stator winding for external line to line fault

Therefore, for fault external to the stator winding, differential relay does not issue trip signal. Figure 14 (a) and (b) shows the magnitude of currents at both ends of stator winding for external single line to ground fault.

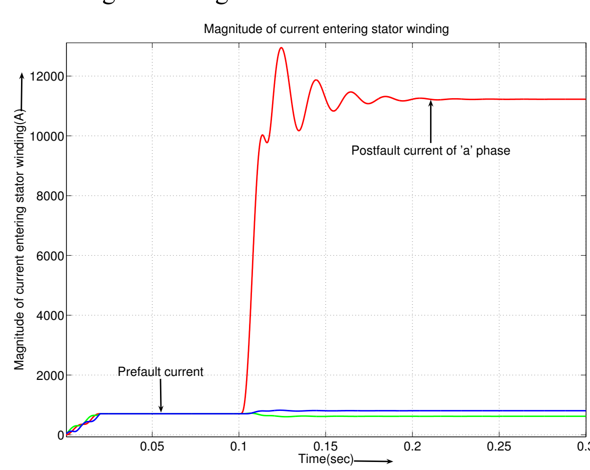


Fig.14 (a) Magnitude of current entering stator winding for external fault

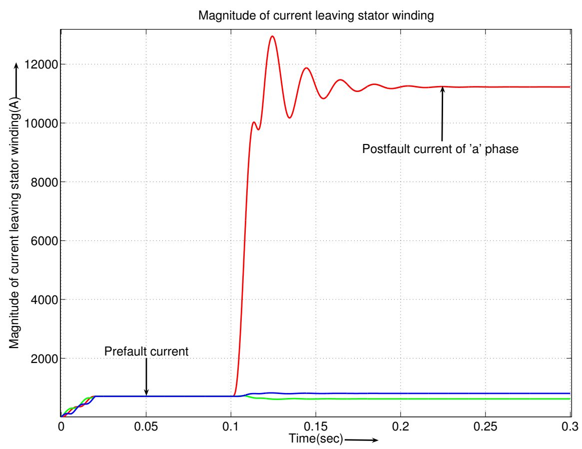


Fig.14 (b) Magnitude of current leaving stator winding for external fault

From figure 14 (a) and (b), it is observed that magnitude of currents at both ends remains same. Figure 15 (a) and (b) shows phase angles of currents at both ends for the single line to ground fault external to the stator windings.

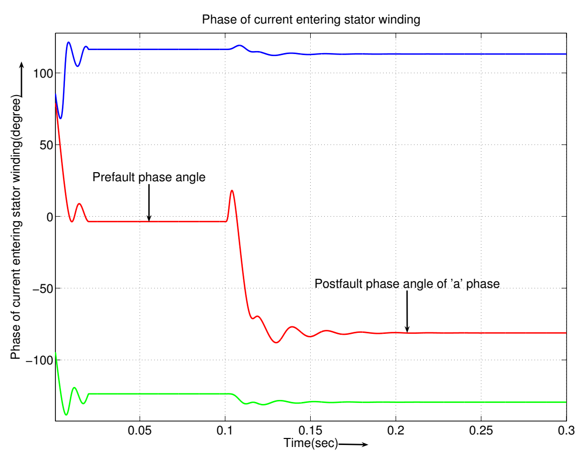


Fig.15 (a) Phase angle of current entering stator winding

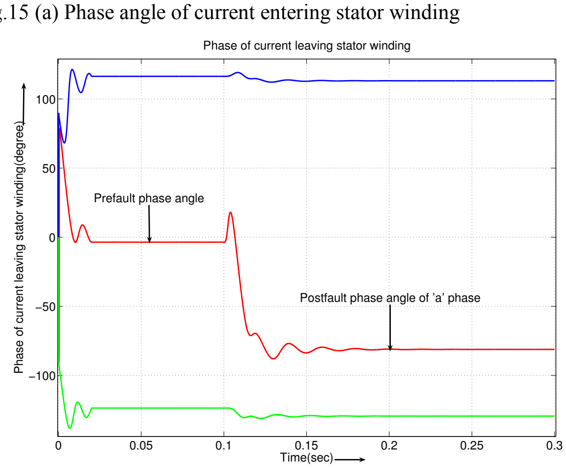


Fig. 15 (b) Phase angle of current leaving stator winding

From figure 15(a) and (b), it is observed that phase angle of currents at both ends of stator windings for external fault remains same. After calculating magnitude and phase angle of currents at both ends of stator windings, there real and imaginary components are calculated. The difference of real and imaginary components of currents at both ends is taken and is as shown in figure 16 (a) and (b) below.

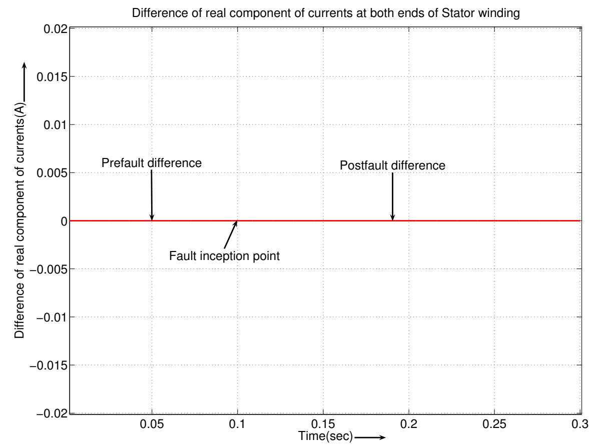


Fig.16 (a) Difference of real component of currents at both ends

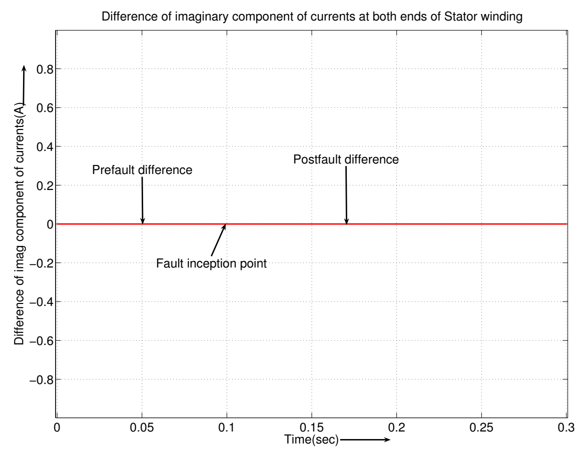


Fig.16 (b) Difference of imaginary component of currents at both ends

It is observed that, difference of real and imaginary components of current at both ends for all three phases is zero for both prefault and postfault condition. Similar analysis is carried out for line to line fault external to stator windings.

Therefore, differential relay does not trip for this external fault. Trip signal for this condition is as shown in figure 17, below.

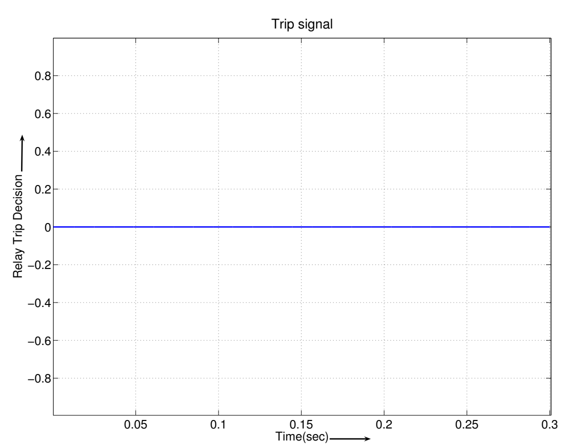


Fig. 17 Trip signal for external fault

Similar analysis is carried out with double line to ground fault internal to stator windings and external to stator windings. It is observed that differential relay does not trip for external fault and issues trip signal for internal fault.

## V. CONCLUSIONS

A digital differential technique for detecting generator stator winding internal faults has been presented in this paper. ATP-EMTP software has been used for generating fault data and then processed in MATLAB to get fundamental frequency current phasors. These current phasors at both ends are calculated using recursive Discrete Fourier Transform algorithm. Current phasors at both ends of stator windings are used in differential algorithm to implement relay logic. Results of case studies of single line to ground and line to line fault are presented.

Case study results shows that the technique used correctly discriminates between internal and external faults on the stator winding. The results are applicable to other internal unsymmetrical faults also.

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