Sequence Component Based RMS Computation for the Detection of Single Phasing of SVPWM Fed Induction Motor

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ABSTRACT
Industry uses three phase induction motors (IMs) extensively because of its durability, low maintenance costs, high efficiency, self-starting torque, and other features. These days, industry also makes extensive use of 'space vector pulse width modulation (SVPWM)' and 'pulse width modulation (PWM)' fed induction motors for smooth control of IM. In all those situations, a strong protection plan is very necessary. Induction motor defects, if quickly identified, can minimize industry downtime. In this work, the root mean square (rms) value of the negative-sequence-component current was analysed to identify the single phasing condition of the SVPWM fed induction motor. 'A-phase' input current of the induction motor has been captured and recorded first, then negative sequence component's root-mean-square (rms) value was calculated. Comparing these values to the ideal situation, single phasing is detected. This suggested method thus allows for extremely early protection of induction motors.

Keywords: Induction motor, Negative sequence component, Root mean square, Single phasing, Space vector pulse width modulation

1. INTRODUCTION

An essential component of industrial processes, three-phase induction motors (IMs) are valued for their resilience, low maintenance costs, high efficiency, and capacity for self-starting. The performance and controllability of these motors have been further improved by the development of control techniques like SVPWM and PWM, making them even more essential to contemporary industrial applications. However, the dependability of these systems depends on efficient protection plans that can quickly identify and mitigate faults, reducing downtime and preserving operational effectiveness. A condition when suddenly one phase among three phases of IM fails is known as single phasing, and it is a common and potentially dangerous fault in induction motors. Single phasing must be promptly detected since, if unaddressed, it can result in imbalanced currents, overheating, and eventually motor failure.

This work presents a novel technique that uses rms value of the negative sequence current to quickly detect single phasing in SVPWM-fed induction motors. The A-phase input current of the induction motor is continuously monitored in our suggested method. The negative sequence component's rms value is computed and compared with the value observed during regular operations.

The single phasing problem can be identified by deviations from the standard, which enables early intervention and motor protection. An inverter which is based on an 'Insulated Gate Bipolar Transistor (IGBT)' is used in this methodology. The process entails converting direct -current (DC) voltage to three-phase alternating-current (AC) voltage using an inverter based on the IGBT, which powers the induction motor. A 400V, 4kW, 1430 rpm, 50 Hz, three-phase induction motor with a modulation index of 0.5 is used in the study to produce the gate pulse of the inverter. To simulate single phasing, a breaker is employed in the input phase of the motor, opening at 0.75 seconds into a total simulation period of one second. Under both normal and single phasing conditions, the RMS values of the negative sequence component are recorded and examined.

2. LITERATURE REVIEW

Identification and mitigation of different faults in induction motors have been the focus of extensive research due to the critical role these motors play in industrial applications. Various methods have been explored to identify and diagnose faults, including vibration analysis, thermal imaging, and electrical signal monitoring. Among these, the analysis of electrical signals, particularly current-based monitoring techniques, has gained prominence owing to its 'non-intrusive' nature and ability to supply real-time information. Negative sequence component analysis has emerged as a significant technique in fault detection. Researchers like Kim et al. (2004) and Henao et al. (2007) demonstrated the efficacy of using negative sequence components to detect unbalanced conditions and faults in induction motors. This approach leverages the inherent sensitivity of negative sequence currents to asymmetries and unbalanced loads, making it a suitable method for early fault detection. Further advancements in control techniques, such as PWM and SVPWM, have improved the precision and efficiency of induction motors. However, these advancements necessitate more sophisticated fault detection mechanisms. Studies by Tavner et al. (2008) and Thomson and Fenger (2001) highlight the need for integrating advanced diagnostic tools with modern motor control methods to enhance fault detection capabilities. Recent works have focused on combining negative sequence component analysis with other diagnostic metrics. For instance, Ayasun and Karbeyaz (2007) utilized RMS values of current and voltage signals to identify faults. 'Motor current signature analysis (MCSA)' is now de facto technique for fault analysis of IM due to its lot of advantages. M. Riera-Guasp et al. (2012) proposed one of the time-frequency based analysis which is Gabor analysis to detect eccentricity and broken bar faults of induction motor. In this analysis motor start up current has been analyzed to detect the above mentioned two faults at first stage. A. Bellini et al. (2008) have done a vivid review of protection and diagnostic of induction motor. In this review, different mechanical, electrical faults and their diagnostics procedures based on signal processing and artificial-intelligence (AI) methods have been lucidly described. Spectrum analysis by Fourier Transform of line current, line partial voltage have been in analysed to identify the different rotor faults of IM (2000).Spectrum analysis has also been done in MATLAB where line current, voltage has been taken from 1.1 kW, 50 Hz, 400V, 2 (two) pole induction machine. Detection of motor faults through spectrum analysis by Fourier transform is difficult for non-stationery nature of motor signals in different conditions. So, to analyze non-stationery motor signals Wavelet transform (WT) plays a crucial role. J. Cusido et al. (2008) proposed WT based power spectral density to detect shorted turns and broken bar of 1.1 kW, 4 pole 50 Hz, 380 V three phase induction motor. S. Chattopadhyaya et al. discussed (2008) WT based statistical parameters analysis like skewness kurtosis to detect single phasing and crawling of induction motor. Crawling has been detected in Clarke plane. A. Chattopadhyaya et al. (2012) discussed WT based statistical analysis to detect crawling of induction motor. WT based skewness and kurtosis have also been discussed by A. Chattopadhyaya et al. (2016) to detect single phasing of PWM fed induction motor drive. R. Boudiaf et al. (2024) discussed bearing fault detection of induction motor by Continuous Wavelet Transform (CWT) based Convolution Neural Network (CNN) technique. In this analysis three wavelets which are Morse, Bump and Analytic Morlet have been used to extricate the features for assessment of faults where highest accuracy is obtained in Morse Wavelet. Wavelet Packet Transform has been used as a tool (2024) to detect broken bars of induction motor where best performance has been achieved in dmeyer mother wavelet with respect to other mother wavelets such as symlet. S. Chikkam et al. (2022) proposed Stockwell transform based rms and standard deviation calculations to detect rotor, stator and bearing faults of induction motor where captured data has been denoised by Wavelet transfom based technique. This multifaceted approach improves detection accuracy and provides a more comprehensive assessment of motor health.

This paper details the modeling, simulation of the 'SVPWM-fed induction motor', and the analytical approach to fault detection based on rms value of negative sequence current component of three phase induction motor input current (stator current). The results demonstrate the efficacy of the proposed approach for identifying single phasing conditions promptly, thus offering a valuable tool for enhancing the reliability and longevity of IMs. The rest part of the work has been organized as follows: section II describes modeling and simulation of SVPWM fed IM, section III narrates results and discussions, section IV is used to narrate specific outcomes of this work and section V and VI are algorithm to detect single phasing and conclusion respectively.

3. Modeling Of SVPWM Fed Induction Motor

SVPWM fed induction motor modelling is depicted in Fig. 1. In this analysis IGBT based inverter has been used to convert dc voltage to ac three phase voltages which fed to induction motor. 400 volts, 4kW, 1430 rpm rated speed, 50 Hz three (3) phase IM has been used for assessment. 0.5 modulation index has been used for generating gate pulse of the inverter. Breaker has been used in the input phase of the induction motor and by opening the breaker in 0.75 second, single phasing has been done. Total simulation time is considered as 1 second. Normal condition and single phasing conditions rms value of negative sequence current component of phase currents have been found out and compare the results with ideal (normal) condition, single phasing has been identified. All the results have been limned and explained in results and discussion section III. The delineative representation of 'SVPWM-fed induction motor' system starts with a 400V DC supply that feeds into a three-phase converter is in Fig. 1. The three-phase AC power required to run the induction motor is produced by this converter, controlled by SVPWM. Following the conversion, measurements of currents are made to monitor the input conditions of the motor. A breaker is incorporated to simulate single phasing by interrupting one of the phases. Then, to efficiently identify and diagnose single phasing faults, the negative-sequence-component of the current is analysed and its rms value is determined.

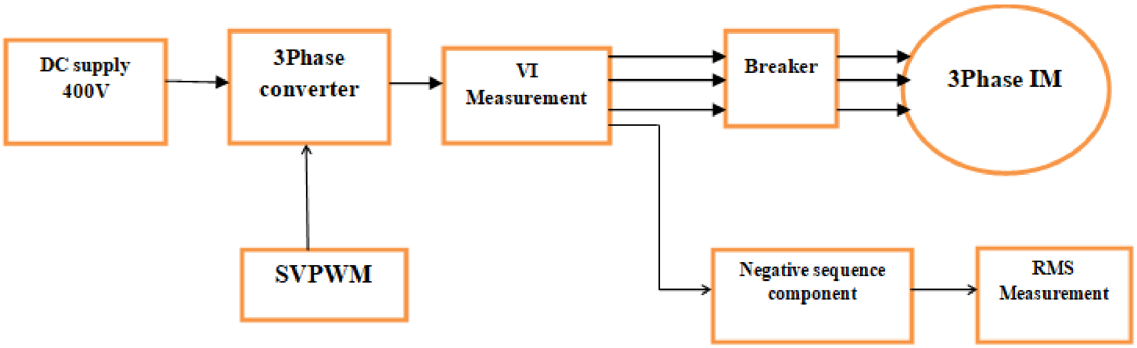

Figure 1. SVPWM fed induction motor model

4. RESULTS AND DISCUSSIONS

A. Case Study 1: (Normal Condition)

The 'A' and 'C' phase current under the normal condition, and rms value of negative sequence current of A phase are depicted in figures 2, 3 respectively. Under ideal (normal) condition rms value of R phase current has been recorded as 12.19 Amp

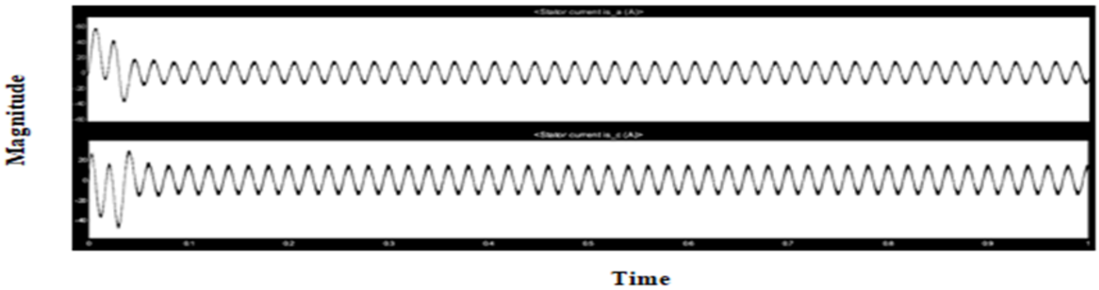

Figure 2. 'A' and 'C' phase current at normal condition

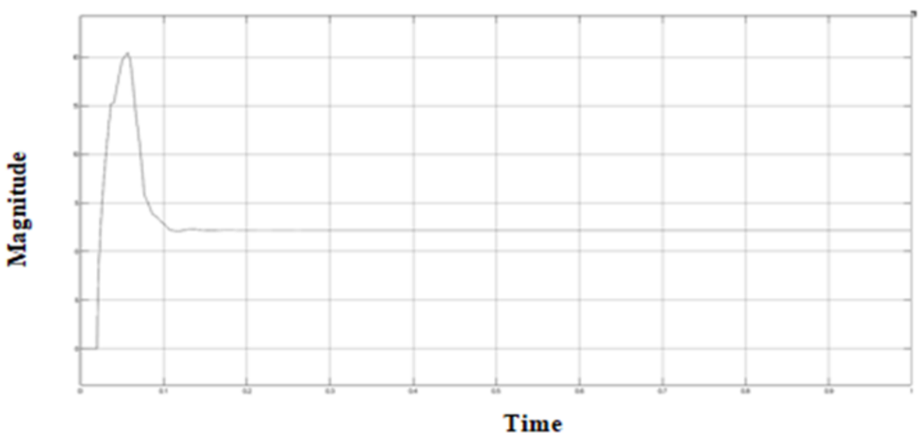

Figure 3. RMS of negative sequence current of phase 'A'

Figures 4 and 5, respectively, show the rated speed and torque under these conditions. No oscillation has been observed in torque in the ideal condition and speed has achieved steady value at very early stage.

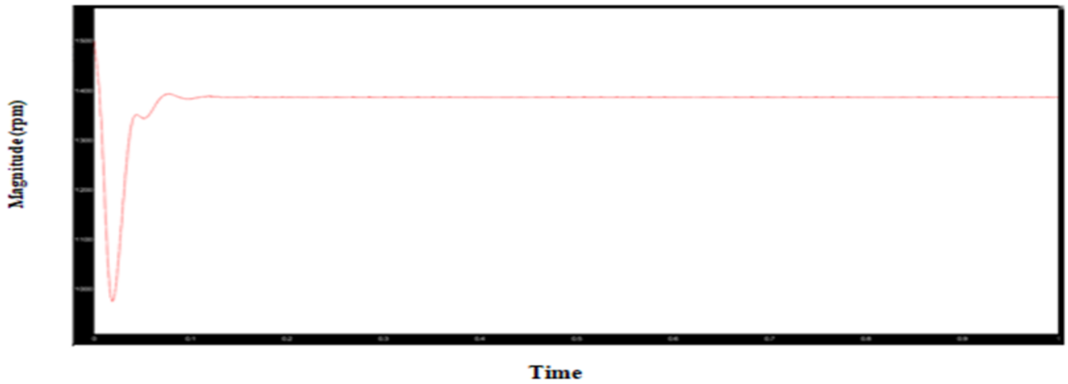

Figure 4. Speed (rpm) in normal condition

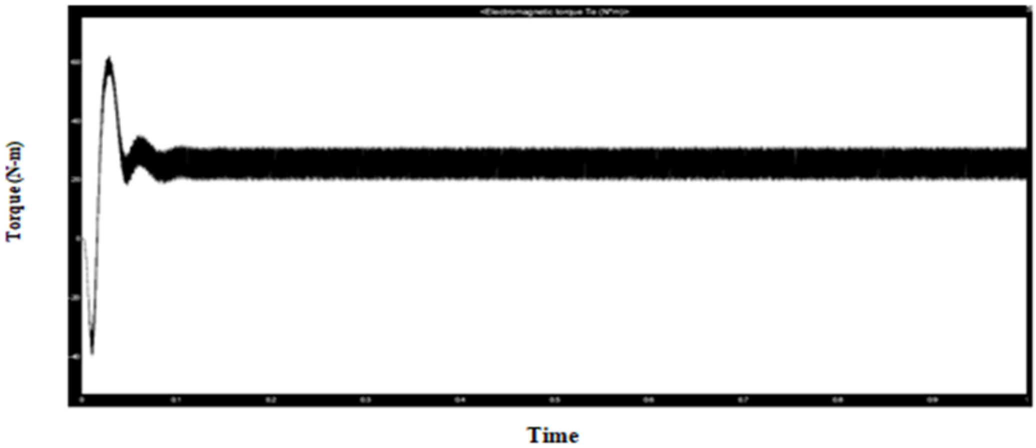

Figure 5. Torque in normal condition

B. Case Study 2: (C Phase Single Phasing Condition)

In this instance, the ‘C’ phase breaker was opened to achieve single phasing in the ‘C’ phase at 0.75 seconds. The healthy phases at this time are ‘A’ and ‘B’, and ‘A’ phase current has been used for condition monitoring of the overall state. The ‘A’ phase and ‘C’ phase currents are shown in figures 6 and 7, respectively. Figures 8 and 9, respectively, depict the speed, torque under mentioned conditions. Speed of the induction motor decreases after 0.75 seconds, and torque fluctuations are seen at that same time as single phasing in the C phase occurs. At that moment, 19.09 Amp was recorded as the rms value of the negative-sequence-component current of ‘A’ phase current. The rms value of the ‘A’ phase negative sequence component current in this scenario is shown in Figure 10.

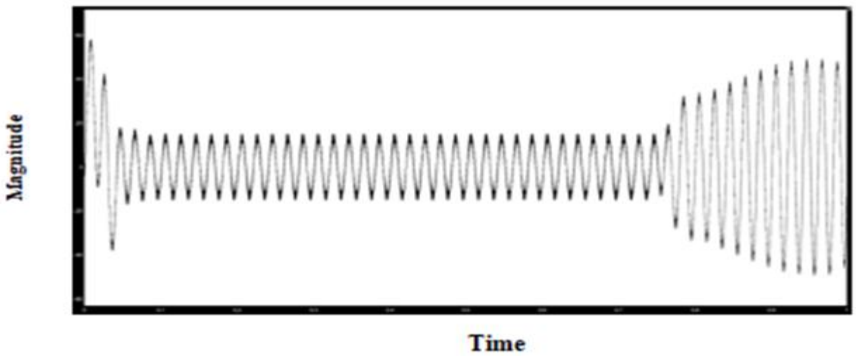

Figure 6. ‘A’ phase current at ‘C’ phase single phasing condition

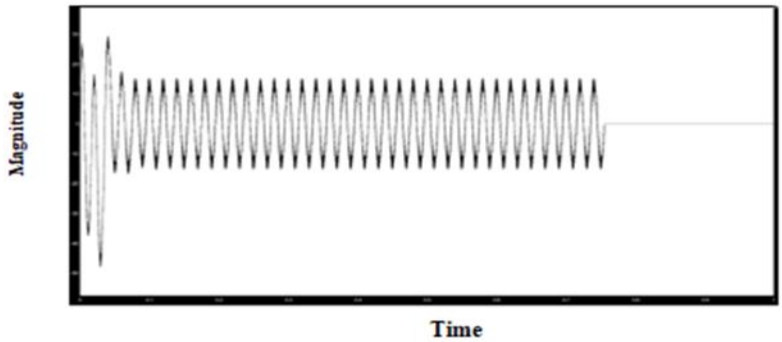

Figure 7. ‘C’ phase current at single phasing condition

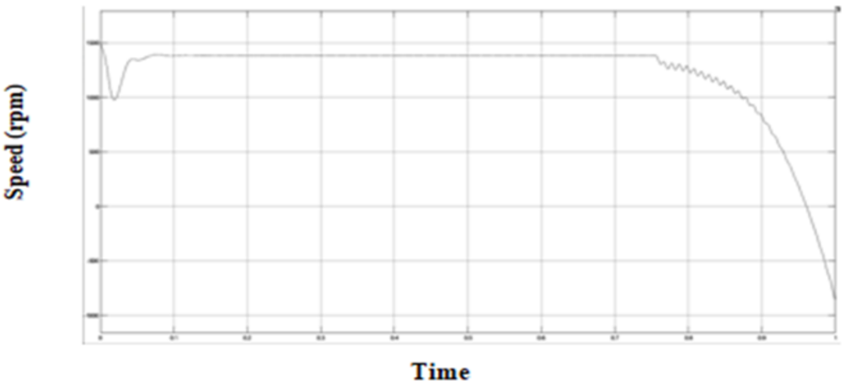

Figure 8. Speed (rpm) in ‘C’ phase single phasing condition

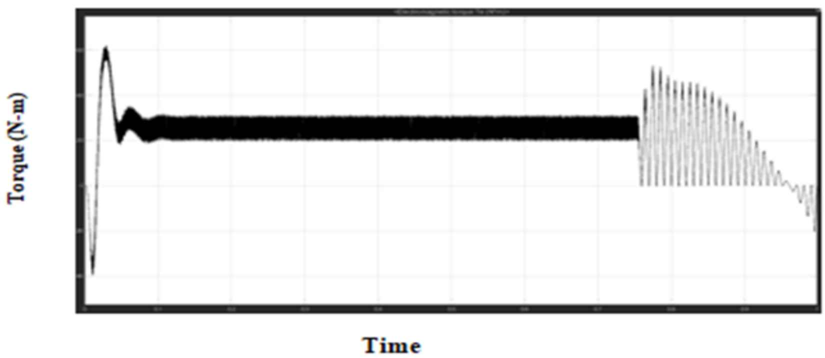

Figure 9. Torque at ‘C’ phase single phasing condition

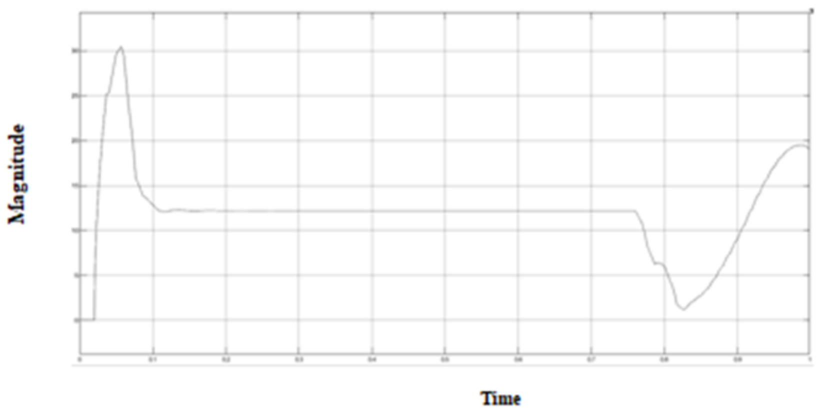

Figure 10. RMS of negative sequence current of phase ‘A’ at ‘C’ phase single phasing condition

C. Case Study 3: (B Phase Single Phasing Condition)

In this particular case, single phasing has been considered at 0.75 second in 'B' phase. At this time 'A' and 'B' phase current has been depicted in figures 11 and 12 respectively. Motor speed started falls down after 0.75 second and huge oscillations has been observed in motor electromagnetic torque. 'B' phase single phasing condition, rms value of negative sequence component current of 'A' phase has been observed as 52.09Amp which is shown in figures 13.

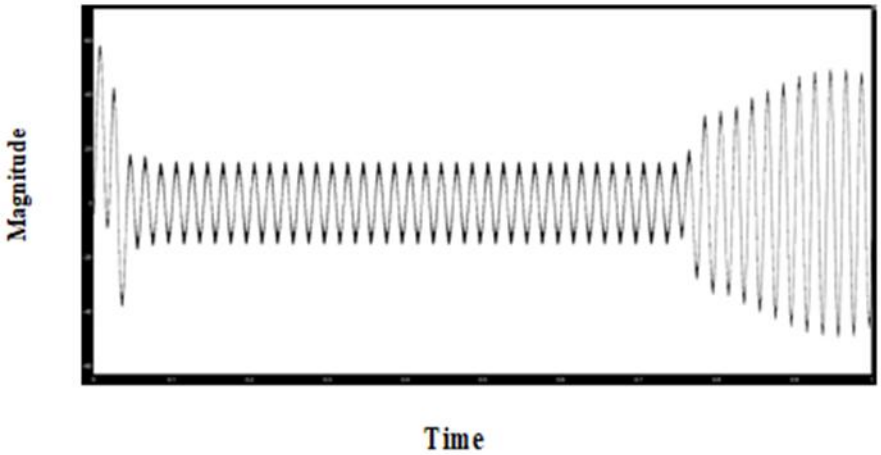

Figure 11. 'A' phase current at 'C' phase single phasing condition

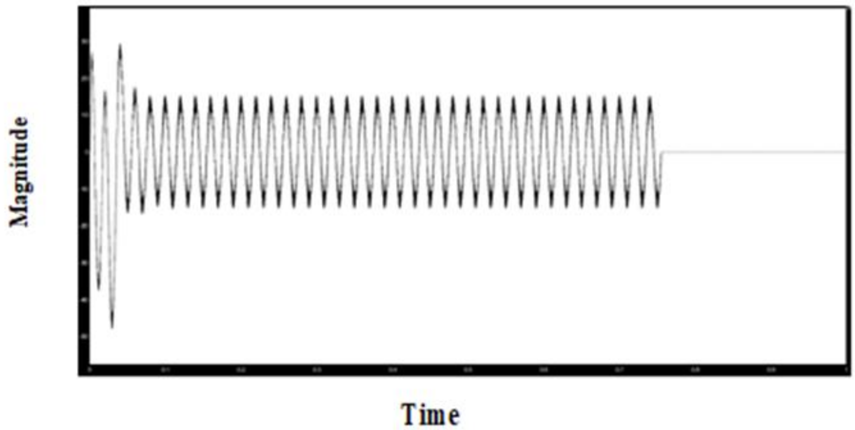

Figure 12. 'B' phase current at single phasing condition

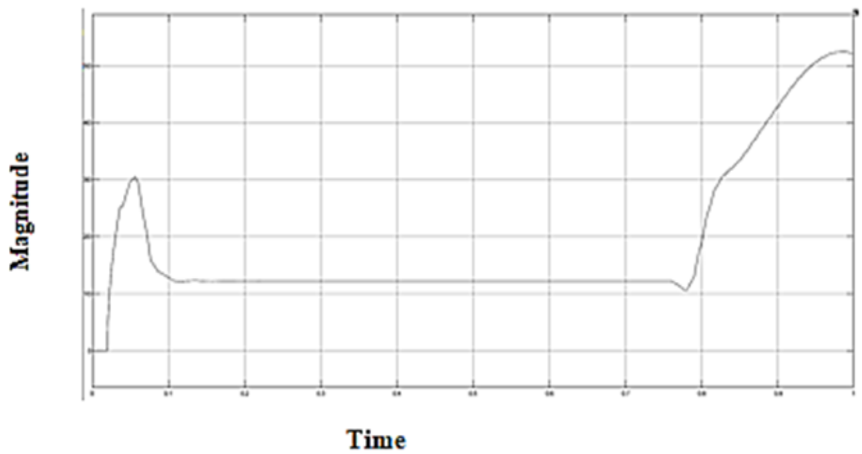

Figure 13. RMS of negative sequence current of phase 'A' at 'B' phase single phasing condition

5. Specific Outcome

In this work, single phasing has been detected based on rms value of 'A' phase negative sequence component current. When, single phasing at 'A' phase is considered then this value has come out zero (0) amp, but for 'B' phase and 'C' phase single phasing condition this value have been computed as 52.09 amp and 19.09 Amp. In ideal (normal) case, rms value of 'A' phase negative sequence component current has been recorded as 12.19 Amp. Specific outcome of this work has been tabulated below. Based on that, an algorithm has been developed in section 5.

Table 1. rms value of 'A' phase negative-sequence-component current at different conditions

Case Study	rms value of A phase negative sequence component current
Normal Condition	12.19 Amp
A phase single phasing condition	0.0 Amp
B phase single phasing condition	52.09 Amp
C phase single phasing condition	19.09 mp

6. Algorithm For Detection Of Single Phasing

Emanated from recorded results an algorithm has been formed which is given below:

1. Capture 'A' phase current data
2. Compute the rms value of negative sequence component current of phase 'A' current data
3. If the value is around 12.19 Amp; indicates normal condition.
4. If it is zero (0); indicates single phasing at 'A' phase.
5. If the rms value of negative sequence component is around 52.09 Amp and 19.09 Amp; indicates 'B' and 'C' single phasing condition respectively.

CONCLUSION

This study used rms value of negative-sequence-component current of the 'A' phase input current of induction motor to detect single phasing condition; the 'root-mean-square' (rms) value of the negative sequence component was computed under various conditions and compared with the ideal (normal) condition; single phasing was then evaluated based on this comparison. The maximum rms value for phase 'A' current was recorded when single phasing was considered in the B phase, whereas in the normal condition, it was recorded as 12.19 Amp. This numerical protection technique can be used for the protection of large induction motors in real-time applications.

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