Detection and Identification of Stator Inter-Turn Faults in Three-Phase Induction Motor in Presence of Supply Unbalance Condition

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***Abstract*— Induction machines play a vital role in process industries due to their low cost, ruggedness and low maintenance. Even though the induction machine is very reliable, many failures can occur due to their non-ideal operating conditions. Literature survey reveals that stator faults occupy a prominent place among the reasons for such failures. In particular, an undetected stator inter-turn fault may progressively lead to a permanent damage of the machine. Hence, early detection of stator inter-turn faults is essential for preventing damage to the adjacent coils and the core of the stator. Also, detection of stator inter-turn faults in the presence of supply unbalance is another challenging task. This paper proposes a new adaptive approach based on wavelet multi-resolution analysis for detecting and identifying the stator inter-turn faults. A fault index is defined based on the slope of detail coefficients to compare with an adaptive threshold for setting the flags. A fault is detected when the flag count reaches 6 over a moving window of 10 samples. Severity of the fault is identified by defining a sensitivity index based on the three phase energies of 4th level approximate coefficients. The proposed method is verified by using experimental data considering supply unbalance as well. Results indicate the effectiveness of the proposed method.**

Keywords*— Adaptive threshold, Discrete wavelet transform, Stationary wavelet transform, Stator inter-turn fault

I. INTRODUCTION

In recent times, motor current signature analysis (MCSA) is commonly used as a non-invasive method for detection of electrical as well as mechanical faults [1]–[2]. In order to make an effective fault diagnosis analyse the signals in frequency domain. But this is more significant under steady state operations only. The monitoring and fault detection of electrical machines have moved in recent years from traditional techniques to artificial-intelligence (AI)-based techniques [3], [4]. Such methods require “minimum configuration intelligence” since detailed analysis of the fault mechanism is not necessary, and also, no modeling of the system is required. The surveys on stator inter-turn fault diagnosis [5], [6] show the robustness of MCSA in the stator inter-turn fault detection. A recent study [7] also emphasizes that, out of various detection schemes for stator inter-turn fault, wavelet analysis [8] and other time–frequency analysis [9] techniques are the most efficient in extracting fault-related features under non-stationary conditions. Many proposals have been presented for use of negative sequence of stator current that is sensitive to different phenomena beyond stator asymmetry [10]. An effective diagnostic procedure should distinguish between negative sequence caused by short-circuit that must be linked to few fundamental parameters of the machine, which are unbalanced voltages, saturation winding asymmetries, and eccentricity. Particularly, there are two main causes that lead to errors in stator inter-turn fault detection. During the stator inter-turn fault, fault signature may be smaller than the noise level under harsh industrial environment which leads to a failure in fault detection and the other reason is presence of supply unbalance. Thus the fault detection techniques may not permit fixed thresholds. Hence an adaptive threshold is essential to diagnose the stator inter-turn faults under non-stationary conditions.

This paper proposes a new method based on the application of wavelets and adaptive threshold logic for detecting the stator inter-turn faults in the presence of supply unbalance. The three phase currents are analysed and reconstructed with stationary wavelet transform of Biorthogonal 5.5 (Bior 5.5) mother wavelet, and again decomposed with discrete wavelet transform of same mother wavelet to extract the fault features. The absolute sum of the slope of the detail coefficients of all phases is defined as fault index and checked with an adaptive threshold to set the flags. A fault is detected when the flag count is greater than or equal to 6 over a moving window of 10 samples. Faulty phase is identified by comparing the three phase peak energies of the slope of detail coefficients over a window of half cycle from the fault instant. Severity of the fault is analysed with the mean value of the three phase energies of 4th level approximate coefficients before and after the fault. The experimental results show the effectiveness of the proposed algorithm.

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II. Fault Detection Algorithm

In actual practice the captured currents are influenced by many factors, which includes supply unbalance, static eccentricity, and noise. Hence it requires a good technique which is having a capability to suppress all those influences without corrupting the fault signature. The stationary wavelet transform (SWT) is capable to extract the fault feature even though it is too minute, because of the shift invariance property. The advantages of SWT over the discrete wavelet transform (DWT) has been discussed in [11], [12]. But in the proposed fault diagnosis both SWT and DWT are used to extract the fault feature and fault severity. So, the proposed approach is a new method and works based on wavelets and adaptive threshold logic, which allows the diagnosis of induction-motor-fault in presence of balanced and unbalanced supply conditions. The step by step process of the proposed stator inter-turn fault diagnosis algorithm is shown in Fig. 1.

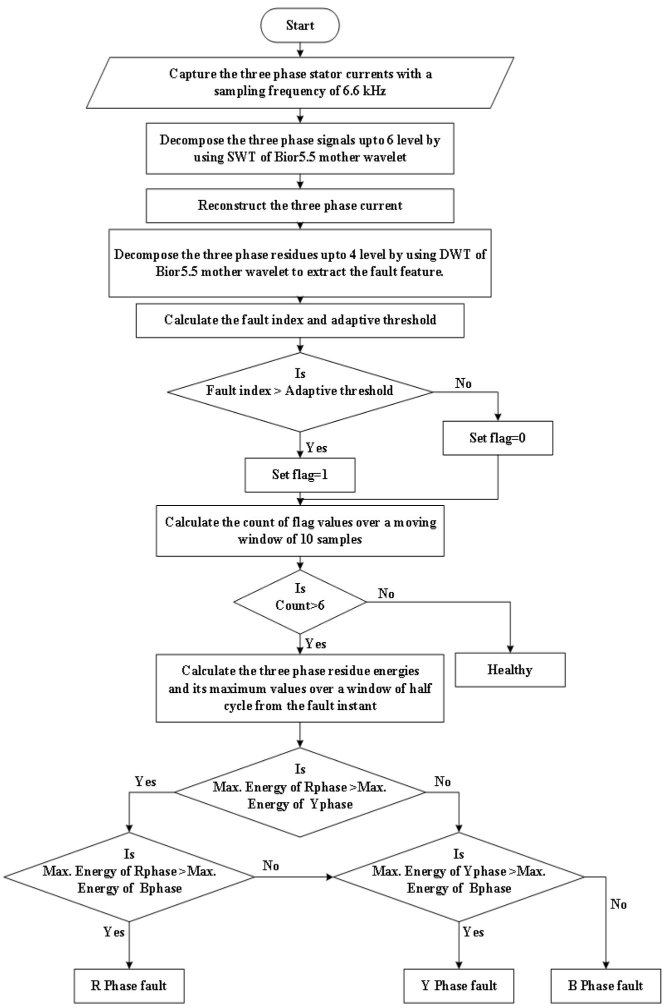

Fig. 1. Flow chart for proposed stator inter-turn fault detection and phase identification

III. Experimental Setup And Results

A 3HP, 3-phase, 50Hz, 4pole, 1425rpm squirrel cadge induction motor with 36slots, 6coils per phase and 72 turns per coil is considered for experimentation. To create the faults each phase of the stator winding is reconfigured and brought out two taping points from the neural point insteps of 0.8ohms. The various levels of inter-turn short circuits are created experimentally by connecting a suitable rheostat in between the one of the tap point and neural. The three-phase current signals are captured by using power network analyser of DIP800 with a sampling frequency of 6.6 kHz. Acquire these signals through RS 232 port and analyse them in MATLAB environment. Fig. 2 shows the experimental setup for 3HP squirrel cage induction motor.

Fig. 2. Experimental setup

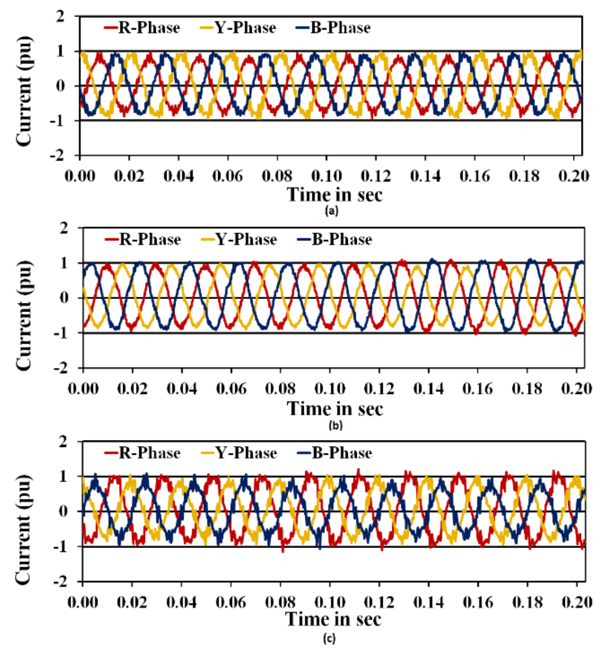

Fig. 3. Three phase stator currents under 3 conditions: (a) Healthy (b) 4 turn short circuit without supply unbalance (c) 4 turn short circuit with supply unbalance of 2%.

Several experiments have been carried out with 3HP squirrel cage induction motor. Initially the motor is started with a balanced supply and capture the three phase stator currents in the absence of fault. Subsequently, stator inter-turn faults are created in stator winding with 2% of supply unbalance in Y-phase and without supply unbalance. In this connection totally four levels of inter-turn short circuit cases have been considered for experimentation such as 2 turns (0.463%), 4 turns (0.93%), 6 turns (1.38%), and 8 turns (1.85%). Fig. 3 (a), (b) and (c) show the captured signals from the experimental setup for healthy, 4 turn short circuit with balanced supply and 4 turn short circuit with unbalanced supply respectively. All these figures are superimposed with noise and certain machine unbalance. To eliminate the unwanted frequencies present in the three phase currents by using SWT of Bior5.5 mother wavelet and decompose upto 6 level. The reconstructed three phase signals are obtained based on the level based thresholds to extract the fault residues. These residues of healthy, 4 turn short circuit with balanced and unbalanced supply conditions of currents are shown in Fig. 4 (a), (b) and (c) respectively.

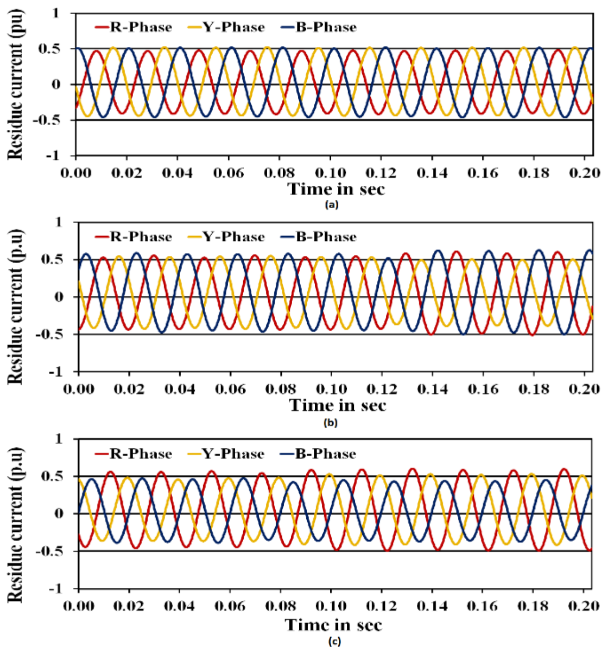

Fig. 4. Three phase residue currents under 3 conditions: (a) Healthy (b) 4 turn short circuit without supply unbalance (c) 4 turn short circuit with supply unbalance of 2%.

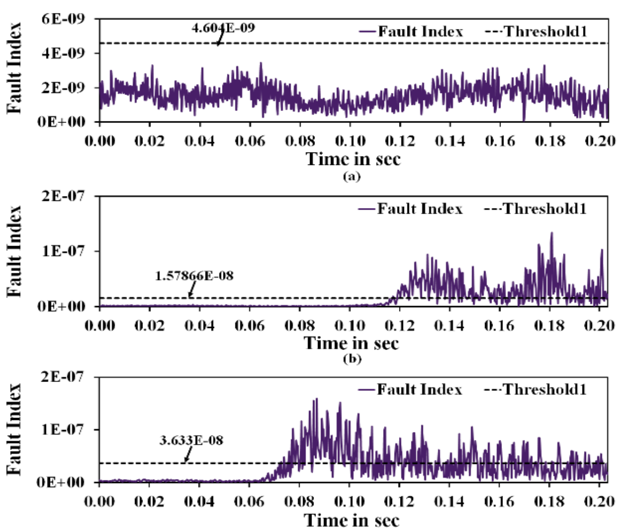

Fig. 5. Variation in fault indices under 3 conditions: (a) Healthy (b) 4 turn short circuit without supply unbalance (c) 4 turn short circuit with supply unbalance

The fault residue of the three phase currents are again decomposed with DWT of Bior 5.5 mother wavelet. A fault index is defined based on the slope of detail coefficients, which is compared with adaptive threshold to detect the fault. Suppose the machine is operated under healthy condition the fault indices are below the threshold, if it is a turn fault case the fault indices are crosses the adaptive threshold from the fault instant and set the flags for every point of crossing. A fault is detected whenever the flag count exceeds the 6 over a moving window of 10 samples. Thus, very clearly based on the proposed method. Fig. 5 (a), (b) and (c) demonstrate the variations of fault indices with respect to adaptive threshold for healthy, 4 turn short circuit without supply unbalance and 4 turn short circuit with supply unbalance respectively.

The stator inter-turn fault introduce certain unbalance into the phases of stator winding, due to this the current in the short circuited phase is increased and it is more than others. But in presence of supply unbalance, the affect given by stator inter-turn fault is compensated with supply unbalance. So, it is very difficult to identify the faulty phase in presence of supply unbalance. Hence, the proposed method is identify the faulty phase by comparing the three phase maximum energies of slope of d1 coefficients over a window of half cycle form the fault instant. The variation in three phase energies due to stator inter-turn fault without unbalanced supply and with unbalanced supply are shown in Fig. 6 (a) and (b) respectively, both the figures show that the faulted phase energy is higher than other phases over a window of half cycle form the fault instant. Thus the proposed method is effective in detecting and identifying the fault even less than 1% of shorted turns.

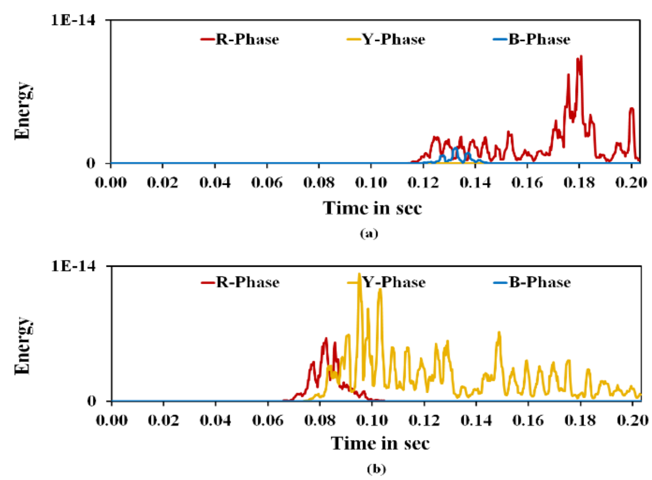

Figure 6. Variation in three phase energies (a) 4 turn short circuit without supply unbalance (b) 4 turn short circuit with supply unbalance of 2%.

The fault severity is identified by using a defined sensitivity index which is based on the energy values of 4th level approximate coefficients of three phase residue currents. The sensitivity index is the ratio between post fault and pre-fault mean energy of 4th level approximate coefficients. Fig. 7(a) illustrates the sensitivity index without supply unbalance.

Similarly Fig. 7(b) demonstrates the sensitivity index with 2% of supply unbalance. From Fig. 7(a) and (b) clearly show that the sensitivity index is monotonic with the faulted turns. But all three phase sensitivity indices may not be equal because of practical problems, those are maintaining of power supply during signal captured period and creating of stator inter-turn fault in all phases at same instant.

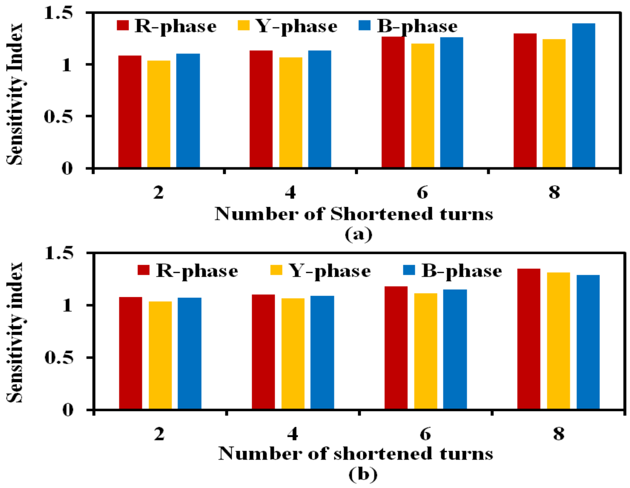

Fig. 7. Effect of sensitivity index (a) Without supply unbalance (b) With 2% of supply unbalance.

IV. Conclusion

This paper presents a new methodology for detecting and identifying the stator inter-turn fault based on combined wavelets of SWT and DWT analysis of stator currents with adaptive threshold, which is suitable for further online diagnosis in induction motors. The results of this paper proves that the proposed method detect and identify stator inter-turn fault very effectively even though the supply is unbalance. The effectiveness of the proposed methodology is also demonstrate with the sensitivity index. Hence the proposed method is simple for detecting and identifying the fault and its severity in the presence of supply unbalance.

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