

Phase to phase fault detection of 3-phase induction motor using FRA technique

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ABSTRACT

The purpose for preparing this paper is to innovate a new method to detection and diagnosis the three-phase induction motor electrical failures, especially the failures that occur in Stator winding. Stator winding breakdown largely contributes to induction motor failures. To understand internal fault in induction motors winding, four cases studies of different three-phase induction motors (TPIM) were analysed according to two conditions: normal winding condition and windings shorted between two phases. In this paper, the measurement of frequency response analysis (FRA) on the stator winding with inter-phase short is presented. Additionally, Frequency Response Analysis (FRA) interpretation technique classify and quantify the fault is also proposed. For interpretation of the FRA, a statistical indicator, which is NCEPRI algorithm is used for comparison the measured responses.

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1. INTRODUCTION

Health of any induction motor is critical in view of availability asset management and cost. Every machine has its own estimated life. This estimate is made by considering various factors such as material used, operating condition, environmental conditions etc. Induction motors failure mechanism are different depend on different part, the most important part is stator winding [1].

According to study that presented by Electric Power Research Institute (EPRI), show that (36%) of motor failure is because of stator winding faults [2, 3]. Motor stator windings failure or breakdown is the most common reasons of TPIM failure [4]. Cases of induction motor failure amount reported because of this category ranged nearly from 30% to 40% [5].

Several reasons result to armature or stator windings insulation failure, among these are [6]: (a) Short circuit or starting stresses, (b) Loose bracing for end winding, (c) High stator winding temperatures, (d) Leakage in cooling systems, (e) Electrical discharges. From other side, insulation failure always related TPIM windings failure and it is counting the main reason of winding failure [5]. As evidenced by credible survey [7-10], stator winding breakdown is a large group of induction motor failures which undetected fault is considered as the root cause for this category of the faults. Any failure in windings should be detected and diagnosis in incipient level to avoid any catastrophic failure it may cause unwanted downtime of production.

To understand the effect of short-circuit fault between winding phases in three-phase induction motor (TPIM), this paper used a new method which is frequency response analysis (FRA) technique. This is achieved by analysing four induction motors with each has a different power rating and two different conditions: (normal winding conditions and short-circuit between phases. The frequency responses (FR) of normal and faulty windings will be analysed by using the North China Electric Power Research Institute (NCEPRI) algorithm. The importance of this study is mainly to valuate the ability of FRA to detect the faulty winding in TPIM.

2. LITERATURE OR BIBLIOGRAPHY SURVEY

Short circuit (SC) winding faults might develop to more complicated types of stator winding faults [11]. Typically, SC stator windings occur: (a) between internal turns in same phase (turn-to-turn), (b) between two coils in same phase (coil-to-coil), (c) between two turns in different phases, (d) between phase to neutral point, (e) between phase to ground and (f) open circuit coil [12]. Figure 1 show the common faults in induction motors.

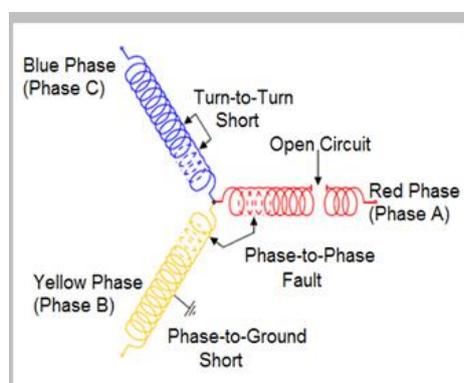


Figure 1. Induction motors common faults and Failures [12].

The types of winding faults that was clarified in the previous paragraph is named by a “stator turn faults” [13]. The responsible for stator windings failures is the stresses, which are may be classified into electrical, thermal, mechanical, and environment. The factor that most influences on for the deterioration of the insulation in most of the cases among them is the thermal stress [14]. A short-circuit (SC) turns fault causes a flow of large circulating current. Thus, this current generates excessive thermal stress in the point of shorted windings thus, that may cause for machin failure [15].

In [16], Statistical process control technique (SPCT) was used to diagnosis and detect windings faults for TPIM. A new model was estimated to detect short-circuit (SC) windings faults in time domain. An author in article [17] developed a fuzzy fault detector (FFD) by using Concordia patterns to diagnosis open-circuit (OC) faults and stator unbalance. Article [18], Discussed the performance of the TPIM and its vulnerability by modelling for detection of induction motor winding fault and its location.

References [19] and [20] reported that they used advanced signal-processing techniques (ASPT) and stator-windings-currents for stator winding fault detection of the IM. The authors in [21] analysed the deviation in frequency response (FR) by using artificial-neural-network (ANN) for faults detection. The electrical fault for induction motors field-windings was detection for first approach through FRA technique with static excitation was reported in [22].

Frequency Response Analysis FRA is an electrical non-intrusive and powerful used technique to diagnosis of many changes, faults, or abnormal conditions in the transformer winding [23]. FRA response is off-line technique for failure diagnosis and faults detection [24]. FRA is considered as one of the comparative tests which are required a reference data (RD) (at healthy operation condition) to compare with it. Therefore, the differences between RD and the new measured responses refer to there fault [25, 26]. Each fault have finger-print or characteristic frequency response. By observation of different responses of data measured, multiple types of fault are detected and also fault severity is identified [27]. The FRA response tool can get hold of the voltage transfer function for windings frequency between (20 Hz to 2 MHz) [28, 29]. The important measurements connections between the FRA instrument device and other equipment such as

transformer are four faults cases which are end-to-end short circuit connection, inter-winding inductive connection, inter-winding capacitive connection and open circuit connection [26].

3. METHODOLOGY FOR FAULT AND MEASUREMENT

3.1. Experimental units choose

Four units of three-phase induction motors were chosen to conduct this study, these units have a different rating power which are 1, 2, 3 and 5.5 horse power respectively. The specifications for these tested units are shown in Table 1. This paper focus on the Wye (Y) connection configuration between phases U, V and W which is widely used for TPIM. Therefore, phases for all experimental units of TPIM windings are connected as Wye (Y) winding configuration.

Table 1. Specifications of three phase induction motor units

Motor	Motor 1 Specifications	Motor 2 Specification	Motor 3 Specifications	Motor 4 Specification
Manufacturer	JILANG	JILANG	JILANG	JILANG
Model	110RK-3DS	Y90S-2	Y90L-2	Y112M-2
Phases	3-Ph induction motor	3-Ph induction motor	3-Ph induction motor	3-Ph induction motor
Power	0.75 KW / 1HP	1.5 KW / 2HP	2.2 KW / 3HP	4 KW / 5.5HP
Rated Voltage	415V / 50 Hz	415V / 50 Hz	415V / 50 Hz	415V / 50 Hz
RPM	1500 rpm	2840 rpm	2840 rpm	2880 rpm

3.2. Creation of fault

The artificial faults in windings which are performed experimentally in laboratory, will use to study the differences in windings response that may be occur due to this fault. In this study, the artificial fault created between two phases of three-phase induction motor. Phase-to-phase (PP) fault occur when single-turn in phase U shorted with single-turn in phase V or between two coils from phases. This paper focus on phase-to-phase turns (PPT) faults, four units of TPIM were used to create short circuit fault between phases windings to get PPT fault. In this study, the short circuit fault was applied in the laboratory between phase U and phase V windings only. The PPT faults procedures for one case of TPIM are shown in Figure 2.

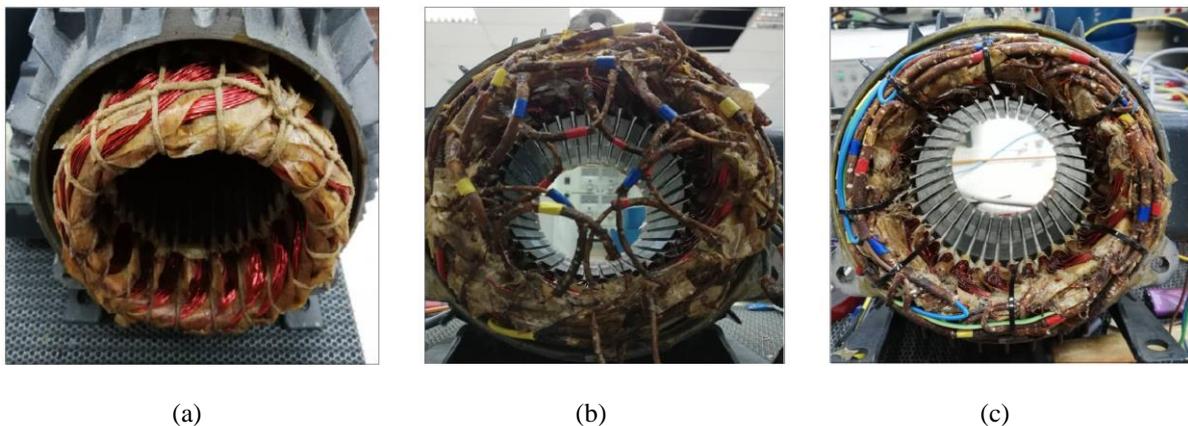


Figure 2. PPT faults creation stages on TPIM, (a) Normal winding, (b) Removing some conductors to create the fault, (c) Completed winding with PPT fault.

3.3. FRA measurements setup

Phase-to-phase turns (PPT) fault commonly occurs to TPIM. Generally, at any short-circuit (SC) in the windings suffer from insulation failure because of the thermal stress which occurs due to the increase of current in the windings. In this paper, FRA measurements are performed on phases U, V and W to diagnose the fault in TPIM windings. The measurements are performed before and after the fault has created. Figure 3 shows connection between the equipments which are used to perform the FRA measurements. In this study, the windings have wye (Y) connection configuration. With wye connection, the frequency responses can be measured between two phase terminals (U-V, V-W, and W-U) only, with assuming that the neutral point (N)

is hidden. The FRA measurements are made on four units of TPIM which are listed in Table 1. The winding frequency responses are later analyzed and interpreted.

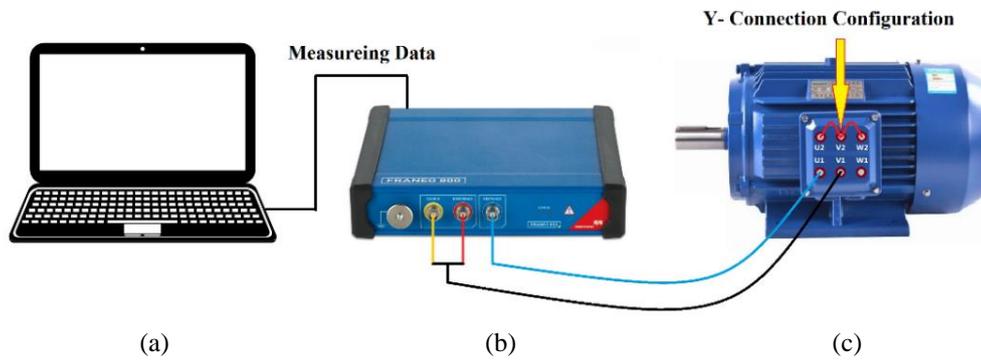


Figure 3. Equipments connection to measured FRA for motor windings (a) Computer, (b) FRANEQ 800 equipment, (c) Three-phase induction motot

4. FRA RESULTS AND ANALYSIS

In this section, the FRA response results for the PPT fault created practically in the laboratory on TPIM stator windings are presented and discussed. For each case, three phases frequency response measured via two steps, the first one during healthy windings condition and the second at PPT fault in the TPIM windings. Figure 4, Figure 5 and Figure 6 shows the frequency responses (FR) curves of the tested four units. As shown, the FR curve was different from machine to other, this is likely depending on four TPIM units power rating.

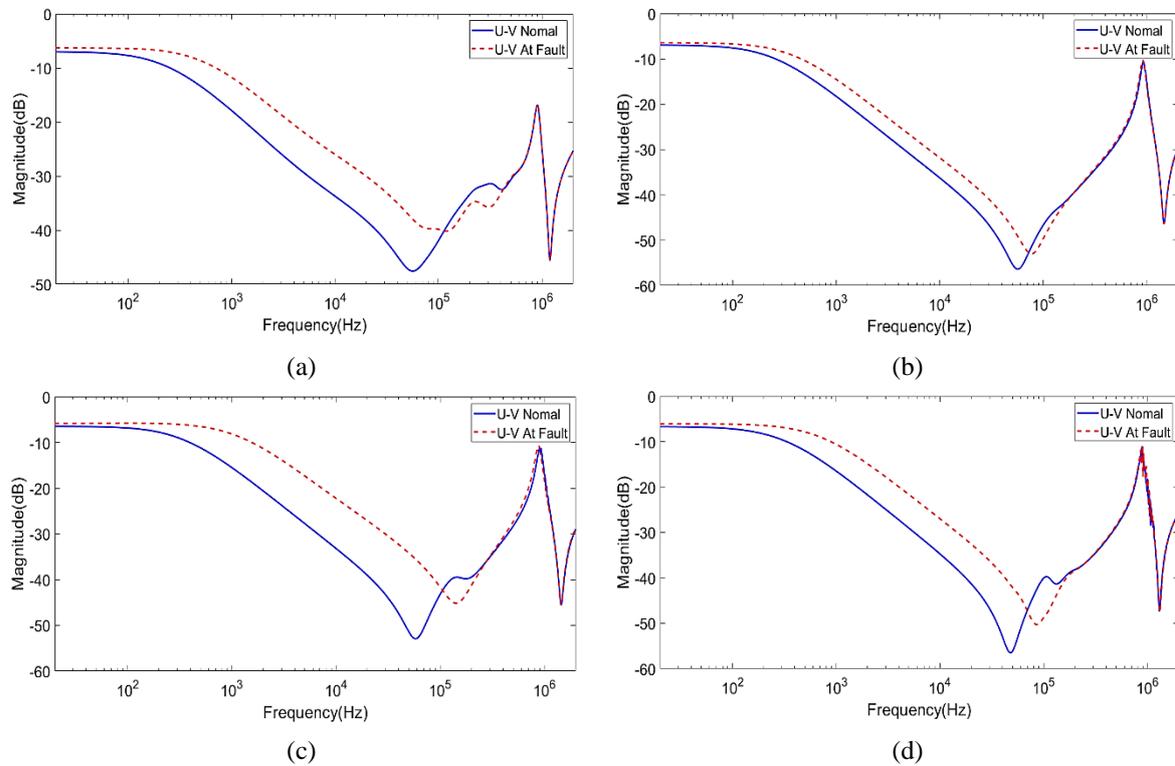


Figure 4. FRA Measurement for terminal U-V at normal condition and PPT fault in phases U and V. (a) FRA for 1HP TPIM, (b) FRA for 2HP TPIM, (c) FRA for 3HP TPIM and (d) FRA for 5.5HP TPIM.

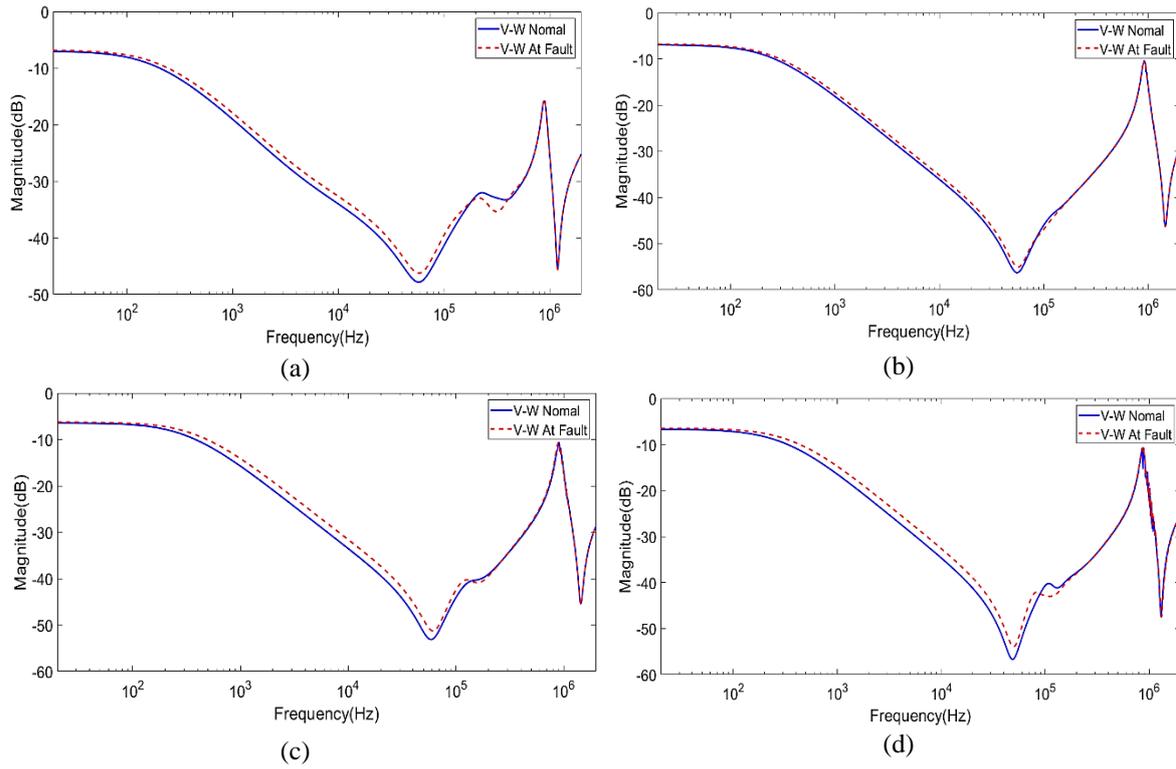


Figure 5. FRA Measurement for terminal V-W at normal condition and PPT fault in phases U and V. (a) FRA for 1HP TPIM, (b) FRA for 2HP TPIM, (c) FRA for 3HP TPIM and (d) FRA for 5.5HP TPIM.

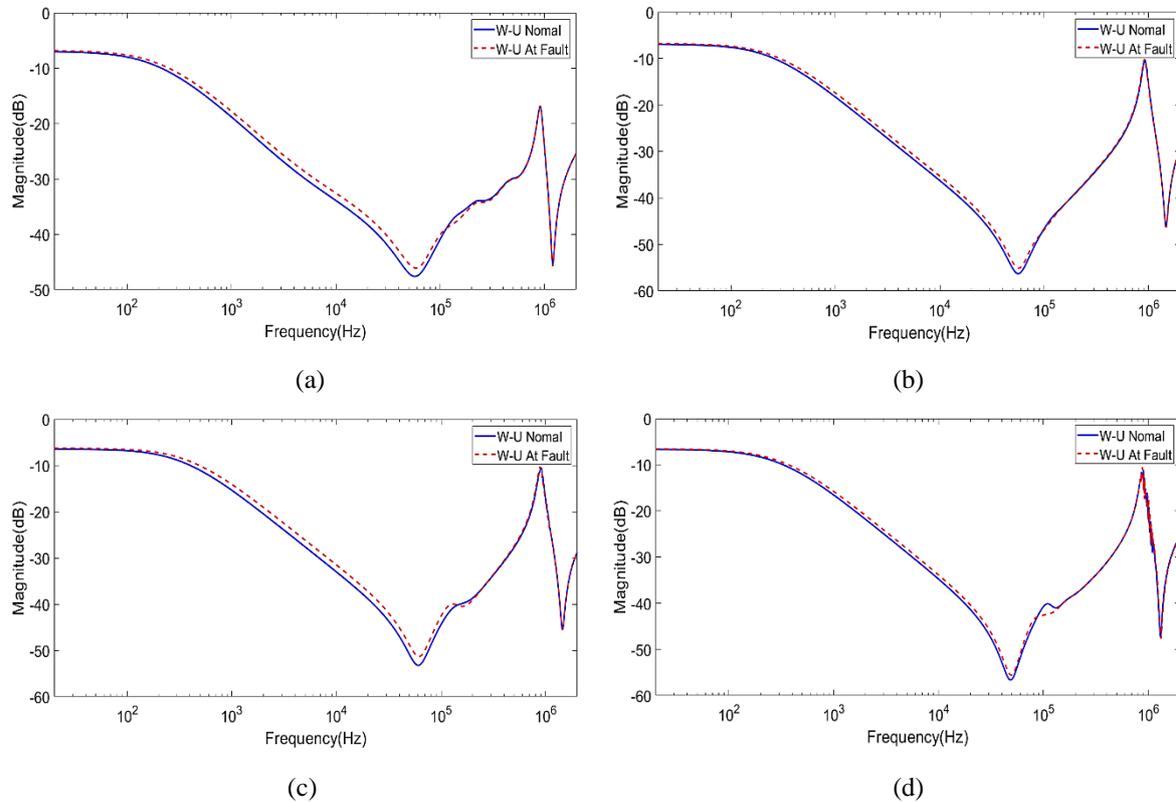


Figure 6. FRA Measurement for terminal W-U at normal condition and PPT fault in phases U and V. (a) FRA for 1HP TPIM, (b) FRA for 2HP TPIM, (c) FRA for 3HP TPIM and (d) FRA for 5.5HP TPIM.

The main effect of PPT fault was by creates a short circuit between phases windings lead to reduce the number of turns less than the normal condition. Thus, that will reduce the windings length of the coils. So that, the total resistance of the coils that make up the phase will decrease. Also, the flux in the coils will reduce. Creation of the PPT fault will lead to reduced magnetizing inductance of phase U and phase V, because of the shorted turns between phases U-V and the turns removed from phase U and phase V. Thus, causes an increase the magnitude of the response and this considered defective response. And surely, the comparison of frequency responses (FR) in case of normal condition and at PPT fault in windings was clearly visible in Figure 4, Figure 5 and Figure 6, and the responses shows the cases of effect according to the connections of measurements conducted, which are the FRA measured for terminals (U-V, V-W and W-U).

For more clarification, the magnitude of defective response between the reference FR and the FR at PPT fault condition for terminals U-V were very evidents as shown in Figure 4, because of the PPT fault was created in the phases U and V windings together since the beginning for all TPIMs. On the other hand, the healthy phase W from the other side. The reason for these defective response was due to the magnetizing inductance limitation in the phases windings of TPIM, which is directly affected when any fault occur in motor windings.

5. ANALYSIS USING NCEPRI ALGORITHM

NCEPRI algorithm was proposed in [30], [31] and has been used as one of statistical methods for analysing the FRA results. In this study, the NCEPRI algorithm is used for interpretation and validation the response. This performed by computing the effective deviation (ED) or assessment factor (E_{12}) by using (1).

$$E_{12} = \frac{1}{N} \sum_{i=1}^N (TF_{1i} - TF_{2i})^2 \quad (1)$$

Where N is the number of point in a frequency response, TF_{1i} and TF_{2i} are the transfer function values of the frequency response of normal winding and faulty winding respectively at frequency i .

NCEPRI algorithm was utilized for distinguish the differences between frequency responses at normal condition and with PPT fault case for four units which are clearly visible in Figure 4, Figure 5 and Figure 6. In this study, the frequency response (FR) curves divided into four regions according to the response wave-shape. As shown in Table 2.

Table 2. Assessment factor (E_{12}) of PPT fault frequency responses by using NCEPRI algorithm

Frequency range	E12 in dB for 1HP motor			E12 in dB for 2HP motor			E12 in dB for 3HP motor			E12 in dB for 5.5HP motor		
	U-V	V-W	W-U	U-V	V-W	W-U	U-V	V-W	W-U	U-V	V-W	W-U
20Hz-2kHz	4.3107	0.8479	0.7707	2.6807	0.5743	0.6341	4.9494	1.1235	0.8886	4.0093	1.2153	0.5342
2kHz-20kHz	7.5660	1.3119	1.2834	4.3512	0.8767	0.9535	10.6256	1.9092	1.4839	7.5834	2.0130	0.8706
20kHz-200kHz	7.0367	1.4621	1.3211	4.7302	0.9690	0.9171	11.4809	1.8078	1.5997	8.7552	2.2878	1.1205
200kHz-2MHz	1.5733	0.8379	0.1595	0.4517	0.1341	0.2407	0.9908	0.2952	0.3493	1.1079	0.8431	1.1207

The assessment factor (E_{12}) values was calculated for all cases in this study by using the equation (1). Table 2 shows the values of E_{12} for the four units of TPIM. As clearly, the E_{12} values for PPT fault are high for the frequency region (20Hz-2kHz), it ranged between (2.6807 to 4.9494) when it calculated for terminal U-V. And for terminals V-W and W-U the E_{12} ranged between (0.5342 to 1.2153). As E_{12} vales showed, the effective of fault was more evident at U-V calculation. This due to the impact of PPT fault was occurred directly on this phase. Therefore, this region is considered as serious failure. For frequency regions (2kHz-20kHz) and (20kHz-200kHz), the E_{12} values for terminals U-V, V-W and W-U was ranged between (4.3512 to 11.4809), (0.8767 to 2.2878) and (0.8706 to 1.5997) respectively as shown in Table 2. That mean it was higher than the first values. So that, this region is considered as serious distorted, this due to the effects of PPT fault in motor windings. For the frequency region (200kHz-2MHz), the recorded values were lower than the values in the rest regions. This means that the effect of PPT fault is relative in this frequency region.

6. CONCLUSION

Phase to phase turns (PPT) fault in TPIM winding was presents in this paper. The comparison of frequency responses (FR) confirmed that the PPT fault in TPIM winding gives some of variation in the FRA response. The variations in FRA signatures for windings was interpreted and analyzed in section 4. A finding of this paper, it has been proven that the defect that occurred due to PPT fault can be diagnose and detected, through the variation in the FRA response in phases when measuring the frequency response. And also, this paper presented the validation for FRA at the PPT fault case by using one of a certified statistical indicators, which is NCEPRI algorithm. Where, the calculation of the assessment factor (E12) shows the highest distortion indicator of frequency regions that has low and medium frequencies range. And in high frequencies range, the distortion level will be relatively insignificant. The method proposed in this paper had a useful result, it can be considered as a new method to detection and diagnosis the PPT fault in three-phase induction motor. And also, the applications of developed method can be used for diagnosis and detection the other types of faults in TPIM.

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