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Feature Selection Based For Broken Rotor Bar Faults In Induction Motors :A Review

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Abstract—**In this survey paper discuss Advanced Feature Selection for Broken Rotor Bar Faults in Induction Motors. In the current generation Advanced Feature Selection for Broken Rotor Bar Faults in Induction Motors. Play on important role in the Frequency Induction Motors. In the last decade there are many research work purposed in the area of Advanced Feature Selection for Broken Rotor Bar Faults in Induction Motors. In this review paper discuss on the Broken Rotor Bar Faults in Induction Motors and its specification. Also discuss the Frequency And Amplitude Control arise in Induction Motors such as power system.**

Keywords— **Industrial Application Society (IAS), Power System, Electric Power Research Institute (EPRI), Finite Element Method (FEM), Broken Rotor Bar (BRB), etc....**

I. INTRODUCTION

Induction motors are widely used in various industry sectors due to their ruggedness and robustness features with relatively low maintenance and competitive cost. For reliable operation in industrial processes, it is important to know the distribution of different failures of induction motors for condition monitoring and incipient fault diagnosis purpose. Based on the survey for 0.75 kW to 150 kW induction motors, faults can be categorized as broken rotor bar faults (7%), stator winding faults (21%), bearing faults (69%), and shaft/coupling and other faults (3%) as shown in Fig. 1, so approximately two third of faults are bearing faults, and one-fifth of faults are stator windings faults. Another survey for medium-size induction motors was conducted by IEEE industrial application society (IAS) and Electric Power Research Institute (EPRI) as shown in Table I, the results are similar to smaller size machine in Fig. 1. except less bearing faults.

Condition monitoring and fault diagnosis techniques for induction motors are critical to detect faulty condition of the machine at an early stage and prevent unnecessary process down time, reduce financial losses caused by the faults. Types of faults caused by various operating conditions. By observing and examining abnormalities in induction motors, the parameters such as voltage, current, and leakage flux can serve as indicators to monitor operating condition of the machines and provide fault diagnoses at an incipient stage.

The finite element method (FEM) is a numerical technique for determining electromagnetic parameters of electric machines using geometry dimensions and material properties of the machine. It estimates the electromagnetic field distribution and considers nonlinear effects of the machine to determine machine parameters including electromagnetic field distribution, flux linkage, electromagnetic torques, flux density, and inductance.

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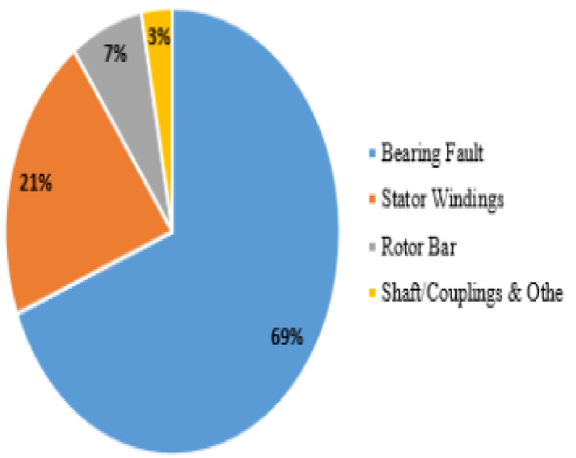

Figure 1. Different fault distribution of induction motor

Statistical Survey Results By Ieee And Epri For Faults At Medium Size Induction Motors

Fault types	IEEE, %	EPRI, %
Rotor faults	8	9
Bearing faults	42	41
Stator faults	28	36
Others	22	14

Faults can be detected by evaluating and justifying this machine parameter. The FEM can provide more accurate results than the analytical analysis. Therefore, the FEM can serve as a feasible technique in fault diagnosis of induction motors. In this paper, a literature review is conducted particularly on induction motor fault diagnosis using FEM under consideration of three type of research schemes: 1) FEM based fault diagnosis approach, 2) FEM and signal processing based approach, and 3) FEM, machine learning and other advanced techniques based approach. In the first scheme, the FEM alone is used for induction motor fault diagnosis. In the literature, it mainly focuses on broken rotor bar (BRB) faults, bearing faults, in equivalent eccentric rotor motion, and stator faults by using the first scheme. The second scheme is a most commonly used approach, which combines the FEM techniques with signal processing. Several methods have been reported in the literature for detecting BRB faults, bearing faults, stator and inter-turn faults, and rotor eccentricity faults by using the second scheme. The third scheme is a more advanced approach, which combines the FEM, machine learning and signal processing method. In the literature, very few works based on third scheme have been reported. This scheme is more time consuming than the second scheme but a reasonable accuracy can be achieved compared to the traditional FEM approach.

II. LITERATURE REVIEW

Ince, T. (2022) - This study presents an application of a new supervised machine learning approach for induction motor broken bar fault diagnosis using only raw stator current data. The proposed system employs shallow, adaptive 1D CNN classifier that combines the feature extraction and classification blocks of a conventional pattern recognition approach in a specialized structure. By learning the optimal features automatically from the raw sensor data with the proper training, it can achieve a high level of generalization as it does not require any manual parameter tuning or hand-designed feature extraction and selection processes. The main advantages of the 1D CNN-based approach are (1) its compact architecture configuration (rather than the complex deep architectures) which performs only 1D convolutions with a set of filters (kernels) and sub sampling, (2) its cost-effective and practical real-time hardware implementation, (3) that it does not require any pre-determined transformation (such as FFT or DWT), hand-crafted feature extraction and feature selection and (4) limited size of training dataset and limited number of BP iterations are sufficient for efficient training of the classifier. **[01]**

Liang, X., Ali, M. Z., & Zhang, H. (2021) - Condition monitoring and fault diagnosis of induction motors is one of the key concerns for reliable operation of critical industrial processes. The finite element method (FEM) offers a great insight of the fundamental principle and demonstrates physical operation of the machine more thoroughly than analytical approaches. It elaborates the machine's complex geometry and illustrates electromagnetic properties of induction motor precisely. It considers nonlinear effects of the machine, and determines the machine parameters such as the magnetic field distribution, flux linkage, electromagnetic torques, and flux density. In this paper, a literature review is conducted on finite element method under consideration of fault diagnosis techniques for induction motors. **[02]**

Glowacz, A. (2019) - In this article the author described bearing, stator and rotor fault diagnostic methods of the single-phase induction motor. The proposed approach used acoustic signals. The author analyzed acoustic signals of 5 states of the single-phase induction motor: healthy motor, motor with shorted coils of auxiliary winding and main winding, motor with shorted coils of auxiliary winding, motor with broken rotor bar and faulty ring of squirrel-cage, motor with faulty bearing. The SMOFS-22- MULTIEXPANDED was implemented as feature extraction method of acoustic signals. For the classification step the NN classifier was used. The obtained results of analyzed approach were good (TERAS was in the range of 94%–97%). The developed fault diagnostic approach was inexpensive. Low-cost capacity microphone and PC cost about 300$. Digital voice recorder also costs 100–300$. Measurement of acoustic signals is also immediate and non-invasive. Information provided from acoustic signals allows us to plan diagnostic review and repairs. The proposed signal processing methods can find application for early fault diagnosis of electrical and mechanical faults of rotating machines. The disadvantage of previously mentioned methods is that acoustic signals are mixed together (e.g. reflections, waves overlapping). **[03]**

Reljič, D., Jerkan, D., & Kanovič, Ž. (2019, July) - This paper considered the possibility of using the ANN and SVMs classifiers to evaluate BRB fault of an induction motor. The two approaches are based on the most relevant BRBs features extracted from simulated motor current and speed signals. In that regard, the advanced model of the IM was developed. The model is based on the MCMC approach. A large number of computer simulations were carried out for healthy and faulty rotor bars, thus providing necessary BRBs features for supervised learning process of the ANN and SVMs. The effectiveness of the proposed methodology was demonstrated through BRB features of additional computer simulation tests. Broken bars were properly addressed, whereas high classification accuracy, across the various levels of fault severity, was achieved. With the fast computing hardware technologies, such as microcontroller units, the proposed method looks promising for implementation of the system for automatic detection and classification of BRBs. **[04]**

Bouchareb, I., Lebaroud, A., Cardoso, A. J. M., & Lee, S. B. (2019, August) - Artificial Intelligence (AI) is expected to be a large driver in industrial applications competitiveness in the not-so-distant future. Induction motors (IMs) are used worldwide as the “workhorse” in industrial applications. The paper reviews the possibility of integrating artificial intelligence techniques for condition monitoring and fault diagnosis of induction motors so-called advanced diagnosis. The paper focuses on advanced diagnosis method related on the recognition, classification and prognostics of eccentricities faults in induction motor drives. Rotor eccentricity has been the aim of many researchers. However reliably detection and accurate prediction of eccentricity fault is still not possible and difficult task if appear individually. To face this situation, an intelligent diagnosis system merges Neural Network and Hidden Markov Model together (NN-HMM) into a common framework to overcome the deficiencies of eccentricity diagnosis. Current measurements based on non– parametrical Time-Frequency Representation (TFR) are used for features extraction. Then, a features selection method using Fisher's Discriminate Ratio (FDR) is applied to select an optimal number of the extracted features associated with polynomial approach to track, recognize of various eccentricities faults types and degree precisely. An experimental study on a 7.5h induction motor prove the reliability and the efficiency of the proposed method in condition monitoring of eccentricities with different degree 0%, 20%, 40%, 60, 80% precisely independent of load or motor type **[05].**

Cipollini, F., Oneto, L., Coraddu, A., & Savio, S. (2019) - In this paper, authors dealt with the problem of assessing the health condition of induction motor bearings. Such electrical machines are fundamental components of any modern automation system and bearings are their first cause of fault, followed by stator winding and rotor bars. To detect faults in the bearings, contrarily to the state-of-the-art approaches exploiting vibration signals, collected by easily damageable and intrusive vibration probes, in this paper, authors exploit the stator currents signals, which are already commonly available, or easily and unobtrusively collectable. Moreover, authors showed that using state-of-the-art deep neural network, instead of the now classic techniques like the PCA, it is possible to extract from the stator current signal a compact and expressive representation of the bearings state, ultimately providing a bearing fault detection system. By exploiting a series of real-data collected from inverter-fed motor mounting different artificially damaged bearings, authors showed the effectiveness of their proposal **[06].**

Liang, X., Ali, M. Z., & Zhang, H. (2019) - Condition monitoring and fault diagnosis of induction motors serve as essential techniques toward reliable operation of critical industrial processes. The finite element method (FEM) offers a great insight of fundamental principle and physical operation of the machine. It can model complex magnetic circuit topology, discrete windings layouts, and nonlinear magnetic material properties of the machine. It determines the machine parameters (such as the magnetic field distribution, flux density, electromagnetic torques, and stator current), and can model localized magnetic saturation due to faults to a high degree of accuracy. Used as fault detection algorithms, the FEM can address the issues such as the lack of comprehensive fault databases through field measurements, and the difficulty in distinguishing fault severity. It can reduce the number of destructive tests required in the field/labs; simulate any faulty states of the machine. Although FEM has been widely used in induction motors’ design and analysis, its application in fault diagnosis is limited despite the promising potential. In this paper, a literature review is conducted on induction motor fault diagnosis techniques using FEM. The state-of-the-art techniques reported in the literature are categorized into three streams: 1) FEM-based fault diagnosis approach, 2) FEM and signal processing-based approach, and 3) FEM, machine learning and other advanced techniques-based approach. The advantages of fault diagnosis techniques using the FEM are demonstrated and the future research direction is recommended **[07].**

III. INDUCTIONS MOTORS FAULT DIAGNOSIS USING ONLY FEM

Set- In this section, the induction motor fault diagnosis for a few major faults (BRB faults, stator faults, and eccentricity faults) using only FEM is presented.

A. Broken Rotor Bar Faults

In the effect of BRB faults is investigated through the influence of the motor’s electromagnetic characteristics and its thermal field distribution. Due to a BRB fault, an asymmetrical magnetic field distribution is observed. In [36], a fluxgate sensor is used to analyze and detect the BRB fault pattern via the leakage flux analysis in induction motors using a two dimensional (2D) time stepping finite element method (TSFEM). The proposed method is more precise and reliable than the classical motor stator current analysis (MSCA) for induction motors a BRB fault pattern has been modeled for fault diagnosis purpose. A squirrel-cage rotor bar circuit is developed for normal and abnormal cases as shown in Fig. 3.1. In this paper, firstly, it is assumed that the broken rotor bar does not affect any other loop of the circuit and the current in the broken bar is zero; secondly, a segment of the broken bar is changed to a non conductive material to emulate the broken bar fault from in the proposed FEM model.

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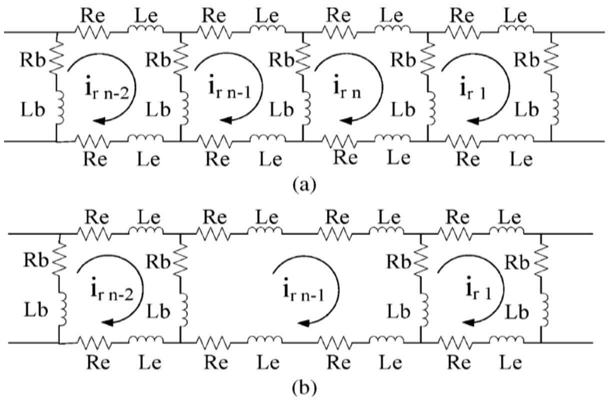

Fig 3.1The circuit setup for a squirrel-cage rotor bar for the FEM models: (a) normal case; (b) a BRB case

In based on the FEM analysis, the effect of BRB fault on the space dependent electromagnetic characteristics of the induction motor is investigated. The simulation models for healthy and one BRB fault conditions are considered. Presents the radial component of the spatial distribution of the magnetic flux density for the healthy and one BRB fault conditions of a 3-phase, 4 kW and 1460 rpm induction motor. The model of the machine with the one BRB fault is shown in Fig. 3.2 (b), and the broken rotor bar is placed at 300 angles with respect to the horizontal axis. The stator and rotor teeth have been marked, the greater saturation of the magnetic flux density as well as the asymmetry of the spatial magnetic field distribution have been observed for the one BRB fault model compared to the healthy model.

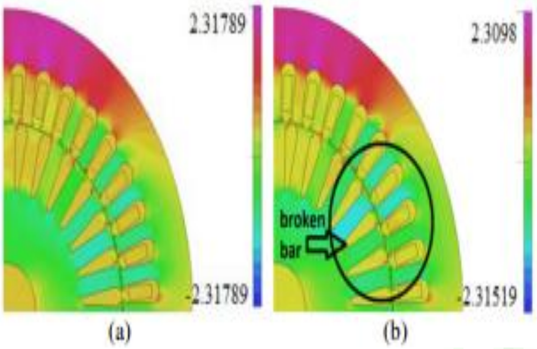

Fig 3.2 Radial component of the spatial distribution of the magnetic flux density for (a) the healthy model, and (b) one BRB fault model

B. Rotor Eccentricity Faults

Mechanical faults of induction motors, such as bearing faults, rotor eccentricity faults, and gear-box faults, can cause severe damages of the machine. Different electromagnetic field distribution between the stator and rotor occur due to nonuniform air gap and unbalanced input voltages. Rotor eccentricity can be caused by misplacement of bearing, misalignment between the rotor shaft and load axis, mechanical vibration in critical speed, and unbalanced electromagnetic force. It is important to detect these faults to protect the machines from permanent damages.

There are three types of rotor eccentricity: static, dynamic and mixed eccentricity. Fig. 7 shows the cross-section area of an induction motor with the three types of rotor eccentricities, where, is the rotor symmetry axis, is the stator symmetry axis, and is the rotor rotation axis. The types of eccentricity are determined by the separation of its axes. The static eccentricity occurs when the axis deviates from other two axes, and the position between the air gap and the stator is static. The dynamic eccentricity occurs when the axis deviates from other two axes, and the position between the air gap and the stator is dynamic with the rotor. Mixed eccentricity occurs when all the axes deviate from each other.

C. Stator Faults

Stator faults are the second most frequently occurred faults after bearing faults in induction motors. Most stator faults can be caused by electrical and mechanical functioning conditions. Stator winding faults are very common faults. The stator faults can be categorized based on fault locations on the frame, the lamination or stator windings as shown in Fig. 3.3. Fig. 3.4 represents different types of stator winding faults for a star-connected stator. Basically, inter-turn faults (also known as turn-to-turn faults) due to degradation of winding insulation is initiated by stator short-circuit faults.

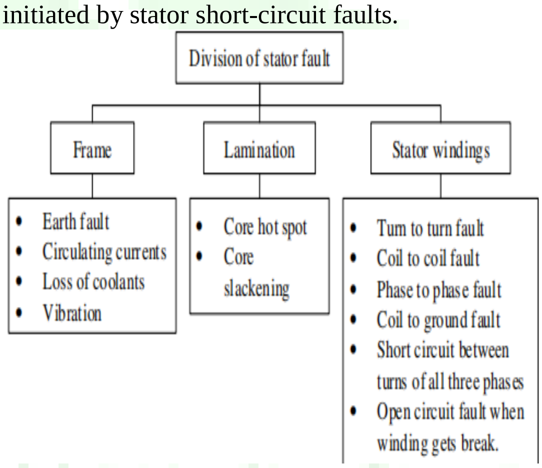

Fig 3.3 Summary of stator fault under three fault divisions

Sometimes, inter turn faults may be untraceable, but short-circuit faults is noticeable by analyzing the unusual machine performance. The unbalanced electric field and magnetic flux distribution, the increase of vibration, the increase of torque pulsation, the decrease of average torque, and the insulation failure may happen due to inter turn faults, which can cause severe damage to the machine. The FEM analysis considers the geometrical shape and different boundary conditions for specific regions of the machine, it is a suitable approach to diagnose stator faults. It offers more accuracy than the traditional fault diagnosis methods.

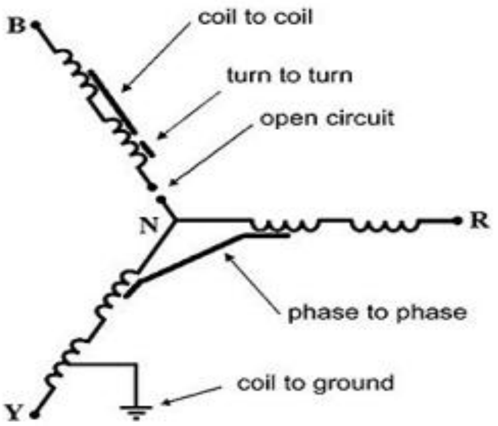

Fig 3.4 Types of stator winding faults for a star-connected stator

In a 2D FEM model based inter-turn short circuit in different winding locations of an induction motor are investigated, and the motor variables influenced by this fault are evaluated. In this model, healthy coils are modeled as a solid conductor, but the coils with short circuit faults are modeled by a number of individual conductors identical to the number of turns of the coil, and the FEM model is attached to an external circuit, which allows to specify where are the faulty turns electrically and geometrically located. This model assembly makes the simulation of different types of short circuit between turns in one coil possible. The current spectra illustrates that the difference between the healthy and faulty motor is the magnitude of a harmonic component at approximate 732 Hz frequency.

IV. BROKEN ROTOR BAR FEATURES SELECTION

The previous section has provided the basis for the BRB features selection. In order to extract the most relevant BRB feature components, the developed IM model was applied to the numerous simulations which were carried out for a healthy rotor, rotor with one and with a few broken bars. The fault was modeled by increasing the faulty bar resistance. Some imperfections in the rotor cage construction were modeled by varying rotor bars resistance in the amount of 1.5% using random number function. The IM was simulated at the steady-state, both, under no-load (friction included) and on-load conditions, with load factor of 10%, 25%, 50%, and 100%. All simulation results are obtained using the 11 kW, 400 V, 22 A, 50 Hz, four-pole, three-phase squirrel cage IM and its related parameters. Overall, 25 computer simulations were conducted (five simulations for each motor load value). Such a large number of simulations are needed to provide sufficient number of BRB features and provide adequate learning capabilities of the AI FD system. The block scheme of the proposed ANN based BRBs detection and classification system is given in Fig. 4.1.

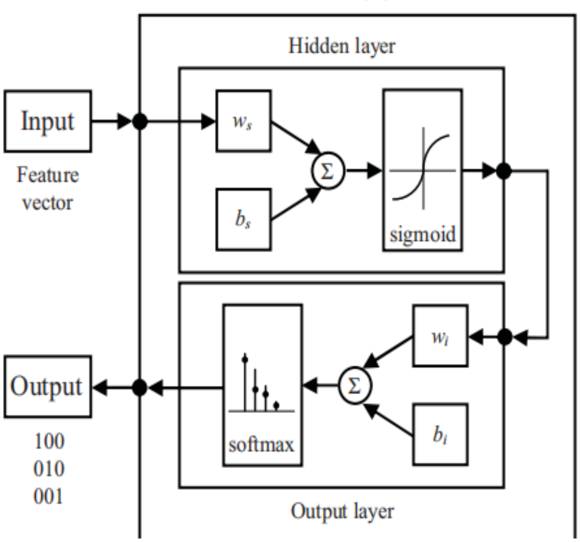

Fig 4.1 Schematic of the proposed feed-forward ANN for BRB FD

The proposed feed-forward ANN was developed using Matlab Neural Network Toolbox, employing the Leven berg Marquardt back-propagation learning algorithm and the cross-entropy cost function in the training stage. The representative feature datasets, consisting of 175 BRBs signatures in total, and their corresponding class labels, were divided into three groups: 70% of them as a training set, 15% of them as a validation set, and 15% of them as a test set. The ANN was trained using the training set, with the aim of updating weights and biases, whereas validation set was used to measure the network generalization during training process. An early-stopping criterion was used to avoid over fitting. Finally, the performance of the fully-specified network was evaluated by test set. The cross-entropy error Fig 4.2. Good overall network performance was achieved. The accuracy of the developed ANN classification model will be verified in the next section, with new datasets, provided by additional computer simulations of IM operations with healthy and faulty rotor bars under different load conditions and drive inertia.

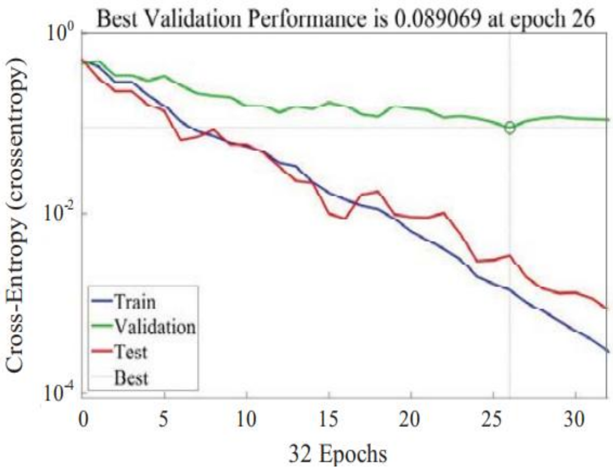

Fig 4.2 The cross-entropy error of the developed ANN

B. Fault Detection Using Support-Vector Machines

Condition monitoring (CM) is increasingly becoming important in manufacturing industry, due to its successful implementation, increasing general reliability and uptime. However, many of the techniques available presently require a good deal of expertise to apply them successfully; simpler approaches are needed which allow relatively unskilled operators to make reliable decisions without the need for a condition monitoring specialist to examine data and diagnose problems. Therefore, there is a demand for techniques that can make decisions on the running health of a machine automatically, and reliably .Reliability of detection is the most important criterion for the success of a condition monitoring system, and as a result, the challenge is to develop algorithms and techniques that are able to detect fault conditions more accurately than those available at present. Research has been carried out into the use of artificial neural networks for fault diagnosis, and the results are promising; as a result, applications are now appearing in CM systems.

Support vector machines are a comparatively recent development, although their origins can be traced back to the late 1960s. SVMs have been gaining acceptance in the machine learning, computer vision and pattern recognition communities for their high accuracy and good generalisation; however, there are still relatively few ‘real ‘engineering applications based around them, and only a few are known to the authors in the field of process/condition monitoring. This paper offers a comparison between the two classification algorithms, ANNs and SVMs, and shows a simple technique for selecting the RBF kernel parameter in SVMs that yields good results in two different examples from this area of engineering.

V. CONCLUSION

In this survey paper discuss on Advanced Feature Selection for Broken Rotor Bar Faults in Induction Motors. The important outcomes of this paper are shown in the section of comparative analysis.

In this survey paper observe that the Advanced Feature Selection for Broken Rotor Bar Faults is the major problem in Induction Motors. Also most of the design Advanced Feature Selection for Broken Rotor Bar Faults in Induction Motors suffer from lower gain problem.

In future design a better Broken Rotor Bar Faults in Induction Motors. That can improve all these problems in this communication area. In future try to design Broken Rotor Bar Faults in Induction Motors that can perform better result in terms of Power System.

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