ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 2, August 2013

Agrees and Disagrees of Mechanical and Electrical Faults Diagnosis of the IM Techniques: A Review

*1Khalaf Salloum Gaeid; 2Adel M. Bash; 3Aref Jasim Abbas; 4Jamal A.Hameed
* 1,2,3,4Tikrit University/Iraq

***Abstract*— The first part of this review covered the field of the fault diagnosis and fault tolerant control up to 2010. The present contribution presents a modified review of the researches on the fault diagnosis and fault tolerant control of induction motors up to now. The classification of the faults which is another interested topics of this research finally the drawback of the method used in the fault diagnosis of the induction motor. The emphasis is on highlighting agrees, disagrees and tradeoffs in the reviewed topics. Sorting and classification is another goal. More attention is paid for the researches done in the last ten years, and a brief description is presented for each issue. Extensive number of papers is reviewed and appointed in the present preview, to provide quantitative description for each agree or disagree.**

Index Terms— **Fault tolerant control, Neural, Fuzzy, IM Faults, Signal Processing Techniques, and Software.**

I. INTRODUCTION

Rotating electrical machines plays important role in many field especially in the industrial processes because their rigid, rugged ,low price, reliable relative simplicity and easy to maintenance which we can represents it as a core of these fields especially the induction motor which takes a great deal of attention for the above performance but , the companies still faces many critical situations results in losses in revenue, also the operators under continuous pressure so that the techniques of the fault diagnosis are very urgent aspects before the catastrophic results in the equipments . The fault diagnosis may be classified into two main parts: (cause-effect and effect cause) the main methods used in the fault diagnosis field are:

- Hybrid Approaches: Combination like I.M Model and any signal processing method, Model and soft computing method etc; are considered here as a hybrid approach for the fault detection of induction motor[1].
- The expert diagnosis: This method is based on human been experience with the system. According to this experience fault diagnoses of the machine directly associated to cause of this fault. This method has several disadvantages such as complexity, bad robustness and need good Experience [2].
- ANN artificial neural network better among many types of fault diagnosis for stable, speed, parallel processing but of some of its architecture cant apply for dynamic processing and need a lot of data. Compared with to finite element method, the solution time for calculating machine circuit parameters using neural network model has been dramatically reduced, while sufficient accuracy has been maintained, as opposed to the conventional techniques (expensive equipment, or accurate mathematical models required) fuzzy and neural network not need it but just the data.
- Polyharmonic Extreme Learning Machine. The method is a novel accelerating extreme learning machine, a combination of polynomial function and sigmoidal function is used instead of using the same type of activation function for all data points [3].
- FFT: the Fourier transforms is a representation of an image as a sum of complex exponentials of varying magnitudes frequencies, and phases. The Fourier transform plays a critical role in a broad range of image processing applications, including enhancement, analysis, restoration, and compression.
- FEM the benefits of this method include increased accuracy, enhanced design and better insight into critical design parameters, but all FE models are just that "models" they are mathematical "Idealizations" of continuous systems. Therefore, all results from any FEA code are not "closed formed solutions". The results are numerical approximations. Good approximations but approximations.
- TSCFE-SS (time step coupled finite element-state space) compute in sampled data from the time domain wave forms and profiles of the input phase and line currents, voltages .power, torques .
- Texture analysis based on local binary patterns [4], according to its capability as well as the gray scale invariance property of the LBP operators enables this method to achieve impressive diagnostic performance even in the presence of high background noise.
- MCSA this method take a great deal of attention because their easiness to use as well as it is not require to access to the induction motor parameters used signal spectral to find the faults according to the position of sidebands frequency harmonics and many another parameters effect the faults can be diagnostic but there are drawbacks of this method ,the amplitude of the current components depends on the loads connected to the motor thus the variation of system load make this method not applicable in all operation condition also when is that frequency s similar to those used for rotor bar can be generated by other causes such as low frequency oscillation. Currents and/or voltages signals can be selected to be analyzed to detect faults inside the motor. The selected

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signal is called a diagnosis media, and the output of the analysis applied to the selected diagnosis media is called a signature [5].

• Wavelet it's a signal analysis techniques to any kind of signal such as human speech, engine vibrations, medical images, financial data and many other types of signal but the draw back its difficult to be applied if the startup very faster and need minimums inertia factor. There more methods as in table 1.

• Complex Park Vector (CPV), the well-known Park transformation allows showing the variables of a three- phase machine through a system of two quadrature (I_d & I_q) shafts, they are a measuring and diagnostic tool in electric three-phase systems. The properties of this method as in table 1.

$$I_d = \sqrt{3/2}I_a - \sqrt{1/6}I_b - \sqrt{1/6}I_c \quad (1)$$

$$I_q = \sqrt{1/2}I_b - \sqrt{1/2}I_c \quad (2)$$

Where I_a, I_b , I_c are the currents of the phases A, B, and C of the stator.

• Axial Flow (AF), An axial-flow induction motor having an alternating magnetic field and associated harmonics, comprising a stator having a winding arranged in a slot and rotatable supported laminated rotor spaced from the stator by an air gap, the rotor including relative to the stator a remotely positioned magnetically conductive layer and a more closely positioned electrically conductive layer, further more as in table 1.

• Impedances of Inverse Sequence (IIS) as can be shown in table 1.The faults of the induction motors components as in Fig. 1 can be divided into two main parts electrical faults and mechanical faults.

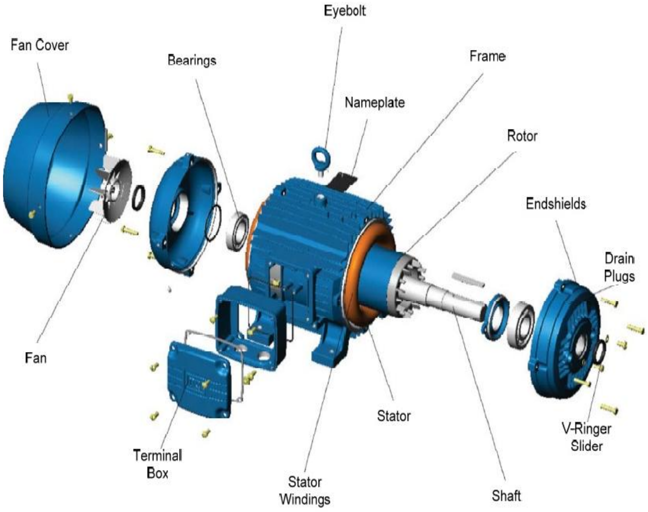

Fig. 1: Induction Motor component

Many researches classifies the fault diagnosis according to the model based fault diagnosis methods and physical based model fault diagnosis but the model based take advantage of mathematical models of the Diagnosed plant. Different faults often require different mechanisms for their detection. A model based method using time-series prediction for fault detection and identification in induction motors is less common. Most methods use fault diagnosis based on data directly through some means of limit checking or classification and not through application of models of the motor itself. Some papers advocate physical model-based systems. These models have the advantage of containing meaningful physical variables, but what the models gain in physical relevance they often lose inaccuracy. For example when feeding a physical-based model with converter fed voltages the results are inaccurate. For purposes of fault diagnosis from the stator current the simple physical-based models do not give enough accuracy when applied to rotor and stator faults. This problem is also noted in research literature. Empirical coefficients are used for phenomena that cannot be accurately. Modeled, so that proper results are achieved for motors of standard design. Problems arise when motors are studied that are of new design, that are in transient states or are fed by non sinusoidal voltages. A reason for why a physical-based model cannot model the motor adequately is that it cannot properly take into account all the mechanical, structural and operational details, which differ from motor to motor. As physical model based systems have their limitations, in this review we will classifies the faults of induction motor into the following, some faults implicitly included in some kinds of the faults such as the external faults of the induction motor, unbalance voltages, vibrations take place in the induction motors, one or more phase unbalanced, torque oscillation or any kind of the faults. For a methods such as ACSA ,park's vector ,motor parameter estimation ,harmonic analysis of speed fluctuations and freq analysis of instantaneous power have some drawbacks such as (its need many sensors these should have high precision ,its need knowledge about the internal structures). Negative sequence may fail under extremely low level of fault particularly when the supply voltage unbalance The main faults of the induction motor are depicted as in Fig.2.

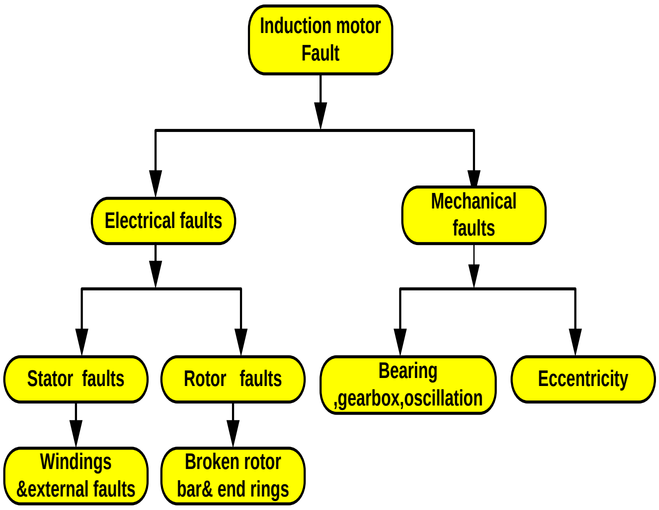

Fig.2: Faults in the induction motors

According to the above faults, the percentage of each fault are as in Fig.3.

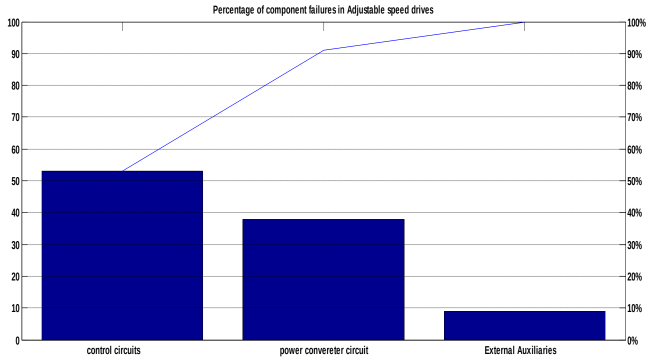

Fig. 3: Percentage failures by components

II. SIGNAL PROCESSING TECHNIQUES

A. Air Gap Eccentricity

A mechanical fault that happened due many reasons such as machine manufacturing, assembly, unbalance load, bent shaft and bearing wear. The static air gap eccentricity expression is

$$f_{secc} = [kQ_r \frac{1-s}{p} \pm n] f \qquad (3)$$

K=1, 2, 3...

n=1, 3, 5, order of stator time harmonics present in the power supply feeding the motor. The dynamic air gap eccentricity expression is

$$f_{decc} = [(kQ_r + n_d)\frac{1-s}{p} \pm n] f \qquad (4)$$

kQ_r is the number of rotor slots

K=1, 2, 3...

n_d is the dynamic eccentric order (n_d =1, 2, 3,).

n=1, 2, 3,

The mixed air gap eccentricity expression is

$$f_{mixecc} = [1 \pm k \frac{1-s}{p}] f \qquad (5)$$

Several contributions deal with these faults. Eccentricity Severity Factor is defined and is shown that this factor increases with increase of air gap eccentricity in the machine which is used as a measure to assess the degree of eccentricity in the machine done by [6].Analytical expressions to calculate time varying inductances of salient pole synchronous machine with any eccentricity type and degree in the frame of a single program for static eccentricity to verify accuracy of the model was done by[7]. The air gap eccentricity detection by analyze the inclined static eccentricity of the I.M done by[8]. the axial non uniform air gap due to off line monitoring of the variations of the surge waveform at the different rotor position the eccentricity detection proposed by [9]. Detection of the faults of eccentricity using ANFIS (adaptive network based fuzzy inference system) techniques presented by [10]. A model of the I.M using a mesh of magnetically coupled reluctances designed by [11]. This model allows the dynamic simulation of the main induction motor variables to detect faults with high efficacy. A new strategy based on the signature analysis of the complex apparent-power detecting the occurrence of air gap eccentricity in operating three-phase I.M presented by [12].Mixed (static and dynamic) eccentricity at the starting period using TSFE, the input of FE calculations was the applied voltage has been studied by [13]. Investigation of static eccentricity severity by the features investigated of RSH and RSH side bands of both the line currents and vibration done by[14]. The evidence theory to find the motor static eccentricity using the BPA for each sensor by noticing the magnitudes features presented by[15]. A review for the best methods to deal with air gap eccentricity like the digital camera or laser sensors to detects the faults introduced by[16]. Investigation of the squirrel cage induction motor eccentricity mixed faults through the instantaneous power factor signature analysis done by[17]. new technique to detect main faults in the induction motors through TSCFE–SS method which can generate a large no. of healthy and faulty IMASD simulations with TSDM techniques was developed by[18] , dealing with the drive of induction motor as closed loop to detect the rotor eccentricity related harmonics in the stator voltage and current space vectors simultaneously using neural networks studied by [19]. new approach to detect air gap eccentricity using instantaneous power signature analysis was presented in[20], the pre established pulse sequence applied by the inverter to the I.M the air gap eccentricity effect on the zero sequence voltage can be detected and the diagnostics results was quite visible was stated by [21], a distinguishing load torque oscillations and eccentricity faults in I M using stator current presented by [22] .A model based mixed eccentricity fault detection and diagnosis for induction motor presented in [23]. Air gap torque as failure signature to detect mechanical faults in particular the eccentricity has been proposed by[24]. They compared current space vector (Park vector) and complex apparent power to detect the eccentricity fault.

B. Gear Box and Bearing Faults

The speed and load conditions of teeth may cause several types of failures on teeth surface of the gears which leads to non-stationary operating conditions. the effectiveness of the new time-frequency distributions called the Zhao-Atlas-Marks (ZAM) distribution to enhance non stationary signal analysis for fault diagnosis in gears [25]

The mechanical frequency needed to investigate the mechanical fault such as gear box, A bearing fault generates an additional torque component that varies at the specific bearing defect frequency [26]

$$f_{mech} = | f \pm m f_{r,m} | \qquad (6)$$

The damage frequency in the outer bearing race is:

$$f_0 = (\frac{N}{2}) f [1 - \frac{BD}{PD}\cos(\beta)] \qquad (7)$$

The damage frequency in the inner bearing race is:

$$f_i = (\frac{N}{2}) f [1 - \frac{BD}{PD}\cos(\beta)] \qquad (8)$$

The frequency of the damaged ball is:

$$f_b = (\frac{BD}{PD}) f\{1-[\frac{BD}{PD}\cos(\beta)]^2\} \quad (9)$$

N =number of bearing balls
BD = ball diameter
PD = ball pitch diameter
β = contact angle of the ball with the races.

However, these characteristic race frequencies can be approximated for most bearings with between six and twelve balls, [27] used the RBF neural network to detect the bearing of outer race defect of ball faults through MCSA techniques,[28], a three shafts and their corresponding gear mesh frequencies (GMFs) the gear box faults can be detected by demodulation of the motor current waveform. [29] Presents the facilities of ANFIS approach in the detection of inter-turn insulation of main winding and bearing wear of a single phase I.M. In [30], the park's vector for monitoring I.M bearing faults by noticing the thickness of Lissajou's curve has been studied. Deal with multistage gearbox of induction motors using tacho generator and dc generator to generate ripple voltage also use MFT done by [31].detection the bearing fault in the intelligent diagnosis techniques uses wave transform and SVD techniques presented by[32]. new method to detect incipient faults based current techniques according to noise cancellation presented in [33]. one of the stator current monitoring to detect the rolling element bearing faults presented in [34], for 0.75 kw [35], found the diagnosis capabilities of the park transform better than Concordia in the bearing fault diagnosis. [36] Present a neural network to detect on line stator and rotor resistance in the sensor less motor. B-spline has been used in [37] as membership of neural fuzzy to detect on line stator fault, a technique to detect a fault in the stator winding using two DRNN to estimate the severity of the fault presented in [38]. Simple open loop inverter (PWM-VSI) fed induction motor to detect to estimate stator flux at zero voltage and low frequency by NN presented in[39].[40] investigates the connection path of uncontrolled rectifier of a variable v/f induction motor drive.

C. Stator Faults Resulting of Opening or Shorting the Stator Coil

The cause of most stator faults is insulation breakdown that leads to winding failure[41]. The frequency of the stator fault is:

$$f_{st} = f[n(\frac{1-s}{p}) \pm k] \quad (10)$$

$n = 1, 2, 3\ldots$
$k = 1, 3, 5, 7,$

The fault diagnosis of the stator inter turn and rotor presented by [42]. Fuzzy and e-mean to detect the stator faults done by[43]. The detection of stator winding interturn shorts done by[44], the fault speed sensor in the induction motor[45], simulation of inverter as switching technique to find the faults[46],wave convolution to diagnose the induction machine[47],two different approaches for diagnosis of induction machine in the transient region presented by [48], signal acquisition of IM presented in [49],diagnostic system based on hidden Markov's modeling of short circuit fault diagnosis of IM[50], fault diagnosis in the auxiliary winding using spectral analysis[51] ,protective relays for the fault diagnosis[52],weak signal detection for fault diagnosis [53], short circuit faults of IM based on hidden Markov model[54], detection of the inter turn faults in the IM using the pendulum phenomena[55], vector control support based classification and monitoring techniques for the IM[56], on line simulation using the finite element method[57], effect of position and the number of broken bar in the motor stator current spectrum[58], using of MCSA techniques to detects the fault in squirrel cage presented in [59], influence of adjustable speed drive on I.M fault detection using SCM[60].

D. Abnormal Connection of Stator Winding

Double frequency tests are used for evaluating stator windings and analyzing the temperature based on MCSA[61], fault detection in the inverters[62], faults detection of low order PWM harmonic contribution of the inverter fed IM [63], the faults of induction machine using the spectral density using the wavelet techniques are investigated, the capabilities of the signature graphical tool to detect the faults in I.M [64],a protection method to detect the unbalance voltage and single phasing faults resented by[65], use the vector Eigen values to detect the faults of the closed loop IM[66], investigation the vibration faults in the winding based EMAM[67], voltage/frequency control usage to predict the fault inverter[68],a statistic moment based method for the detection and diagnosis of I.M stator fault presented by [69], a model of dual stator winding induction machine in case of stator and rotor faults for diagnosis purposed[70], diagnosis of IMs for implicit faults introduced in [71].

E. Shorted Rotor Field Winding

A method for analyzing electrical shorts in field windings of a synchronous machine having a rotor using a magnetic flux probe, the method includes: monitoring flux signals generated by the flux probe wherein the flux signals are indicative of magnetic flux emanating from the field windings done by[72], .Daniel F. Leite et al (2007) according to model based detect the alternators & I.M faults[73],PDA method usage in the monitoring and diagnosis[74],study the torque and current peculiarities [75], the rotor fault diagnosis using wavelet spectral analysis investigated[76], modeling techniques based on the model of the IM and the pumps [77], many faults in the IM as well as the monitoring of the machine investigated by[78], a research on the rotor and stator double faults squirrel cage in the IM presented in[79], the methods and technologies of the rotor fault diagnosis presented by[80],new faults indicators in the rotor for squirrel cage IM [81], diagnosis of rotor faults in closed loop induction drive[82], Welch, Burg and MUSIC methods to detects the faults on the rotor applied by [83], slide mode observer in rotor fault diagnosis [84], indicators of the rotor in FOC

Drives[85], detection of rotor faults in squirrel cage IMs using Adjustable Speed Drives introduced by[86],PQ transformation technique in the rotor fault diagnosis[87], early detection approach for fault diagnosis[88], wavelet of One Cycle Average Power in the rotor fault diagnosis[76] ,analytical investigation on the effect of the negative sequence on stator fault[89], diagnosis and fault tolerant control and many examples in this book[90].

F. Broken Rotor Bar and Crack End Ring

The percentage (5-10%) is the broken rotor bar fault This type of fault is occurred during the course of running, starting or load changing, voltage fluctuation, torque oscillation. Large current may flow through the bars or end ring; large heat will be generated in the end ring joints or bars [91]. The rotor broken bar frequency in asymmetry condition and comparison between the internal and external methods when the detection of faults by the spectral analysis [92], the effect of current of the bar and axial flux on the faults [93], fault diagnosis through the identification parameters of the IM [67], the broken bar faults using the discrete and continuous wavelet presented by[94],in his thesis [95] introduce the fault diagnosis methods and take many cases of the process monitoring. Faults diagnosis of broken bars using the global fault index introduced in [96], the inter turn stator faults and broken bar of poly phase IM introduced by[97], the faults of inter turn and broken bar presented in [98], the wave let fault diagnosis of inverter fed IM used by[99],new method in the fault diagnosis of IM using wavelet transform to find rotor bar faults used by [100], broken bar diagnosis using starting current analysis[101] fault in the rotor bar through the voltage analysis modulation[102], new approach to detect the broken bar using vibration techniques given by [103], finite element characteristics to detect broken bar of squirrel cage IM[104], broken bar and the effect of load of the induction during the rundown [105],detection of broken bar using Hilbert Transform presented by[106], broken bar and stator short circuit due to stator current [107], fault diagnosis of broken bar for load variation in the IM using wavelet [108], fault diagnosis of the broken bar Use of a Lower Sampling Rate with DTFT and AR[109]. The legalistic rules for fault diagnosis of broken bar with many cases are introduced by [110], condition monitoring vector data base of broken bar faults in the IMs[111].

G. Shaft Bent

Bent shaft which can result in a rub between the rotor and stator, causing serious damage to stator core and windings[112],.for a 1.5 Kw an IM, shaft misalignment, damage bearing tested [113], different kinds of faults such as transverse cracks, imbalance, misalignment, bent shafts, and combinations thereof are considered. Off-line and on-line experiment analysis are carried out[114], flexural vibrations of a rotor system with transverse or slant crack are analyzed under torsion excitation, The numerical and experimental investigations demonstrate these features can be used to distinguish between the transverse crack and the slant crack on the shaft of a rotor system[115].

III. ARTIFICIAL INTELLIGENCE TECHNIQUES

Compose of many types of methods deals with the fault diagnosis of IMs such as neural networks ,fuzzy logic, or the combination of both, genetic algorithm, even expert network can be included witch introduce many facilities with respect to the signal processing techniques but its need a large amount of data about the motors which sometimes difficult to get it. Description of a new approach for fault detection and diagnosis of IMs using signal-based method. It is based on signal processing and an unsupervised classification technique called the Artificial Ant Clustering done by[116], hybrid model to detect some internal and imbalance faults[117], the controller is derived using neural network and slide model in the IM [118], ARR technique to detect centrifugal pump was proposed by[119], sensor faults of IM[120], analogue device and dual core SP to detect the faults in the inverter implemented by [121], negative sequence through MCSA to detect the faults presented in[122], detection of broken bar and air gap eccentricity through MCSA[123], with high advance on line monitoring detect faults in the IM using MCSA was presented in [124], diagnosis based on Markov's which is used in recognition of speech to detect the faults[125], the bond graph modeling to detect the fault[126], Kohen's SOM to detect the three phase inverter faults[127], a review for the multiphase of IM given by[128], signals filter in the inverter fed IM using neural without any sensor[129],self organize with radial bias function as a new techniques to detect the faults[130], new approach in fault diagnosis of IM using wave let using real time implementation of wavelet packet transform-based diagnosis[131], soft computing used techniques for fault diagnosis of uncertainty propagation [132], indirect vector controlled IM using hybrid classical controller and fuzzy controller[133], new approach for fault diagnosis using back stepping digital techniques for IM presented by[134],new procedure using non invasive Beirut diagnosis for the IM drives presented by[135], wavelet convolution to detect on line system fault[47],based on soft computing investigate the propagation uncertainty in fault diagnosis[132], Fig.4 shows the neural network.

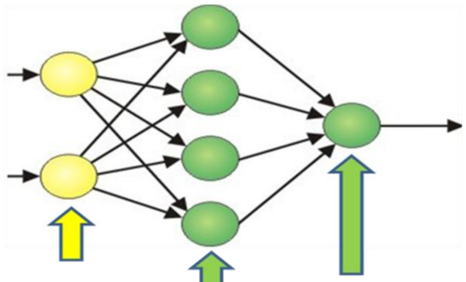

Fig. 4: Neural Network

wavelet decomposition using power spectral density in diagnosis of induction machine[136], fuzzy logic to detect the

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 2, August 2013

faults of the inverter fed the IM [137],feature vector is constructed based on park's vector approach to detect the broken bar and stator short circuit faults[138],the design methods and real time realization and classification through the neural network presented by[139],the neural network fault diagnosis capabilities of multilevel inverters investigated[140], Hall effect in the fault diagnosis of rotor broken bar through neural in the large IMs investigated [141],sensor less speed estimation of line connected using RNN used by[142], NN based fault identification in the IMs[143],RBF Neural Network Based on Dynamical PCA for the fault identification in the IM[144], model based fault diagnosis in the IM using ANN [145], neural network in the torque estimation and d-q transform[146],induction condition monitoring using NN modeling [147], fault diagnosis of IM using the NN[148], optimization of flux by NN using a model of losses in IM drives [149], Comparison of on line control of Three Phase IM Using RBF and B-Spline Neural Network presented in [150], monitoring and diagnosis of external faults using artificial neural network[151],N.N. schemes control for I.M drive systems[152], incipient faults of three phase I.M. using NN identification [153],image processing for neuro-fuzzy classifier in detection and fault diagnosis of I.M[154],adaptive neural model-based fault tolerant control for multi variable processes[155],fault tolerant control based on stochastic distributions via multi layer perceptron neural networks[156].

IV. SOFTWARE USED WITH FAULT DIAGNOSIS

The main software programs that can be used with fault diagnosis techniques either with classical methods or the artificial methods to give high facilitate .here we manifests the most important among them: DOCTOR ,Matlab program, Tiberius program ,Ansys program, Lab view program ,Knoware program, ABAQUS program, SAMCEF program ;OOFELIE program CalculiX program, OOFEM program, ALGOR program; Sundance program ,JMAG; program, PERMAS program ,STRANDS7 program, PAM program ,solid work program, Neural net. Program ,Jaffa neural program ,Free Master program ,Maxwell pc program, Motor monitor program, Neuro solution program, DLI watchman program COSMOS work, program, Maple Sim program, Fault tolerant software,Sim20 software ,PSCAD software, Free Master ,etc.

There are much more deals with the modeling and simulation of the induction machines but those according to author's knowledge. These programs not applicable for all methods, for example the Tiberius program can be used with neural network and the ANSYS for the finite element method, electromagnetic field and so on.

V. FAULT TOLERANT CONTROL

Many efforts in the control community have been recently devoted to study “Fault-tolerant” control (FTC) systems, namely: a fault-tolerant controller (FTC) of IM (IM) with inter-turn short circuit in stator phase winding. The fault-tolerant controller is based on the indirect rotor field oriented control (IRFOC) and an observer to estimate the motor states done by[157],fault -tolerant control systems details for the types of fault tolerant control, its areas ,architecture, control systems able to detect incipient faults in sensors and/or actuators on the one hand and on the other, to promptly adapt the control law in such a way as to preserve pre-specified performances in terms of quality of the production, safety, etc[158]. The fault tolerant control consists of two steps: fault diagnosis and re-design controller Currently, FTC in most real industrial systems are realized by hardware redundancy. For example, the majority-voting scheme is used with redundant sensors to cope with sensor faults. However, due to two main limitations of the hardware redundancy, high cost and taking more space, solutions using analytical redundancy have been investigated over the last two decades. There are generally two different approaches using analytical redundancy, passive and active approaches. Recently, an elegant design method of passive approach was proposed, in which the linear matrix inequality method was used to synthesis the reliable controller. The disadvantages of passive approach are the method is based on an accurate linear state space model and therefore is not capable of controlling a non-linear process for which an accurate analytical model is usually unavailable. In addition, because the passive approaches consider fault tolerance in only the stage of controller design and without taking adaptation when faults occur, the amplitude of the faults that can be tolerable is usually small and cannot meet the requirements in practice. There are many method deals with active fault tolerant control (adaptive control) such as linearization feedback linear quadrature method, Pseudo inverse method, Eigen structure assignment method, neural network ,control law rescheduling, model predictive control MPC,HY, norm optimization, 4 parameter controller, The main disadvantage of their designs is that they consider large fault effects which do not challenge the robustness problem! A consideration of smaller or incipient (hard to detect) faults would have given a more realistic and challenging robustness problem to solve, etc. the remote diagnosis is another type used with fault tolerant control. Off board component has (nearly) unlimited computing power but has to cope with limited and possibly biased measurement data ,on board component has to work with restricted computing power and memory size which limits the algorithm complexity of the task to be performed. A novel isolation scheme with its robustness and sensitivity properties using adaptive thresholds in the residue evaluation stage in three tank system, a rigid link robotic manipulator and the Van der Pol oscillator system presented by[159], fault tolerant control design that consists of two parts: a nominal performance controller and a fault detection element to provide fault compensating signals to the feedback loop presented in [160]. The nominal controller can have any given structure that satisfies the performance

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ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
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specification. The detection element will operate in parallel with the system until a fault is detected. Fault tolerant operations of soft starters and adjustable speed drives (ASDs) when experiencing power switch open-circuit or short-circuit faults, a method for designing switching controls and analyzing achievable performance for motor drives presented by[161], a collection of results towards a unified framework for fault tolerant control in distributed control systems are given in[162], who presents a fault tolerant strategy for the problem of loss of one phase in a field oriented controlled three phase IM. The proposed solution, rather than previously suggested solutions, is a control strategy in the single phase mode of operation of the IM, same above authors describes a novel strategy for restarting the three phase IM in a voltage fed field oriented drive operating in the single phase mode after the loss of one of the inverter phases. In [163] an original strategy of fault tolerant operating in case of doubly fed induction machine (DFIM) is given, the voltage and current control of a five-phase IM drive under fault conditions investigated by[164], the advantages and the inconveniences of using remedial operating strategies under different control techniques, such as the field oriented control and the direct torque control given in [165], Global results are presented concerning the analysis of some key parameters like efficiency, motor line currents harmonic distortion, among others, the problem of designing a fault tolerant system for IPMS motor drive subject to current sensor fault considered by[166]. To achieve this goal, two control strategies are considered. The first is based on field oriented control and a developed adaptive back stepping observer which simultaneously are used in the case of fault-free. The second approach proposed is concerned with fault tolerant strategy based on observer for faulty conditions, on-line sliding mode control allocation scheme for fault tolerant control proposed by[167]. The effectiveness level of the actuators is used by the control allocation scheme to redistribute the control signals to the remaining actuators when a fault or failure occurs, a novel intelligent nonlinear state estimation strategy is proposed in [169], which keeps diagnosing the root causes of the plant model mismatch by isolating the subset of active faults (abrupt changes in parameters/disturbances, biases in sensors/actuators, actuator/sensor failures) and auto-corrects the model on-line so as to accommodate the isolated faults/failures, a control system design for a rotor magnetic bearing system that integrates a number of fault-tolerant control methods considered by [170], a plug-in robust compensator for speed and position control enhancement of an indirect-field oriented control induction machine drive is developed[171], vector control algorithm, based on indirect rotor flux orientation, is at first briefly described[172]. Special attention is paid next to the current control issue, from the point of view of the minimum number of current controllers for six phase IM. The IFOC can transform the IM from nonlinear into linear system but with many assumption ,its well known the output response is sensitive to the plant parameters variations such as the rotor resistance, a bibliographical review on reconfigurable (active) fault tolerant control systems (FTCS) is presented by[173]. The existing approaches to fault detection and diagnosis (FDD) and fault-tolerant control (FTC) in a general framework of active fault-tolerant control systems (AFTCS) are considered and classified according to different criteria such as design methodologies and applications. as in Fig.5.

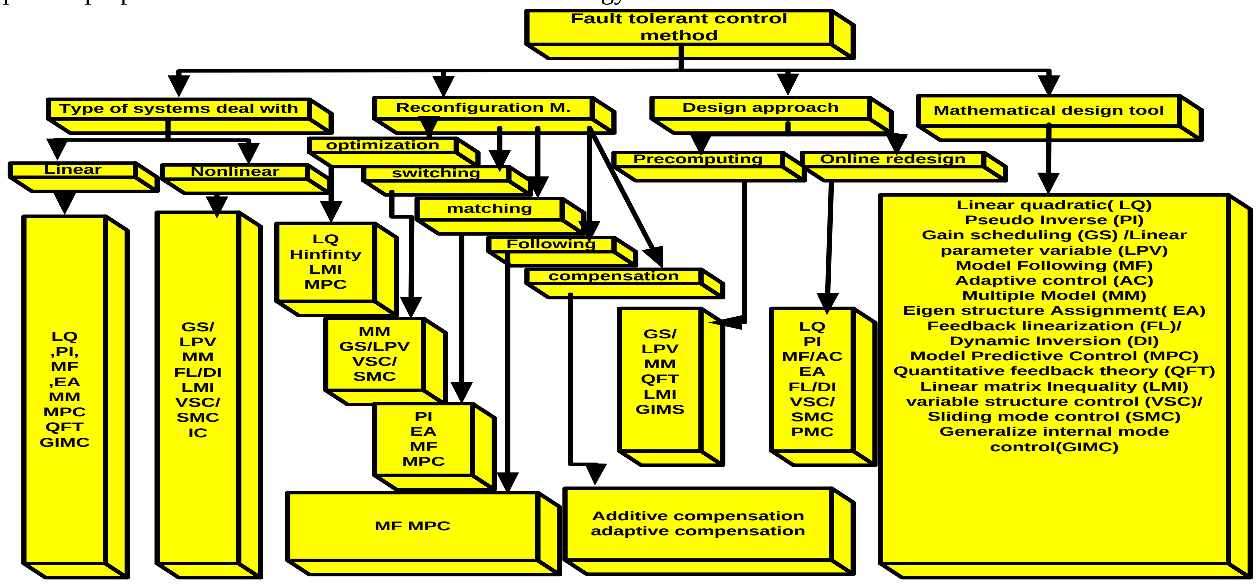

Fig. 5: Active fault tolerant control methods

adaptive fault tolerant control(FTC) of nonlinearly parameterized systems with uncontrollable linearization[168]. The progress was made due to the development of a novel feedback design technique called adding a power integrator, which was motivated by homogeneous feedback stabilization and proposed initially in new strategy for the fault tolerant control for aircraft systems presented by[174],analytical redundancy relation (ARR) based approach for fault detection and isolation (FDI)with application to hydraulic and a thermo fluid process using

ISSN: 2277-3754
ISO 9001:2008 Certified
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Bond graph to modeling FDI presented by[175], introduce in his Ph.d thesis the main methods in the fault tolerant control[176], typically, an active FTCS consists of three parts: a reconfigurable controller, an FDD scheme, and a control law reconfiguration mechanism as shown in Fig.6.

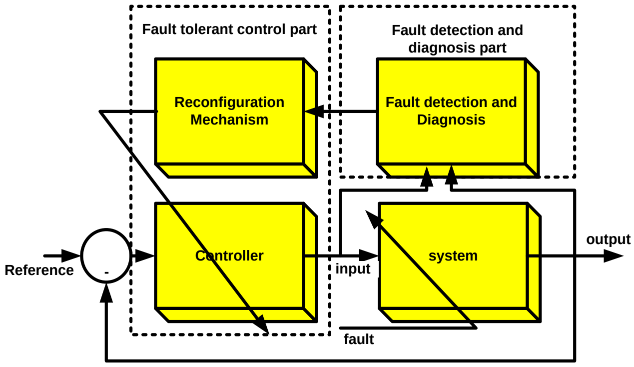

Fig. 6: Main component of fault tolerant control

The key issues of the fault tolerant control are how to design: A robust reconfigurable controller, AN FDD scheme with high sensitivity to faults and robustness to model uncertainties and external disturbances,(include residual generation and residual evaluation, threshold determination),and A reconfiguration mechanism which can organize the reconfigured controller in such a way that the pre fault system performance can be recovered to the maximum extent as shown in Fig.7. Fault tolerant control of IMs is proposed using both vector control as the dominant controller and a voltage-to-Frequency (V/F) controller as the complimentary controller has been done by[177].According to the depth of the information used of the physical process, the approaches to the problem of failure detection and isolation fall into two major groups: of plant dynamics, or, model-free FDI; or, model-based FDI. More than 13 papers published in the Journal of Control Science and Engineering about the fault tolerant control and fault diagnosis [178]. The existing FDI approaches can be generally classified into two categories: model-based and data-based (model-free) schemes; these two schemes can further be classified as quantitative and qualitative approaches as shown in Fig.7.

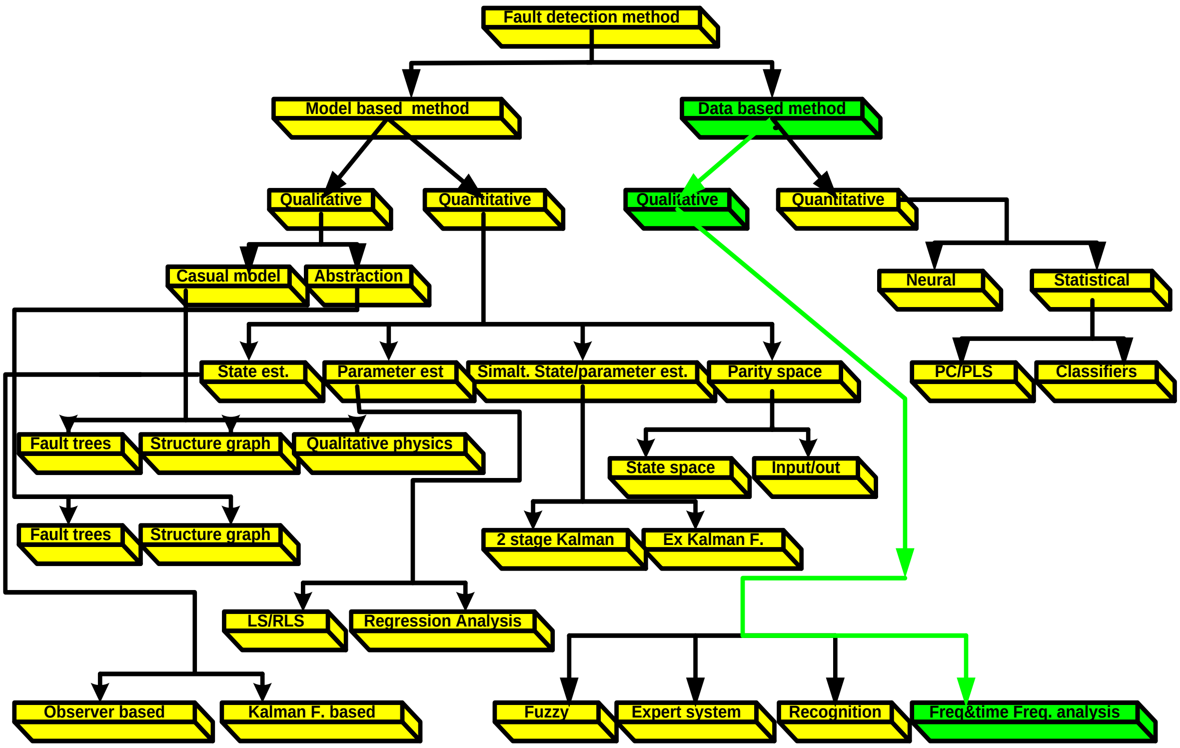

Fig. 7: Methods of fault detection and isolation part of FTCS

VI. CONCLUSION

This review for more interest research for last ten years in the fault diagnosis and FTC techniques. Included the general layout of the electrical and mechanical faults happened in the induction motor, methods to detects these faults and the agrees and disagrees of the most popular techniques deals with the fault diagnosis and fault tolerant control. Applying IM systems in critical path applications such as automotive systems and industrial applications requires design for fault tolerance. The successful detection of IM faults depends on the selection of appropriate methods used. There are a number of results related to using FDI to mechanical systems and control surfaces of an IMs such as online identification of fault models with time-varying nonlinearities and robust FDI using closed loop models are still of research interest. Rapid detection and isolation of faults is necessary to minimize the undesirable effects of detection and reconfiguration delays. Finally the software programs, which acts as a tool to satisfy the above solving strategies. The authors would like to thanks

Thanis Sribovor, professor Hew Wooi Ping from University of Malaya at same time apologize to those whose papers are not included.

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Table 1: Summary of Some of Fault Diagnosis Method Properties

Techniques	Required Measurement	Application	Advantages	Drawbacks
MCSA	One stator curre nt	Rotor broken bar Stator winding turn fau lt Air gap eccentricity	Low cost Non invasive	Frequencies' vary from one motor to other Limited to some states
Complex Park Vect or (CPV)	2 stator currents	Rotor broken bar Stator winding turn fau lt Air gap eccentricity	Non invasive Simple	Mismatch faults
Axial Flow (AF)	Axial flux	Rotor broken bar Stator winding turn fau lt Air gap eccentricity	Low cost	Non invasive
Torque Harmonics Analysis(THA)	2 stator currents and voltages	Rotor broken bar Stator winding turn fau lt Mechanical faults in lo	Mechanical fault detecti on Non invasive	Not effective in short circui t. Faults

		ad		
Impedances of Invers Sequence (IIS)	**Two stator currents and voltages**	**Stator winding turn fault**	**Incipient faults detection Non invasive**	**Require great meas. precision**
ANN	**2 stator currents & voltages**	**Stator winding turn fault**	**Incipient faults detection Non invasive Easily to adapt to each Motor**	**Required training period Not effective in the motors changes states**

AUTHOR BIOGRAPHY

Khalaf Salloum Gaeid was born in Iraq in 1969.He received the B.Eng. and M.Sc. from the University of Technology/Iraq in 1993, 2003 respectively, and Ph.D from University of Malaya/Malaysia in 2012 all in electrical engineering, specializing in control systems. and machine drive. He is IEEE member and he has a lot of publications in control of machine drive and fault tolerant control through the wavelet techniques.

Adel M. Bash was born in Iraq in 1968.He received the B.Eng. and M.Sc. from the University of Technology/Iraq in 1991, 1998 respectively, in mechanical engineering, specializing in applied mechanics; he has a publications in his field.

Aref Jasim Abbas was born in Iraq in 1962.He received the B.Eng. , M.Sc. and PH.D from the University of Technology/Iraq in1999,2002and 2006 Respectively, all in electrical engineering, specializing in AC and DC machines. He has a publications in the machine drive and power electronics fields.

Jamal A.Hameed Jamal A. Hamid was born in Iraq in 1953.He received the Diploma Eng. and PhD. from the University of TU Chemniz (Germany) in 1979, 1987 respectively, all in electrical engineering, specializing in computer Technology. He is currently working he is director of Electrical Engineering Department/Tikrit University. Dr.Jamal has a lot of publication in his field.