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Implementation of Health Monitoring System of Induction Machine Using Computational Intelligence

Abstract: - The induction machine is a critical component in various industrial applications, and its reliable operation is paramount for uninterrupted processes. To ensure the continuous performance and prevent unexpected failures, the implementation of an effective health monitoring system is imperative. In this study, we propose a novel approach to monitor the health of induction machines using computational intelligence techniques. The proposed system integrates advanced computational intelligence algorithms, including machine learning and signal processing methods, to analyze the operational data and identify potential faults or anomalies in the induction machine. Specifically, we employ techniques such as artificial neural networks, support vector machines, and genetic algorithms to process the sensor data acquired from the induction machine. The health monitoring system operates in real-time, continuously analyzing various parameters such as current, voltage, temperature, and vibration patterns to detect deviations from normal operating conditions. By establishing baseline performance profiles and employing pattern recognition algorithms, the system can identify early signs of degradation or impending failures, allowing for proactive maintenance interventions. Moreover, the proposed system offers flexibility and scalability, enabling adaptation to different types of induction machines and operating environments. It facilitates remote monitoring capabilities, enabling maintenance personnel to access real-time health status and diagnostic information from anywhere, facilitating timely decision-making and proactive maintenance strategies.

Keywords: Induction machine, Health monitoring system,Computational intelligence, Machine learning, Signal processing

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Introduction

Induction motors are most commonly used machines employed in fans, pumps, electrical vehicles as well as in small, medium and large scale industries such as rolling mills, cement, sugar mills and can be considered as a backbone of any industry. This motors and drives are very prone to different kinds of faults due to its heavy duty usages. Therefore, for the researchers it is very challenging to diagnose the faulty condition of induction motor. Machine failure can cause sudden break in the production of the industry which leads to a great loss economically and safety too. In order to attempt the fault diagnosis it is difficult and daunting job for operators and plant engineers. The various methods used for monitoring the condition of motors are acoustic emission monitoring, thermal monitoring, chemical monitoring and vibration signals monitoring. Failure detection and monitoring improves the reliability and availability of an existing system thus avoiding the sudden failure which has serious effects. Detection and diagnosis of faults are crucial with reference to condition monitoring. Fault is present or not, comprises to detection of faults, but information about nature and place of fault is provided by fault diagnosis. The above facts lead to reduce the downtime of the machine and to plan the routine maintenance action schedule. The maintenance action depends upon statistical data or on prognostic condition monitoring. Even the strategy run-to-failure can be adopted. The strategies can be selected depending upon economic or social circumstances[1]. The maintenance cost which includes loss in production, cost of repair, condition monitoring cost can be minimized by applying routine maintenance. The statistical life estimation of the machine depends on fact finding information about the behavior of ripen components. Besides that there are many factors which can lead to machine failure such as loading and temperature. The objective of condition monitoring is to inform about further damage, if action is not taken. So, this difference between condition monitoring and safety of motors averts the additional damage in the induction motors which can cause high loss economically as it leads to shut down the production. Monitoring the condition of induction motors can also be done on-line, which uses computers and computational efficient devices by analyzing continuous information supplied to it or by providing collected data occasionally[2].

The protection can be achieved through an alarm before it is going to trip with the help of sensitive protection relay; however it is insecure and risky as it may lead to false alarm and also less confident method for condition monitoring[3]. Therefore, for exact condition monitoring it is must to evaluate those parameters which will furnish desirable information leading towards failure, so that maintenance work can be applied before any serious damage occurs. The target of electrical drive manufacturers and operators is to minimize the cost of maintenance and restrain infrequent suspension through condition monitoring, in order to minimize performance loss and improve monetary resources. From the above discussions, it can be emphasized that there is an utmost need of employing the system of condition monitoring to the induction motors. Any contribution in the analysis and implementation of useful methods of condition monitoring would be of much help towards the improvement in industrial production and in turn would be a service to humanity[4]. Actually, accurate diagnosis and early revelation of incipient faults causes infrequent maintenance resulting small downtime for the ongoing process. This avoids destructive effects and diminishes financial loss too. Some research has been reported in ecent years for the improvement of condition monitoring system that overcomes the limitation of conventional methods for the same. As the application of electrical machines is increasing day by day, therefore its condition monitoring is critically important and attractive too for the researchers. This is an era of digital revolution and the human nature is becoming such that it prefers automated systems which need least human intervention. For this, first embedded system revolution was initiated, then the use of PLC, SCADA etc[7]. Nowadays, it is time for Artificial Intelligence (AI) wherein the computer programs, replicating the human thinking process, are used for decision making. Once trained, these algorithms are capable of making decisions without any human intervention. In this way it is obvious that the application of AI techniques would be desirable in the field of condition monitoring also.

Faults In Induction Motor

The Induction motor is often used in all industrial applications since it is fault tolerant and robust by nature. Therefore, precautionary measures are always considered for the diagnosing the condition of motor when it will become faulty. The continuous monitoring is always advisable for these kinds of the machines[8]. Due to heavy duty usage and condition of the environment it may lead to failure before its lifecycle. The identification of the root cause is also important to distinguish the failure pattern. The real cause of failure is to be traced and its analysis is also required that why it has occurred. However, condition monitoring system should be applied in reverse order for the prediction and causes of failure. [1] A research paper describing the faults in induction motor in the range of 0.75 to 150 kW, as well as its maintenance process is discussed [2]. Besides the unknown faults, main fault lies as 69% due to bearing, 21% due to winding of stator, only 7% due to rotor bar and rest are only 3%. This means induction motor fails mostly due to bearing fault as its percentage is very high in comparison to stator faults and others.

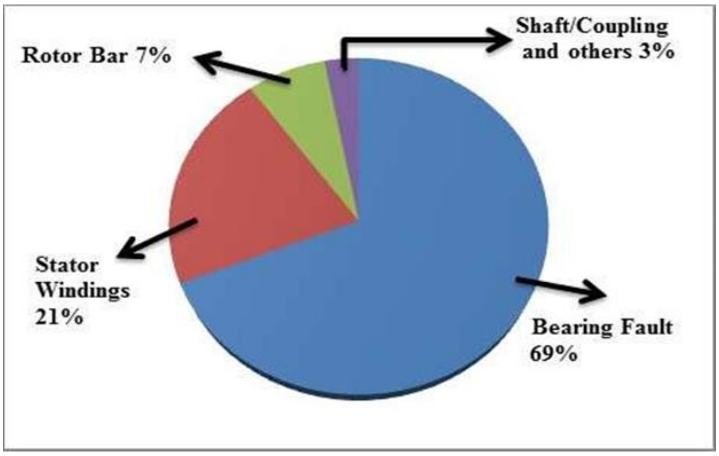

Figure 1: Fault percentage in induction motor

Mechanical Fault

Bearing Fault

Faults in bearing develop gradually, so it is disastrous for induction motor. Bearing used in motors is represented in Figure 2. If bearing is improperly placed on the shaft or in housing it always causes problem in installation of motor and is the major reason for metal surface premature failure of raceways[9]. If the bearing is misaligned it can also cause failure later on. Damaged bearing results in mechanical displacement and causes variation in air gap in such a way which is portrayed by combining rolling eccentricities working in either direction. When the load is excessive or lubrication is less, even though the bearing is going to fail. Bearing failure also results in excessive temperature on the face of the bearing or housing[10]. Since the rotor is on the support of bearing, extra radial motion is developed between rotor and stator due to bearing fault. Another consequence of damaged bearing is that the rotor became eccentric in the stator bore which causes extent of static and dynamic eccentricity. This disrupts the balance of magnetic force of poles adjoining each other, therefore, causing extra load on bearing. This alteration in air gap affects shaft dynamics causing more vibration. Bearing is also damaged if current is flowing in the stator shaft [3].

Figure 2: Induction motor bearing

Eccentricity

Eccentricity in motor is the major reason for its fault. When eccentricity increases it generates an unbalanced radial force causing rubbing of stator with rotor and results in damaging the stator and rotor as well. The reasons of eccentricity may be due to unshaped inner cross-section of the stator, stator and rotor misalignment, improper placement of bearing, variation in the alignment of load axis and shaft, vibration at crucial speed, unequal load and slanting of rotor axis[11].

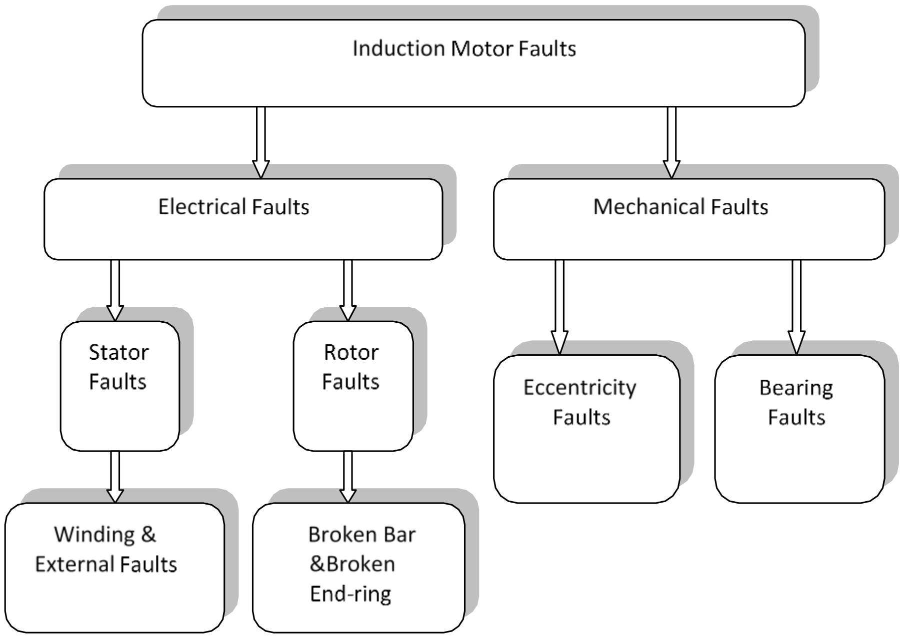

Fig. 3: Classification of Induction Motor Faults

Existing Condition Monitoring Techniques

The status of rotating equipment is monitored using a variety of approaches. Methods including electricity, chemicals, vibration, and temperature are all part of this category. In addition, electrical or vibration methods can detect mechanical problems, such as loose stators, mechanical losses, or faulty bearings, which are common in motor drive systems.[12]

Electrical Technique

In rotating electrical machines magnetic flux and electric field varies circumferentially in the air-gap. Ideally these magnetic fluxes and electrical fields are symmetrical, but are distorted due to electrical defects. The faults in stator and rotor can be detected by fixing electrical sensors on it. The radial and circumferential patterns of fluxes are disturbed due to faults in stator or rotor and these changes can be observed outside the machine by measuring its voltage, current and power[13]. Current and voltage transducer installed in motor driving system are used to measure the electrical signal of the motor. To detect faults, Motor Current Signal Analysis (MCSA) is commonly used method. First reason is that the spectral component of current signal is able to detect mechanical and electrical faults, secondly it is advanced and asymptotic technique, thirdly online measurement of current can be done and therefore, Oak Ridge National Laboratory has directed MCSA as advance means to detect mechanical and electrical faults in any motor driven system

Vibration Technique

An induction motor is a complex electro-mechanical system due to its support structure along with coupled load and carries mechanical and electromagnetic forces. Interaction of these two forces is liable to its stability with minimal vibration and noise. Normally, any kind of fault if occurs in the motor, results in enhancement of motor torque which causes vibration. The other causes of variation in motor due to torque are: Stator core response against the developed magnetic force in between stator and rotor due to its energetic behaviour; Rotor and bearing being the movable parts; Transmission of vibration from rotor to shaft bearing, structure and foundation of motor; Stator winding response due to electromagnetic forces produced by conductors;[14] The response of motor drive system on variation of load. Due to impulsive excitation, motor vibrates at its intrinsic frequency and this varies due to torque oscillation. This causes, high noise which is not acceptable, or gradual mechanical damage due to tiredness, and results in failure of motor.

For monitoring the faults in motor using vibration signal, only those components are taken in to account which vibrates during operation [7]. A substantial change in vibration pattern is perceived when the fault occurs in motor. These changes in the vibration signal due to faulty components can be applied to suitable data analysis algorithm to decide the motor status. However, many efforts have been made for the detection of the faults by using vibration signal in induction machine[8]. Vibration analysis is considered to be significant component for monitoring as well as detection of faults in an induction motor. Measurement of vibration signal during normal operation and fault induced operation is done separately which is done through RMS value of the vibration level over a pre-selected bandwidth[9]. Velocity of vibration and acceleration at bearing cap are measuring parameter used often in practice. This is a favorable technique since statistical base of machine failure is available through studies already done in past, which resulted as recommendations for vibration severity standards in the form of publications. .

In industry rotating electrical machine is widely used machine. The main reason of the rotating machine to become faulty is due to bearing fault besides the others. Therefore, to enhance availability and reliability of the machine it is necessary to have continuous monitoring of bearing and the machine. Since rotating machine comprises many moving mechanical parts due to which vibration and noise are generated when it is operational. Every machine have associated particular vibration signal trend which may vary as the state of the machine changes from normal to faulty which may be used to interpret inceptive defects before it may lead to critical. The goal of monitoring the condition is to extract the facts about the vibration signature and utilize it for detection of faults as early as possible. The techniques used for diagnosing the faults are important for condition monitoring of bearing and machine. The conventional techniques used for fault diagnosis have its own limitations; such as poor visibility of defect frequency. So, some extra pre-processing methods have to be applied to know the facts about signal received. Therefore, advance signal processing techniques if applied will be more effective as per the researchers of this field.

Development Of Innovative Integrated Intelligent Approach For Health Monitoring Of Three Phase Cage Rotor Induction Motor (CRIM)

Due to its adaptability and durability, induction motors serve as dependable machines in a wide range of sectors. For both practical and financial reasons, they are among the most ubiquitous electrical machines in the sector. Despite the widespread use of induction motors in modern industry, these devices are vulnerable to a wide range of harmful conditions, including manufacturing flaws and environmental hazards. Additionally, typical issues such as an imbalance in the mains supply, being underloaded, overloading, or having a clogged rotor can lead to machine harassment. In spite of this unsavory circumstance, these devices encounter a number of stresses while functioning. Sooner or later, failure is likely to occur due to the high likelihood of faults caused by these unpleasant situations and other stresses.

In today's and tomorrow's increasingly automated world, the induction motor's practical applications will only grow in complexity. The induction motor's reliance on drives and automation has made its control and fault detection sufficiently complex. Modern power electronic devices have simplified machine design, simplified operation, and enhanced load variety, all while making motors more efficient and easier to use. However, the likelihood of machine malfunctions is increased by the use of those sophisticated equipment. Early defect detection for any crucial machine, such as an induction motor, has become an integral measure for consumers in the competitive world of drives and automation, as the use of complex electronic gadgets becomes an essential element of contemporary life for their numerous amenities. Consequently, operational engineers are increasingly concerned with the early detection of defects. One may broadly categorize the many methods used to monitor the induction motors' health as either model-based, signal processing, or soft computing. For model-based fault diagnostics to work well, accurate models of malfunctioning induction motors are crucial. The use of model-based approaches in health monitoring might be challenging since it is not always easy to construct an accurate model taking into account all the relevant aspects of the malfunctioning machine. When suitable models are unavailable, soft computing techniques nonetheless allow for superior analysis of a malfunctioning system.

These methods are not progressive in performance, but they are easy to extend and change. The incorporation of fresh data or knowledge allows for their adaptive preparation. The investigation of induction motor flaws is now possible with the help of numerous soft computing techniques.

Primarily, these include methods from the fields of artificial neural networks, fuzzy logic systems, genetic algorithms, and quantum computing. These forms of soft computing are highly effective for the given task at hand, and they excel in their own domains. The majority of the researchers used a variety of soft computing techniques to create the health monitoring system. However, a novel approach to monitoring the health of three-phase induction motors is going to be developed in this thesis. With the help of soft computing approaches, the tools are now much better at what they do. Thus, for the study of the health state of three phase IM, better health monitoring systems including soft computing approaches are relatively error-free.

Soft Computing Methods

Many problems arise in the real world that defy logical solutions, or that have theoretical solutions but are impractically impossible to implement owing to the large amounts of resources and time needed for computing. In most cases, solutions derived from nature are the most effective and efficient means of dealing with these challenges. A near-optimal solution is often sufficient for most practical reasons, even though the answers obtained by these approaches are inherently not always equivalent to the mathematically rigorous ones. 'Soft computing' describes these biologically inspired approaches. The phrase "soft computing" describes a wide range of computer methods. The idea of fuzzy logic was originally proposed by Professor Lotfi Zadeh, who also coined the phrase. Both artificial and natural concepts form the basis of soft computing. A computational intelligence technique is what it is called. In contrast to traditional, or "hard," computing, this method is a little different. In order to create better rapport with reality, low solution cost, tractability, approximation, and uncertainty, partial truth, and vagueness are embraced by soft computing. In order to avert motor failure, health monitoring is a preventative measure. In order to keep tabs on the induction motor's health, various diagnostic and health monitoring approaches are employed, as previously mentioned. Methods such as model-based approaches, signal processing methods, and soft computing methods are typical. In the absence of precise models, soft computing approaches offer superior system analysis. Intelligent computers, which can reason and learn just like the human brain, are a long way off, but soft computing is seen as a potential solution. When we talk about "soft computing," we're referring to the branch of computer science that studies how people really organize, membership, and classify different quantities in the real world.

Since it seldom requires rigorous mathematical descriptions and characteristics for the system's components, this extension of natural heuristics is able to handle complex systems. This is not the same as hard computing. Soft computing, as contrast to hard computing, allows for some degree of uncertainty, partial truth, and imprecision. In this context, "soft computing" is synonymous with vagueness and ambiguity. The diagnostic process relies on soft computing approaches to help it correctly understand the defect data. Many soft computing diagnostic approaches have been proposed for the purpose of automating the diagnostic process. These include adaptive neural fuzzy inference systems, genetic algorithms, fuzzy logic, artificial neural networks, and quantum computing. Soft computing takes its cues from the human brain. This is a collection of computational methods from computer science, AI, and machine learning that are applied in engineering domains like HVAC, spacecraft communication networks, mobile robots, power electronics, electric power systems, motion control, inverters and converters, and so on. There have always been four main areas of technology that make up soft computing. Two of these reasoning techniques rely on prior knowledge: probabilistic reasoning (PR) and fuzzy logic (FL). Neuro Computing (NC) and Evolutionary Computing (EC) are two other technical fields that use data-driven optimization and search strategies.

Fuzzy Logic System

We are going to implement a fuzzy rule-based expert health monitoring system in this method with the help of accrued data from the different sensors used in the induction machine. For health monitoring of any machine, it is quite indispensable to evaluate its health conditions during its whole working life. Health monitoring of a machine and safety schemes are necessarily the functions of preventive maintenance. Health monitoring of IM must be designed so as to anticipate defects that could be occurred. It may be used as a means to provide primary protection to IM. Though, its actual task is to detect the faults at the beginning stage. Such well in advance caution is expected since it permits supervisor engineer bigger liberty to program outages in the suitable approaches.

It is possible to prevent unexpected machine breakdowns by keeping an eye on the status of IM. In addition, there is a significant decrease in both maintenance time and expense. By keeping tabs on how a system is doing, health monitoring systems can spot certain patterns that are associated with known issues. Once these issues are identified, they offer ways to handle them specifically. The majority of diagnostic systems are rule-based expert systems, which rely on a predefined set of rules to characterize specific patterns. In order to assess these norms, data that has been observed is gathered and used. When the rules are met in a logical way, the pattern is identified and a problem related to it is proposed. A fuzzy logic system is a method for translating between fuzzy inputs and fuzzy outputs. The mapping then serves as a foundation for making decisions or identifying patterns. Members functions, operators for fuzzy logic, and if-then rules are all part of a fuzzy logic system's process. There are two main categories of fuzzy logic systems that can be used with the Fuzzy Logic Toolbox. Two types of them are Mamdani and Sugeno. In this case, we will apply a fuzzy inference system of the Mamdani type. An MF is a curve that represents the mapping of each point in the input space to a degree of membership, or a membership value between 0 and 1.Occasionally, the input space is called the discourse universe.

When it comes to membership functions, you may classify them as either input or output. The use of natural language to draw conclusions from ambiguous data is a hallmark of human reasoning, and fuzzy logic is a manifestation of this trait. Using linguistic variables, fuzzy logic describes the motor's defective situation. A data-base and a rule-base comprise the knowledge base that is prepared. A simple approach was given to model electrical situations prior to faults, including undervoltage, overload, imbalance, winding overcurrent, and winding short circuit. The electrical pre-fault condition monitoring of CRIM also included a mechanism that used fuzzy logic to analyze the stator current signal, speed, and current signature. We offered a dependable approach for detecting stator winding defects by monitoring the amplitudes of the line currents. Here, judgments regarding the stator motor's health are based on fuzzy logic. One potential issue with the method is that it could incorrectly attribute a current imbalance that is happening at the source to the machine. Fixing this requires keeping an eye on the voltage and updating the inference rules. In recent times, Fuzzy Logic systems have emerged as an ideal instrument for the control and monitoring of subway systems and intricate industrial processes, as well as analysis tools for home electronics and many skilled systems. The ability to accommodate values that lie between two extremes—true or false, zero or one—is at the heart of what is known as a fuzzy logic system. The computer software can mathematically express and create most real-life phenomena, such as somewhat heavy or very heavy objects.

A more compassionate method of computer programming becomes feasible in this way. The use of fuzzy logic in controllers is an interesting application of the idea. Their method of operation is very different from traditional controllers, and they rely on expert knowledge rather than a plethora of equations to describe a system. The sensors' time domain current signals are used in the motor health monitoring approach. By analyzing signals in the time domain and the frequency domain, the investigator has become an expert in determining the IM's health state and the nature of the malfunction. The measurement data is frequently not conclusive, though, so it usually takes an experienced engineer to make it a reality.

The diagnosis of CRIM's health might benefit from a fuzzy approach. The system is able to make decisions using fuzzy information because it is built on the same pattern of thinking as humans, which is based on their experiences. It is possible for modules to be in states other than "Perfect" or "Faulty" when performing health analysis. Actually, it might be in two ranges at once. Actually, the idea of fuzzy logic can be used to make CRIM condition interpretations. Now we can use language variables to characterize the motor health. To put it simply, a fuzzy system can bestate this language input directly. Engineering decision-making issues involving uncertainty, vagueness, or qualitative aspects are addressed using fuzzy logic. Designing systems for control and analysis makes use of fuzzy logic since it speeds up technical development and, in the instance of extremely complicated systems, can be the most cost-effective solution to the problem. The language factors are used to describe the motor health condition in this investigation. The stator current amplitudes can be described by assigning fuzzy subsets using matching membership functions. To enable fuzzy inference, one can construct a knowledge base, which consists of a base and a database, that is necessary for motor defect detection. Fuzzy inference, which can yield a detection model with a high degree of accuracy, is the basis for the induction motor condition. In Figure 4, we can see the framework of the fuzzy logic system.

Genetic Algorithms

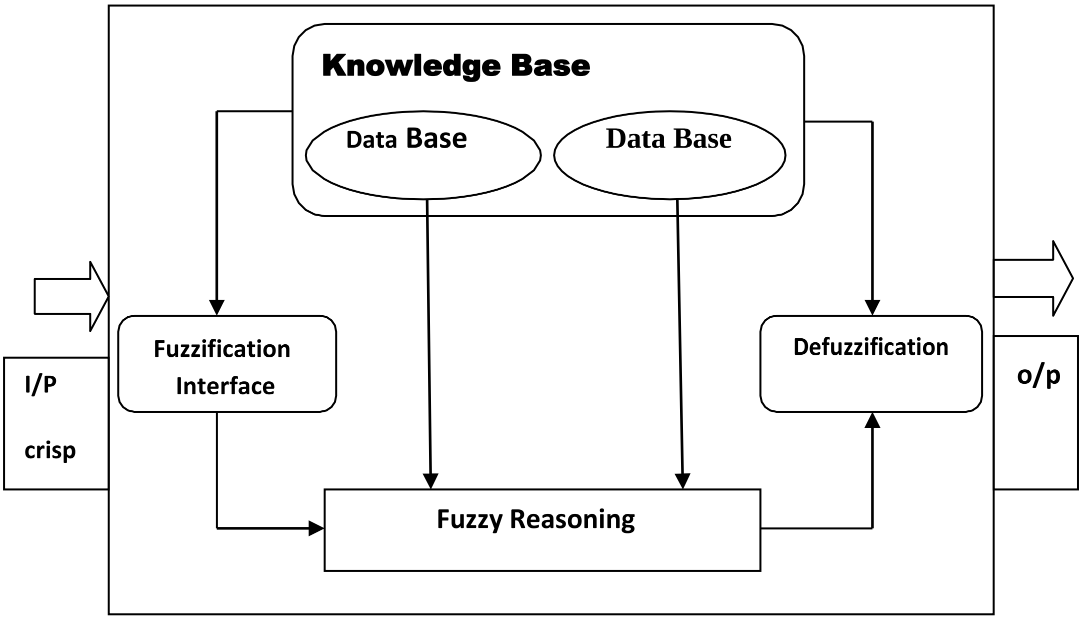

Fig. 4: Structure of fuzzy logic system

Genetic Algorithm

In an effort to mimic some of the processes seen in evolution, Genetic Algorithms (GA) were developed. Life with the degree of complexity that we see may have evolved in the very short period indicated by the fossil record, which surprises many academics and biologists. In engineering, the optimization issue is often addressed by using the GA concept. The term "genetic algorithm" is often used to refer to John Holland, who developed the concept in the early 1970s. The method is based on artificial intelligence and efficiently chooses a solution from a set of possibilities. GAs use the process of natural selection and are based on genes present in nature. Reproduction, crossover, and mutation are some of the operators used by GA.For the purpose of solving nonlinear mathematical expressions of systems, GAs use a variety of optimization strategies. There is no need for an experience-based database that is issue-specific when using GAs since they do not need any core information about the problem. If you have a complicated issue that needs solving fast, a genetic algorithm is your best bet. While they may not be immediate or even near, they do a fantastic job of navigating a complicated and expansive search environment. For a search space where little is known, genetic algorithms work best. Sometimes we have a clear understanding of the result we want from a solution, but we're unsure of the best way to get there. Genetic algorithms are quite useful in this context. They come up with answers that address the issue in ways we would not have thought about. On the other hand, they may come up with ideas that are great in a simulated setting but completely fail when put into practice in the actual world. Genetic algorithms, in a nutshell, are great for a lot of difficult tasks that other algorithms just can't do. Optimization issues are the most common ones that genetic algorithms attempt to solve using a targeted random search method. The principles of population genetics and natural selection inform the development of these optimization and search algorithms for use in scientific inquiry. The generalized a priori (GA) aims to construct complex structures using reduced procedures and express them using simple representations. All of the participants in the race are in sync with one another in terms of some fitness metric. Over a domain, the GA may realize the ideal solution globally. A lot of essential parts are there, including as the fitness function, population initialization, mutation, crossover, and selection. Here are the procedures to take in order to carry out the standard GA process: Step 1: Arbitrarily generate an initial population of individual character strings.

Step 2: Calculate the fitness values of each character of the recent population.

Step 3: Create a new population by applying crossover and mutation operation to the individual.

Step 4: Discontinue the algorithm when the convergence criterion is achieved, if it is not that, jump to step 2. Every individual is related to a potential problem solution in the GA. To support the genetic diversity, the matching routing path is arbitrarily created for every individual in the initial population. Populations are normally programmed by strings of variables. Crossover generates latest offspring by choosing two strings and replacing portions of their structures. Mutation is a confined operator with a very less probability. Its purpose is to modify the value of arbitrary position in a string.

A population of individual resolutions is modified repeatedly by the genetic algorithm. The GA always utilizes a random selection of people from the most recent population as parents to produce offspring for the next generation. The population eventually adapts to the optimal option via the process of natural selection. Many optimization issues that do not lend themselves well to more traditional optimization methods may be solved with the help of genetic algorithms. This encompasses issues when the goal function is very nonlinear, stochastic, non-differentiable, or discontinuous. When it comes to mixed-integer programming, the genetic algorithm can handle the issues.

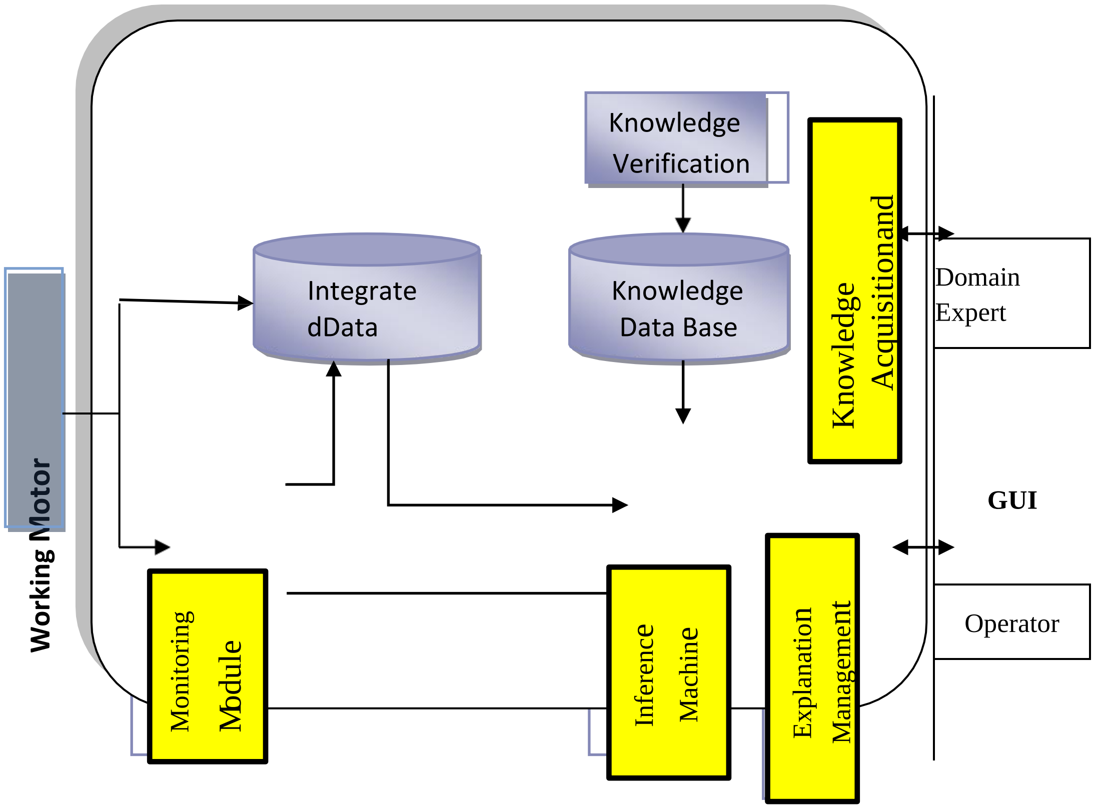

Fig. 4: The structure of an expert system

This integrated system is expected to be more efficient, errorless and reliable for the health monitoring of the motor. Here in this research we are going to develop the above said integrated soft computing tool that can easily identify the fault condition of the machine. Various soft computing such as Neural approach, fuzzy logic system, genetic algorithm and most recent quantum computing are combined to develop an efficient integrated soft computing tool for the health monitoring. Individually all the above mentioned soft computing techniques are used one by one to identify the fault. Then we combine the Fuzzy - ANN and Q-GA-GNN to make an integrated intelligent system for the more effectiveness of the monitoring process. In the thesis it is shown in the later chapter. The result obtained for the integrated system is more efficient compare to the separate individual system. A structure of an expert system developed by the method of integration is shown in fig. 4

Conclusion

The implementation of a health monitoring system for induction machines using computational intelligence techniques presents a promising approach to ensuring their reliable operation in various industrial applications. By integrating advanced algorithms such as machine learning and signal processing, the proposed system offers a proactive solution for detecting faults and anomalies in real-time, thereby preventing unexpected failures and minimizing downtime. Through the analysis of operational data, including current, voltage, temperature, and vibration patterns, the system can accurately identify deviations from normal operating conditions and establish baseline performance profiles for early fault detection. Techniques such as artificial neural networks, support vector machines, and genetic algorithms enable effective processing of sensor data, enhancing the system's ability to detect incipient faults and provide timely warnings to maintenance personnel.

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