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COMPARATIVE IMPROVEMENT CONTROL TECHNIQUES FOR ASYNCHRONOUS MOTOR DRIVE

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Abstract— Induction motors are the most important workhorses in industry. They are mostly used as constant-speed drives when fed from a voltage source of fixed frequency. Advent of advanced power electronic converters and powerful digital signal processors, however, has made possible the development of high performance, adjustable speed AC motor drives. About half of the electrical energy generated in a developed country is ultimately consumed by electric motors, of which over 90 % are induction motors. For a relatively long period, induction motors have mainly been deployed in constant-speed motor drives for general purpose applications. The rapid development of power electronic devices and converter technologies in the past few decades, however, has made possible efficient speed control by varying the supply frequency, giving rise to various forms of adjustable-speed induction motor drives. In about the same period, there were also advances in control methods and artificial intelligence (AI) techniques, including expert system, fuzzy logic, neural networks and genetic algorithm. Researchers soon realized that the performance of induction motor drives can be enhanced by adopting artificial-intelligence-based methods. Since the 1990s, AI-based induction motor drives have received greater attention. The objective is to make a critical analysis of these methods in terms of ripples reduction, tracking speed, switching loss, algorithm complexity and parameter sensitivity. Further, it is envisaged that the information presented in this review paper will be a valuable gathering of information for academic and industrial researchers.

Key Words—Vector Control (VC), Direct Torque Control (DTC), Artificial Intelligence (AI), Fuzzy Logic (FL), Artificial Neural Network (ANN), Genetic Algorithms (GA), Expert Systems (ES)

I. INTRODUCTION

In industry, more than half of the total electrical energy produced is consumed by electric motors [1]. Among several types of electric motors, three-phase induction machines (IMs) occupy a prominent place. Indeed, at least 80% of industrial control systems use induction motors [2], which have gradually taken the place of DC machines because of their good performance: reliability, simple construction, low cost and simple maintenance [3, 4]. However, these numerous advantages are not with- out inconvenience, the dynamic behavior of the machine is often very complex [5, 6], since its modeling results in a system of nonlinear equations, strongly coupled and multi variable. In addition, some of its state variables, such as flux, are not measurable [7]. These constraints require more advanced control algorithms to control the torque and flux of these machines in real time [8].

For several years, academic and industrial research has been carried out to remedy the control problem of the IM and to develop robust and efficient controls [9]. In this context, scalar control is the first technique that has been developed to control electrical machines, this control strategy consists of keeping the V/f constant to keep the flux in the machine constant [10, 11]. It is characterized by its simplicity of implementation, its simple structure, which is based on the stator flux control [12]. However, on a start-up or for change the rotation direction of the machine, the flux oscillates strongly with large amplitudes and its modulus is variable during the transient states [13, 14]. These oscillations will impact the quality of the torque and the speed, thus de- grading the performances in transient state of the machine. This type of control is therefore used only for applications where the speed variation is not great, such as in pumping or ventilation [15, 16]. Subsequently, the Field Oriented Control (FOC) method was developed to control transient torque [5]. This control provides a behavior of the IM similar to that of the DC machine with a decoupling between the torque and the flux of the machine [17–19], this decoupling provides a very fast torque response, a large speed control range and high efficiency for a wide load range. However, this control also has a high sensitivity to the parametric variations of the machine especially that of the resistors whose value changes substantially with temperature [20–22]. Any difference between the pa- rameters used by the FOC algorithm and the actual pa- rameters of the machine is translated by errors in the output values of the flux and the torque, which leads to increased losses in the machine and reduced perform- ance of the system to be controlled [23].

High-performance control of an induction motor is more difficult than D.C. motors, because the induction motor is inherently a dynamic, recurrent, and nonlinear system. Induction motor control problems have attracted the attention of researchers for many years. Most of the earlier researches are based on classical control theory and electric machine theory, using precise mathematical models of the induction motor. As shown in Fig.1, an induction motor control system consists of the controller, sensors, inverter and the induction motor. It can be seen that a study of induction motor control involves three main electrical engineering areas: control, power electronics, and electrical machines (Bose, 1981). The induction motor can be described by a fifth order nonlinear differential equation with two inputs and three state variables. (Marino and Tomei, 1995).The control task is further complicated by the fact that the induction motor is subject to unpredictable disturbances (such as noise and load changes) and there are uncertainties in machine parameters. Induction motor control has constituted a theoretically interesting and practically important class of nonlinear systems, and is evolving into a benchmark example for nonlinear control.

Intelligent control, which includes expert-system control, fuzzy-logic control, neural network control, and genetic algorithm, is not only based on artificial intelligence (AI) theory, but also based on conventional control theory. Consequently, new control methods can be developed by the application of artificial intelligence (Bose, 1993)

The GA theory (also known as evolutionary computation) was proposed in 1970s and it is based on principles of genetics (or Darwin's survival of the fittest theory of evolution). Basically, it solves optimization problem by an evolutionary process resulting in a best (fittest) solution (survivor). Lofty Zadeh, the inventor of FL, defined ES as hard or precise computing and FL, NNW and GA as soft or approximate computing [1-2].

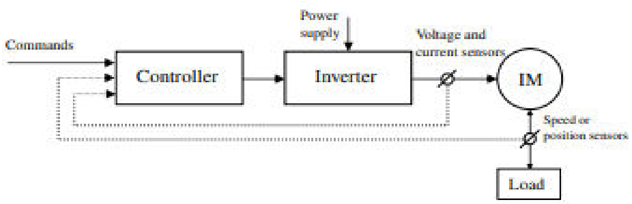

Fig. 1 An Induction Motor Control System

II. CONTROL APPROACHES OF INDUCTION MOTOR

Scientists and experts have devoted a lot of efforts to induction motor control in the past decades. Developing new control principle, algorithm, and hardware for induction motor control has become a challenge that industry must face today.

Recently, revolutionary advances in computer technology, power electronics, modern control and artificial intelligence have led to a new generation of induction motor control that may provide significant economic benefits. The voltage or current supplied to an induction motor can be expressed as a sinusoidal function of magnitude and frequency or magnitude and phase. Accordingly, induction motor control methods are classified into two categories: scalar control in which the voltage magnitude and frequency are adjusted, and vector control in which the voltage magnitude and phase are adjusted. Various control approaches of induction motor are as follows:

(a) **Scalar Control: -** The scalar controllers are usually used in low-cost and low-performance drives. They control the magnitude/frequency of voltage or current. Typical studies of scalar control include open-loop voltage/frequency (V/Hz) control, closed-loop V/Hz control, and stator current and slip frequency control (Bose, 1981). When the load torque is constant and there are no stringent requirements on speed regulation, it suffices to use a variable-frequency induction motor drive with open-loop V/Hz control. Applications which require only a gradual change in speed are being replaced by open-loop controllers; often referred to as general purpose AC drives (Rajashekara, Kawamura, and Matsuse, 1996). When the drive requirements include faster dynamic response and more accurate speed or torque control, it is necessary to operate the motor in the closed-loop mode. Closed-loop scalar control includes closed-loop V/Hz control and stator current and slip frequency control.

(b) **Vector Control (VC):**-In Vector Control, the instantaneous position of voltage, current, and flux space vectors are controlled, ideally giving correct orientation both in steady state and during transients.

The vector controllers are expensive and high-performance drives, which aim to control the magnitude and phase of voltage or current vectors. Vector control methods include Field Oriented Control (FOC) and Direct Self Control (DSC). Both methods attempt to reduce the complex nonlinear control structure into a linear one, a process that involves the evaluation of definite integrals. FOC uses the definite integral to obtain the rotor flux angle, whereas DSC uses the definite integral to obtain the stator flux space vector. Although the implementation of both methods has largely been successful, they suffer from the following drawbacks [1, 11]:

1. Sensitivity to parameter variations;
2. Error accumulation when evaluating the definite integrals; if the control time is long, degradation in the steady-state and transient responses will result due to drift in parameter values and excessive error accumulation;
3. In both the methods, the control must be continuous and the calculation must begin from an initial state.

(c) Direct Torque Control (DTC):- The direct torque control (DTC) for induction machines was proposed in the middle of 1980s by Takahashi [24] and Depenbrock [25]. Comparing to the vector control, it is less sensitive to parametric variations of the machine [18], its control algorithm is simple because of the absence of pulse width modulation (PWM), of Current Controllers and Park Transformations. It does not use PI regulation loops, which should improve its dynamic skills a priori and eliminate the problems related to the saturation of PI regulators. DTC control ensures high efficiency operation and provides accurate and fast torque dynamics. The principle of DTC is based on the direct application of a control sequence to the switches of the voltage inverter (switching states) placed upstream of the machine. The choice of this sequence is made by the use of a switching table and two hysteresis regulators. Whose role is to control and regulate the electromagnetic torque and the flux of the machine in a decoupled manner. Fig. 2 shows a simple structure of the DTC control. The electromagnetic torque is controlled using a three level hysteresis comparator. While the stator flux is controlled using a two level hysteresis comparator. The outputs of these comparators, as well as the flux vector information, are used to determine the switching table.

In DTC, the accuracy of electromagnetic torque and stator flux estimation is very important to ensure satisfactory performance. So, several parameters must be determined, the stator current is measured while the stator voltage depends on the switching state (Sa, Sb and Sc) produced by the switching table and the DC link voltage Udc.

- DTC algorithm. No current control loops, so current not directly regulated.
- Coordinate transformation not required.
- No separate voltage PWM is required.
- Stator flux vector and torque estimation is required

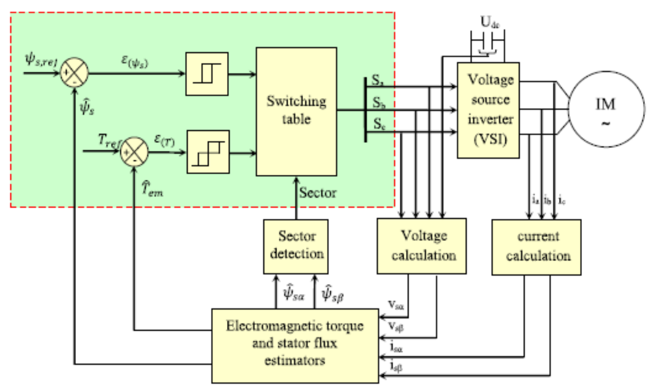

Fig. 2. DTC control of the induction machine

(d) Speed Sensorless Control Method:- Speed sensorless control of induction motors is a new and promising research trend. To eliminate the speed and position sensors, many speed and position estimation algorithms have been proposed recently. These algorithms are generally based on complex calculations which involve the machine parameters and the measurement of terminal voltages and currents of the induction motor. Speed sensorless control can be regarded as open-loop control because the measurement is included in the controller. Advantages of such “sensorless” schemes include [1], [2]:

- More compact drive with less maintenance;
- No cable to machine transducers, easier application particularly to existing machines, reduced electrical noise;
- Transducer cost is avoided.
- Suitable for hostile environments, including temperature.

Despite much effort and progress, operation at very low speed is still problematic particularly for an IM sensorless drive. Proper comparative analysis of the many variants in the extensive literature on this topic is difficult. This is mainly because a standard set of tests or benchmarks has not been agreed. Even quite simple schemes can give results which are adequate for undemanding applications. Such simple schemes can usually demonstrate operation through zero speed provided the transition is fairly rapid.

III. INTELLIGENT INDUCTION MOTOR CONTROL SCHEMES

Despite the great efforts devoted to induction motor control, many of the theoretical results cannot be directly applied to practical systems. The difficulties that arise in induction motor control are complex computations, model nonlinearity, and uncertainties in machine parameters. Recently, intelligent techniques are introduced in order to overcome these difficulties. Intelligent control methodology uses human motivated techniques and procedures (for example, forms of knowledge representation or decision making) for system control.

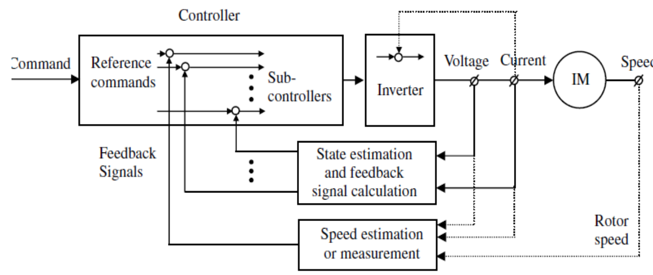

Fig .3 Control system of Induction Motor

Intelligence is defined as the ability to comprehend, reason, and learn. The definition of intelligent control from Astrom and McAvoy has been used widely: ***'An intelligent control system has the ability to comprehend, reason, and learn about processes, disturbances and operating conditions in order to optimize the performance of the process under consideration'*** Intelligent control techniques are generally classified as expert system control, fuzzy-logic control, neural-network control, and genetic algorithm. Intelligent induction motor control thus refers to the control of an induction motor drive using the above artificial intelligence techniques. The applications of expert system, fuzzy-logic, neural-network, and genetic algorithm in induction motor drive system have been proposed in the literature.

(i) Expert-System Control Scheme: - Expert system is the forerunner among all the AI techniques and from the beginning (1960s) to 1980s, both terms (expert system and artificial intelligence) have been used synonymously in the literature. Expert systems have been considered as a powerful method to solve control problems without having strict knowledge of mathematical

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description, particularly to deal with qualitative knowledge and reasoning with symbolic operation in a complex system. Expert systems have been used for choice of a.c. drive products, monitoring and diagnostics, design and simulation for a drive system. However, their applications in induction motor control are relatively few, an expert-system based acceleration control scheme is proposed. [9-10].

(ii) Fuzzy Logic Control Scheme:- Fuzzy logic is another form of artificial intelligence, but its history and applications are more recent than expert systems. A fuzzy logic controller consists of fuzzification, fuzzy inference with rule base and database, and defuzzification. Some fuzzy-logic controllers have already been designed for induction motor control, such as FOC with fuzzy efficiency optimizer and fuzzy-logic based DSC, a hybrid fuzzy/PI two-stage control scheme. In the scheme, the fuzzy-logic frequency controller and the PI current controller produce almost the same frequency and current magnitude control characteristics as a field-oriented controller. Effects of parameter variation, effects of noise in measured speed and input current, and effects of magnetic saturation are investigated [6-7].

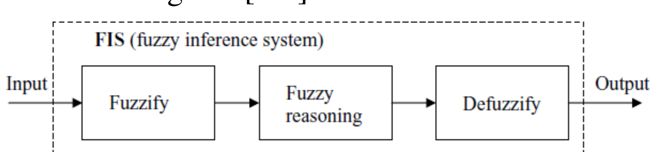

Fig: 4. A basic fuzzy inference system

(i) Neural Network Control Scheme:- Neural network is the most generic form of AI for emulation of human thinking compared to expert systems and fuzzy logic. In many literatures, a neural-network based DSC scheme is proposed to decrease the controller time delay so that the torque and flux errors of a DSC can almost be eliminated.

The application of neural networks to DTC ensures a good dynamic response of torque and flux with fixed switching frequency, which leads to a considerable re- duction in torque ripples and the harmonic rate of the currents compared to other conventional techniques. Moreover, it is very robust against the various un- certainties of the motor parameters. However, this proposed technique has the disadvantage of the internal structure that is more complicated.

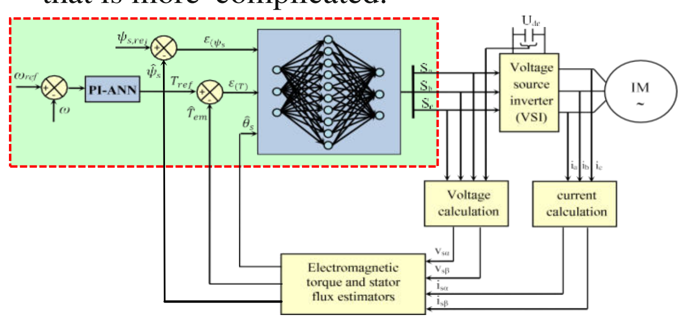

Fig: 5. ANN control of the induction machine

(iii) Genetic Algorithms (GA):- Holland, while evolutionary strategies were developed in Germany by I. Rechenberg and H.-P. Schwefel. The GA differs substantially from the more traditional search and optimization methods, and the followings are the most significant:

- GA searches a population of points in parallel instead of a single point.
- GA does not require derivative information or other auxiliary knowledge; only the objective function and the corresponding fitness levels will influence the directions of search.
- GA uses probabilistic transition rules instead of deterministic ones.

Genetic Algorithms (GAs) represent a fairly rich and interesting family of stochastic optimization algorithms that are based on techniques derived from natural evolution and genetics. The principle of these algorithms is to proceed by a stochastic search on a large space and through a population of pseudo-solutions. The robustness against parametric variations is one of the main features of genetic algorithms; they allow to supply one or several good quality solutions to problems highly varied, by requesting a rather low investment (time and computing power).

However, it has the disadvantage of parameters selection, because the choice of these parameters depends strongly on the studied problematic and the knowledge of the user regarding this problem.

IV. Conclusion

The demand for high performance induction motor drives is rapidly increasing, particularly in the area of the traction, electric vehicles, oil drilling and aerospace applications. An ideal induction motor drive should have following function:-

A. High performance control.
B. Performance should be unaffected by machine parameter variation.
C. Possibility of speed –sensorless control.
D. Low cost and fast dynamic response.

Currently, vector control technique has only provided a practical solution for target A and parameter estimation technique may be a possible solution for target B, while speed and position estimation techniques are being developed to achieve target C.

Addressing the unresolved problems with present-day induction motor controllers, the four artificial intelligence (AI) control techniques for the induction motor drive. They include an expert-system-based controller which gives a complete solution for targets A and B, a genetic algorithm optimized extended Kalman filter with high-precision speed estimation for a sensorless drive and an integral model based sensorless drive which give a practical solution for target C, and a low-cost neural-network-based vector controller will give a hardware solution for target D. In future, ANN-based induction motor controller may be integrated in several ASIC (application specific integrated circuit) chips with fast parallel calculation and low hardware cost to replace the present DSP (digital signal processor) based controller.

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