Evolution of Controllers for the Speed Control in Thyristor Fed Induction Motor Drive

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Abstract

Induction Motors (IMs) are now becoming the pillar of almost all the motoring applications related to the industry and household. The practical applications of IMs usually require constant motoring speed. As a result, different types of control systems for IM's speed controlling have been shaped. One of the important techniques is the utilization of thyristor fed drive. Although, the thyristor fed induction motor drive (TFIMD) offers stable speed performance, the practical speed control demand is much more precise. Hence, this drive system utilizes additional controllers to attain precise speed for practical applications. This paper offers a detailed review of the controllers utilized with the thyristor fed IM drive in the past few decades to achieve good speed control performance. The clear intent of the paper is to provide a comprehensible frame of the pros and cons of the existing controllers developed for the TFIMD speed control requirements.

Keywords: Thyristor Fed Drives, Induction Motors, Speed Controller, Conventional Controllers, and Soft Computing Techniques.

Introduction

The machine that performs a conversion of AC electrical power into the mechanical form of power through the concept of electromagnetic induction is known as Induction Motor (IM) or Asynchronous motor [Hazzab, 2006]. A symbolic illustration of IM is given in Fig. 1.

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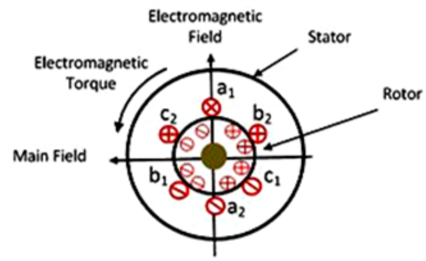

Figure 1: Symbolic illustration of Induction (Asynchronous) Motor.

In an IM, the armature winding works as both the armature as well as field winding. Whenever, AC power supply is provided to stator windings a flux is formed in the air gap. The flux rotates at a constant speed known as synchronous speed. As a result, voltages have been induced because of this rotating flux in both the stator winding and rotor windings. If the circuit of rotor part is closed, the current flows inside the rotor winding, which reacts to rotating flux and hence a torque is generated. The rotor rotation speed is very near to the synchronous speed in steady state operation. The IM is generally classified into two important types namely: single phase and three phase IMs [Mehrizi-Sani, 2009].

An IM drive is an electronic device that exploits and controls the electrical energy fed to the induction motor. The drive system fed electricity to the motor in variable amount and frequencies, thus indirectly controls the torque and speed of IMs [Mutlag, 2014]. A basic structure of IM drive system is defined in Fig. 2which comprises following main components [Christian, 2017]-[Jayanta, 2017]: (1) Load, (2) Motor, (3) Power modulator, (4) Source, (5) Control Unit, and (6) Sensing Unit.

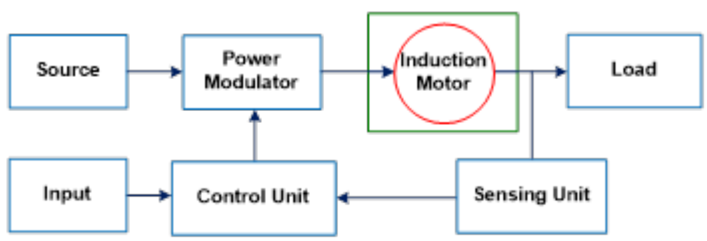

Figure 2: A Basic block diagram illustration of IM drive system [Christian, 2017].

Among, the available IM drives, the thyristor fed IM drive is the utmost popular due to its ability to provide good speed control characteristics with low complexity [Kumar, 2012]-[Costa, 2018]. Usually, The expression for the rotor speed (N_r) of an IM can be defined as [Elmas, 2007]:

$$N_r = N_s (1-s) \quad \ldots\ldots\ldots\ldots(1)$$

here, slip value of motor is represented by s and N_s is the synchronous speed of induction motor given by,

$$N_s = \frac{120 f}{P} \quad \ldots\ldots\ldots\ldots(2)$$

Therefore, using (1) and (2), the final equation for the induction motor rotor speed N_r is defined by [Elmas, 2007],

$$N_r = \frac{120f}{P}(1-s) \quad \text{.........(3)}$$

Therefore, the induction motor speed in which total poles are constant depends on slip value s and input frequency f of power supply, which finally relies on the motors supply voltage or current and their frequency. A broad classification of IM speed control techniques is depicted in Fig. 3.

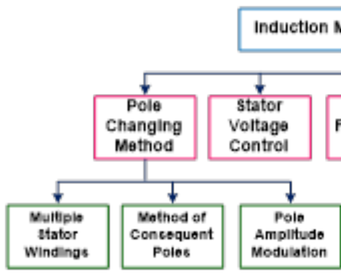

Figure 3: Classification of IM speed control techniques [Christian, 2017].

Among, the above five conventional IM speed control techniques shown in Fig. 3, the most significant techniques are [8]:

1) Controlling of voltage by stator technique, also known as variable voltage constant frequency control, is a technique for controlling the voltage of a generator and,
2) Variable voltage variable frequency control technique.

Which are basically utilize the concept of thyristor fed induction motor drive and hence this drive system is very popular for the practical speed control applications of the IMs.

The variation in stator voltage is usually performed by the means of an ac regulator, which basically controls the RMS value of input ac voltage fed to the motor by the thyristors that are connected back-to-back way in each supply line. Next, the variable frequency-controlled power is obtained by the means of a device called cyclo-converter that directly converts the constant frequency ac to the variable frequency ac or by another device called inverter, which converts dc supply to ac.

Usually three phase IM is the most important choice for the practical applications. Hence, this article aims to focus on the review of controlling the speed of three phase IMs.

Controlling of Three-Phase Induction Motor by Thyristor

This section presents detailed description about the basic principle of the two important thyristor fed controlling of speed of IMs techniques namely, voltage control by stator technique and, the variable voltage variable frequency control technique.

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Voltage Control by Stator Technique

The voltage control by stator approach is a method for controlling the speed of an induction motor by changing the voltage at the stator terminals. Principally, the square of the applied stator terminal voltage (V) determines the induction motor's torque(T) as shown by,

$$T = kV^2 \quad ...(4)$$

Where, k is a constant. Now, from (4), it is obvious that change in applied voltage also alters the motor torque. In order to properly analyze the relation between terminal voltage and the torque of motor its speed torque characteristic for three different voltages is illustrated in Fig. 4.

From the speed Vs torque characteristics represented in Fig. 4, we can observe, at any value for terminal voltage of motor, the starting torque is initially low, which rises as soon as increase in rotor speed occurred. Consequently, the control of speed of IMs by utilizing stator voltage control technique is appropriate for the loads that requires low amount of starting torque but further requires higher torque as the speed increases.

Thyristor based voltage controllers can be used, in particular, in the induction motors having thyristor fed drive to obtain mutable voltage for the controlling of speed in three phase IM.As illustrated in Fig. 5, three different pairs of consecutive coupled thyristors are needed here, one pair in each phase. Each set of thyristors in a pair regulates the voltage of the connected phase. By altering the thyristor’s conduction period, the motor's speed can be controlled. Due to the drive circuit's simplicity, induction motors with voltage stator techniques are frequently applied in low-power drives.

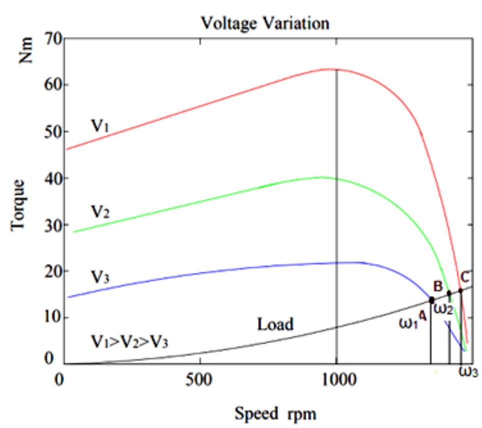

Figure 4: Speed Vs Torque characteristics of induction motor for three different terminal voltage conditions [Christian, 2017].

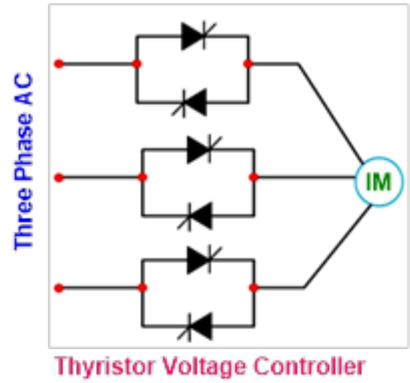

Figure 5: Stator voltage control of three-phase IM by using thyristor based voltage controller [Elmes,2007].

Technique of Variable-Voltage with Variable-Frequency technique of IM

The technique of variable-voltage with variable-frequency control of an IM usually involves a controlled rectifier which uses thyristor to generate variable dc link voltage from a fixed ac source and a square wave inverter is utilized to vary the frequency. The basic diagram of a variable-voltage with variable-frequency drive IM is illustrated in Fig. 6.

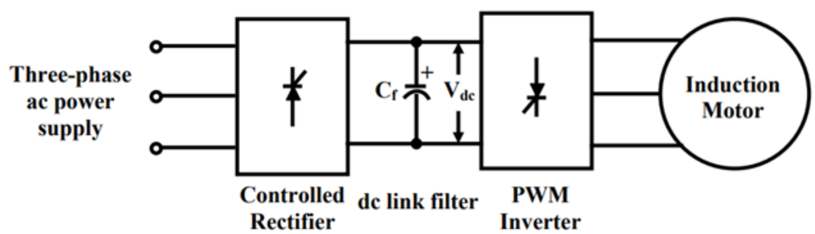

Figure 6: Variable-voltage with variable-frequency drive IM.

Thyristor Controlled Induction Motor Drives: Advantages and Disadvantages

Thyristor control technique for the IM drives has the following advantages and disadvantages [Ion, 2013]-[Piao, 2015]:

Advantages of Thyristor control technique:

1.The reaction of the control device becomes faster as the thyristor control eliminates the time lag establish by the inductances presented in the generator and armature fields.

2.The effectiveness of the controller becomes high owing to the low voltage drop at the thyristors.

3.The control device consist small size, lighter weight, and hence becomes cheaper as well as requires less space and low maintenance.

4.The operation of this control technique is simple and reliable also.

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Disadvantages of Thyristor control Technique:

1. Due to high ripple elements existing at the output of converter, the heating of motor and the problem of commutation becomes serious.
2. Because of the switching of thyristors and the currents non-sinusoidal nature, there is a high possibility for interference related with the communication networks.
3. The speed control efficiency of the thyristor based electrical drives is superior to the conventional drives, but the accuracy is not satisfactory for the accurate speed control application in industries.

Evolution of Speed Controllers for Thyristor Fed Induction Motor Drive

In the previous section it has been established with the detailed description that the thyristor fed induction motor drive consists of two main configurations for monitoring of speed namely, controlling of voltage by stator technique and, controlling by variable-voltage with variable-frequency technique.

The speed controller capability of these two configurations for thyristor fed IM drives are better than the conventional drives, but their speed regulation efficiency is not satisfactory for accurate speed control applications in industries [Christian, 2017]. Hence, to overcome this issue, usually in practical applications some additional controllers have been utilized in the closed loop mode to achieve the desired motor speed [Jayanta, 2017].

In the past few decades several additional controller techniques been to put control thyristor fed IM drives. Among those, some controllers are the conventional type such as PID, PI, and PD controller. All the conventional controllers are developed in year 1936 by the Taylor Instrument Company [Piao, 2015]. Due to its straightforward construction, ease of usage and low manufacturing cost, the PID controller is regarded as one of the best control techniques. Consequently, the PID is introduced in many engineering applications in conjunction with the controlling techniques based on vector and scalar [Ion, 2013]-[Dahlin, 1968]. PID is also employed in IMs to control important system variables like rotor flux, voltage, currents, torque and speed. [Dahlin, 1968]. However, it is difficult to estimate the controller parameters of PID for a system, such as derivational gain(K_D), integral gain(K_I) and proportional gain(K_P). These different types of parameters perform a significant part in controlling of a model in terms of stability and sensitivity [Ion, 2013], [Boulouiha, 2015]-[Zheng, 2013]. Hence, the parameters of PID controller must be appropriate for the abrupt deviations in the speed or load of motor [65]. The PID coefficients can be determined by numerous approaches, like Ziegler-Nichols technique [Hughes, 2013], scheme by Cohen et. al. (1953), Lambda tuning process by Dahl in et. al.(1968) [Basilio,2017] and visually analysis-based loop-tuning process. However, all schemes, also involve the procedure upset and, go through faults and trials and also need numerous numerical calculations along with the precise modelling [Daya, 2013]-[Ali, 2016].

In order to resolve these issues related to conventional controllers which are basically based on crisp logic, in 1965 Zadeh [Ali, 2016] proposed a controller based on fuzzy-logic, which has attracted significant attention for control applications. In recent times, FLC has been widely utilized due to its online adaptable control ability according to the flexible modelling facility with abrupt incident variations in the systems [Ali, 2014]-[Basilio, 2002]. Furthermore, the FLC can work without a precise mathematical model; it can perform control for both the non-linear as well as linear systems; and it relies on the human logic based linguistic rules [Ziegler,1942]-[Kabziński, 2013]. Hence, the FLC has becomes progressively widespread in the development of the controllers for various real time systems. Like in Ref. [Zheng, 2014]; the FLCs were employed to achieve better IM speed control along with scalar control scheme. Next, in

Refs. [Kabziński, 2013], [Melkebeek, 2018]-[Zeb, 2017],the FLCs were utilized to model vector control scheme for IMs. In Refs. [Melkebeek, 2018], [Zadeh, 1965]-[Abd Ali, 2015], FLCs were utilized for controlling of speed variations in wind turbine which contains a generator with induction concept of dual-star. The controller based on fuzzy-logic was correspondingly utilized inreference [Suganthi, 2015], to improve the sensor-less stator FOC on an IM.

Pulse-width-modulation based methods are also incorporate for governing the inverter having the voltage source of three-phase during controlling of IMs by governing the switching devices [Gaballah, 2015]-[Hannan, 2017]. Therefore, the core theory of inverter having the voltage source of three-phase is to regulate the output of alternating frequency and alternating voltage from a DC voltage supply. Additionally, the Pulse-width-modulation based methods generate the inverter's waveforms to attain a low distortion with high efficacy, easy implementation, fewer losses during switching, to maintain minimum harmonics and small-time computation [Mannan, 2006]. Sinusoidal type pulse-width-modulation is a modulation technique, where the modulation waveform taken for reference is equated by carrier-wave of triangular shape, and their convergences basically describes the switching instants. The average output-voltage value reaches the reference-value on each carrier cycle. Similar to the pulse-width-modulation, the sinusoidal pulse-width-modulation technique is also an easy and simple structure [Mannan, 2006]. Space-vector type pulse-width-modulation is among the utmost accepted pulse-width-modulation techniques, which has been currently attracted the attention of academics and scientists for the control of IMs. Piao and Hung [Chebre, 2011] incorporated a space-vector type pulse-width-modulation method for the controlling of multi-level inverters that needs nonlinear compound computations and also involves space-vector pulse-width-modulation implicit modulation functions. Generally, nearly all the space-vector pulse-width-modulation techniques require online complex computation which makes them difficult for the real-time applications and implementation. Hence, the conservative type of space-vector pulse-width-modulation techniques require extra resources and memory which restricts the fast frequency switching and thus decreases the efficiency of the space-vector pulse-width-modulation. To resolve this issue the space-vector pulse-width-modulation based on genetic algorithm (GA) was utilized [Farah, 2018], but the GA needs large iterations to find the best possible results, which intern converted in a process that consumes much more time. Furthermore, some optimization-based hybrid modulation approaches on the ground of many divisions of control and active vector time are used to enhance the elimination of harmonics, small losses in switching and the ripples in currents of IM drive [Saad, 2012]. However, the foresaid approaches also faced problems since they required extensive training, enormous data, large time for learning of nonlinear and linear functions which leads tremendous memory consumption for practical applications and implementation. In reference [Mohan, 2001], BSA optimization was utilized for a technique based on random-forest regression for the execution of space-vector pulse-width-modulationat2-level inverter to improve the performance of IM drive as compared to conservative methods in respect of the error in steady-state, settling time, temporary state-response for various operating situations and damping capability.

Computational intelligence-based optimization processes are computational techniques that are inspired by the composite real-world problems and nature. These techniques split into the evolutionary algorithms (EAs) and the swarm intelligence techniques. Swarm intelligence-based optimization algorithms basically utilize the small mathematical models to follow the complicated social behaviour of animals or insects. Artificial bee colony (ABC) optimization, ant-colony-optimization (ACO) and particle swarm optimization (PSO) are the three most significant swarm intelligence-based methodologies. The

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ACO technique mimics the behaviour of the ants for search of optimal path from their colony to source of food. Likewise, the ABC scheme is based on the food-seeking approach of honeybees and follows the searching activities of these insects. Similarly, the PSO simply tries to mimic the activities of the fish schooling or bird assembling. The EAs gain their principles of working from the normal genetic progression. At every generation, the finest possible individuals from there cent population persist and generates offspring that replicate them. Therefore, the population slowly contains improved individuals. Operations, like recombination process, crossover process, mutation process, selection process, and adaptation process, are actively allied in the method of evolutionary algorithm. Current evolutionary algorithm examples are genetic-algorithm, differential evolution, evolutionary-programming, genetic-programming and evolutionary approaches. All of these ideologies - the Darwinian-Theory and other theories of the evolution of living things - serve as the foundation for these systems. In recent times, several researchers worked on multi objective approximation of induction motor parameter to reduce the fault among the assessed and statistics of manufacturer by means of sparse-grid optimisation process [Francis, 2015], a search algorithm built on backtracking [Ziegler, 1942], explicit-model based prognostic controller through quadratic design approach [Lodhi, 2016].

Nearly all the optimization problems related to real-world, essentially involve the complex interactions and nonlinearities among the variables of the problem, and hence to solve this problem the optimization techniques inspired by nature are widely applied. The problem-resolving capability of these methods is usually accomplished by altering the current algorithms, hybridizing the present techniques, and development of advanced algorithms. Numerous optimization methods that are nature-inspired have been proposed in the past to conquer the drawbacks of their predecessors. In the following part of this section a detailed descriptions of the latest optimization methods inspired by nature which are available in the literature are highlight.

In recent times, the optimization methods are widely used in numerous works to enhance the ability of the control schemes. For example, conventional controllers that are utilizing the optimization techniques enhance the control scheme required in the IM system [Llorente, 2020]-[Chekkal, 2014]. In Ref. [Gdaim, 2015], to select the PID coefficients GA was used to IM module speed control. Likewise, a hybrid GA–PSO optimisation approach were utilized to improve ability of secondary vector-control technique for minimum losses and best possible torque controller for IMs. A multi-objective optimization based fuzzy decision model was reported to achieve advanced predictive torque control of IM drives that allows better performance and fast dynamics response [Lekhchine, 2014]. Next, in Ref. [Ziegler, 1942], a search algorithm built on backtracking (BSA) based optimization method was utilized to get better ability of the FLC based controller for IMs. However, optimization methods usually have restrictions on global and local minima, trial-and-error and ideal trapping technique. They are similarly constrained with a difficulty in classifying the processes and the time consumption to attain best performances for optimization. In order to resolve the aforesaid problems of optimization, a new search algorithm based on quantum-lightning is also employed to IM for enhancing speed performance using FLC to control the module related to damping competency and transient performance for the diverse speed and load situations against the several other existing FLC based optimization systems [Ustun, 2008].

Limitations of the Speed Controllers for the Practical Applications

Commonly, the Proportional-Integral-Derivative (PID) and Proportional-Integral (PI)controllers are actively involved as additional controller in AC motor systems for the speed governor, which have been stated to attain an acute transient reaction and decent steady-state reaction [Calderaro, 2008]. However, the Proportional-Integral-Derivative and Proportional-Integral controllers are generally sensitive to variations in the parameters of the motor, non-linearity of system, load disturbance, and variations in the speed, which are consequently become responsible for the degraded drive performance [Sakthivel, 2012]. Therefore, some intelligent and adaptive controllers based on the concept of soft computing and the optimization process has been utilized in place of conventional PI or PID controllers. Again, one of the promising controllers for the AC drives speed control is the FLC controller, because it has load variation elimination abilities, fewer sensitivity for variation in parameters, decent handling ability non-linearity, and also robustness in variation of speed. These key features of FLC projected it as a leading choice for high-rating AC drives [Leonhard, 2006]. Over the many years, the FLC controller is the leading controller of speed for IM drives, that attain a decent and dynamic steady-state responses [Luan, 2014 , Luo, 2012]. The FLC recompenses for error in speed depending on Membership Functions (MFs) and fuzzy rules designed by experts. The quantity of MFs and size of rule base directly influences the FLC built drive efficiency. As measure of MFs and amount of rules base are increased, leads to better treatment of the fuzzy variables. Hence, performance of induction motor drives is improved for specific system set-ups [Elbarbary, 2018]. However, the big size of fuzzy rule base enhances the performance of AC motor drives, but it also imputed a high computational load during real-time hardware-based operation. In Ref. [Hongbo, 2015], three different rule base sizes of 9, 25, and 49 rules were implemented for IM drives and experimentally compared on the ground of computational time and control performance. As a consequence, it was established that during experimental implementation with a large fuzzy rule base size of 49 rules the FLC imputed higher computational burden and consumes huge time for execution as compared to the smaller size fuzzy rules base of 9 rules. Hence, the speed control performance of the existing FLC is constrained between the higher complexities and poor control performance.

Conclusion

In this paper, a detailed review of existing speed controllers for the thyristor fed induction motor drive has been presented along with a detailed description of the advantages and limitations of the controllers for practical real time applications. The review presented in this review delivers a comprehensible and pinpoint explanation of the ability of existing controllers to help the industry for the proper selections of the speed-controllers for thyristor fed IM drive during the implementation of the control system for the different practical applications.

Authors of this paper strongly believe that evolution of controllers present in the paper will be very much helpful to the researchers and industry for getting best relevant references as well as the comprehensible details of preceding work done in the field of controller development for the thyristor fed induction motor drive.

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