A Status Review of Different Industrial Drives

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Abstract:

In almost all industries adjustable-speed motor drives are used.Electric drives have inherent advantages over other prime movers.Conventionally, dc motors have been used in such applications.However, moderndevelopments in semiconductor power electronics, microelectronics and artificial intelligence have made it possible to use ac motors in many variable speed drive applications. Introduction of new control techniques, like vector control, variable-structure control with sliding-mode features have made ac motorsviable alternatives to dc motors in high-performance drive applications. These complex techniques have been made possible due to implementation of microprocessors / microcontrollers / microcomputers/soft computing techniques (GA, Fuzzy Logic, ANN). In this paper development of the control is discussed, focusing on recent trends suitable for practical applications in industry with good dynamic behaviour.

Index Terms — *AC motor, DC motor, Controlled electrical drives, GA (genetic algorithm), ANN (Artificial Neural Network)*

I. INTRODUCTION

The paper begins by reviewing briefly electrical machines for electric drive applications. The dsasurvey then moves on to discuss control techniques for drives. It covers the important historical developments before concentrating on recent research advances, particularly contrasting traditional sensor based schemes with sensorless methods, complementing and updating two extensive reviews by Holtz [1], and recently by Acarnley and Watson [2]. Such sensorless techniques are the subject of much active research. Electric drives are visibly gaining momentum for industrial application. The three basic electric machines dc, induction, and synchronous have served industrial needs for nearly a century. DC machines have traditionally dominated the area of drive systems. However, the main disadvantages are its commutators and brushes and the frequent maintenance required for its operation. Ac machines[3], [4]**,** on the other hand, are rugged and less expensive. Historically, they have been accepted for fixed speed applications due to its complexity and high cost. The research and development efforts in ac drives technology have been focused recently on solving the problem. Asa consequence, the cost and performance of ac drives have improved considerably. Their acceptance in industry is positively increased. Traditionally, electric motors were controlled manually resistance control of dc motors and variac control of ac motors being examples. Electronic control started with the advent of gas tubes such as thyratrons and ignitrons in the 1930’s. The modem era of control began with the invent of power Semiconductors in the 1950’s. Resulting progress in power electronics and microelectronics has intensely influenced the operation and performance of drive systems. Ac machines exhibit highly coupled, nonlinear, multivariable structures, as opposed to dc machines (separately excited), with their much simpler decoupled control structure. Recent advancements in power electronics, micro-electronics, and microcomputers have made it possible to implement sophisticated control tasks at reasonable cost. Technology advances have made ac drives viable alternatives to dc drives in many applications. In high-performance drive applications, for example, in the areas of robotics, machine tools, and rolling mills, drive systems are required that can provide fast dynamic response, parameter-insensitive control characteristics, and rapid recovery from speed drop caused by impact loads. Conventional linear controllers (PI, PID) cannot achieve these requirements simultaneously. Some techniques as model reference, adaptive control, and variable-structure control (sliding-mode control) [5] have shown promise in meeting the needs of high-performance drives.

II. DC MOTOR DRIVES

Control of dc machines is simple . The field mmf and the armature mmf are decoupled. The torque depends on armature current and field flux ($T \alpha I_a, \phi_f$),and the field flux depends on field current ($\phi_f \alpha I_f$**).** This decoupled feature provides enhanced speed of response for torque and speed. The control of torque is normally achieved by controlling the armature current with constant field current. Field weakening is employed to increase the speed beyond a base speed. The simplicity and flexibility of control of dc motors[6] have made them suitable for variable speed drive applications.

Fast torque response has favoured their use in high-performance servo drives. In fact, a majority of industrial drives today use dc machines. Fig.1illustrates a typical dc motor speed drive system in which an outer speed loop and an inner current loop are implemented. The addition of the inner current loop-which indirectly provides the torque control can limit the excursion of current**.** However, because of time delay involved in the imperfect analog devices normally used for implementation (such as in a PI controller for speed loop), the initial excursion of current cannot be limited. A variation of the speed controller, known as the IP controller, can overcome this problem. The IP controller can be designed to provide negligible speed overshoot and fast recovery from impact load while simultaneously retaining the inherent advantage of zero steady error of the PI controller. The converters available bephase-controlled rectifiers or choppers, depending on the supply available. Two quadrant converters can provide regeneration capability. A dual converter can provide fast speed reversal and are frequently used in mill drives. Adc machine, although is ideal from the standpoint of control, is, in general, bulky and expensive compared with an ac machine. In addition, commutators and brushes require periodic maintenance and make the dc machine less reliable and unsuitable to operate at high speed or in an explosive environment.

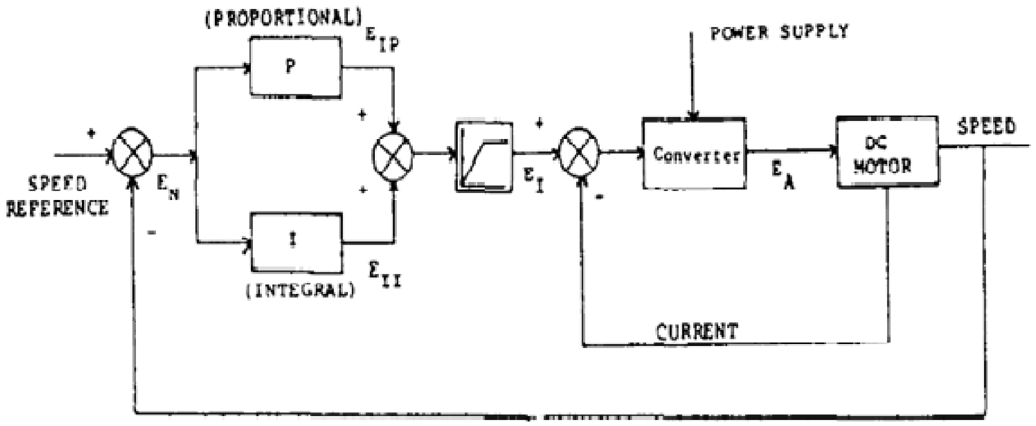

fig. 1 Block diagram of general P-I Controller for a DC motor

As a consequence, for more than a quarter century, attention has been diverted to develop ac drives as a viable alternative to dc drives in many applications.

III. INDUCTION MOTOR DRIVES

The induction motor is the principal workhorse in industrial drives. **A** substantial portion of utility energy is consumed by this class of machines. At steady state, an induction motor may be characterized by a transformer equivalent circuit. The induction machine is a rugged, reliable, and less expensive ac machine. It has been the economical workhorse for use in ac motor drive applications during the past quarter century. It has been used for both low performance as well as high-performance drive applications. Basically, there are two types of induction machines: the squirrel cage induction machine (SCIM) and the wound rotor induction machine (WRIM). The SCIM is less expensive, more robust, and has been extensively used in a wide range of power ratings. It will continue to play a prominant role in ac drive systems in the future.

A. Control of the SCIM

Different control methods of varying degrees of complexity have been proposed and used for the control of induction machines. The nature of application dictates the acceptance of a particular method. A simple and economic method of control is to vary the stator voltage at supply frequency using thyristors (or triacs)**.**This method of control is characterized by poor dynamic and static performance. Although it is inefficient because of high slip power loss, it is used in fans, pumps, and blower drives.

An efficient method of speed control for induction motors is to change the stator frequency [3]. Since the speed is close to synchronous speed, the operating slip is small, and slip power loss in the rotor circuit is small. However, this will require a frequency converter, which is expensive. In drive systems, it is desired that the machine flux is regulated to provide better utilization of the machine. A requirement for maximum possible transient dynamics is to operate the motor at its rated flux level. Indirect flux regulation schemes such as the “volt/Hertz” controland the “slip-current” controluse variable frequency control and have been extensively used in industry.

B. Flux Regulation by Stator Voltage and Frequency

Variable-frequency drives originally used open-loop,volt/Hertz control to regulate machine flux. They were found to be satisfactory for low-performance, cost-effective industrial drives. Closed-loop control with slip regulation was introduced later for improved drive performance. The airgap flux can be regulated if the airgap voltage and frequency are varied simultaneously at a constant ratio[3]. Maximum torque per ampere of stator current can be obtained by a coordination between torque and flux at a particular loading condition. The concept of variable-voltage variable-frequency control is illustrated in Fig.2.Below the base speed, constant flux operation it used. Beyond the base speed, constant flux operation is used. Beyond the base speed, the motor terminal voltage is constant, and as the decreases (which is known as field weakening). The machine can be operated in constant power mode.

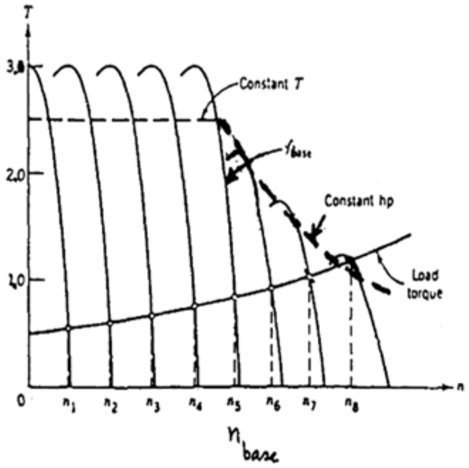

fig. 2 Variable Voltage Variable Frequency control

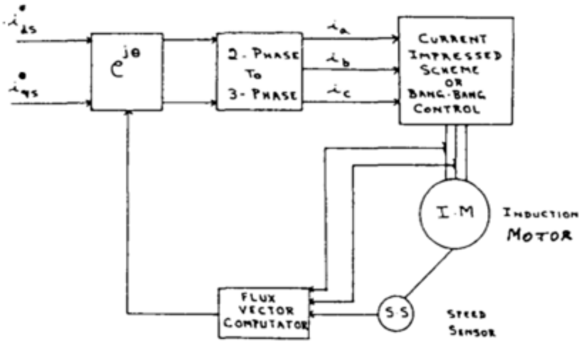

fig. 3 Direct field-oriented control control scheme

C. Flux Regulation by Current and Slip Frequency

Another method that is often used for flux regulation is based on a coordination of stator current and slip frequency. A closed-loop systembased on this technique**.**A current source inverter is suitable for this drive. Unlike the volt/Hertz control, the current-slip frequency control technique is independent of stator parameters (resistance, leakage inductance). Hence, flux regulation can be achieved even at low speeds.

D. Field-Oriented Control

Both the volt/Hertz and current-slip frequency control provide satisfactory steady-state performance. The volt/Hertz control scheme is quite simple to implement. On the otherhand, the current-slip frequency control scheme requires closed-loop current regulation as well as accurate speed measurement and, therefore, is somewhat complicated to implement. However, both these methods fail to provide satisfactory transient performance. In current-slip frequency control scheme the machine torque and airgap flux experience oscillation during transient. High-performance drives, such as robotics, rolling mills, and machine tools require fast and precise torque response. To achieve this, the dynamic structure of the machine has to be taken into account. Several methods [7] have been proposed to obtain fast torque response with flux regulation.

However, the emerging consensus is to use field-oriented control (FOC) [7], [8]. Field orientationis a technique that provides a method of decoupling the twoComponents of stator current: one producing the airgap flux and the other producing the torque. Therefore, it provides independent control of torque and flux, which is similar to a separately excited dc machine. The magnitude and phase of the stator currents are controlled in such a way that flux andtorque components of current remain decoupled during dynamic and static conditions.

In FOC, the stator phase currents are controlled in afictitious synchronously rotating reference frame (aligned with the flux vector) and are transformed back to the stator frame to feed the machine (Fig.3). Field orientation can be achieved by aligning the rotor flux linkage vector along the d axis of the reference frame. With this arrangement, the control dynamics of the highly coupled nonlinear structure ofthe induction machine becomes linearized and decoupled.The induction motor is controlled like an armature controlled dc motor, with i_{qs}**,** analogous to the armature current and i_{ds}**,** analogous to the field excitation.

Several methods have been proposed to implement field oriented control. Basically, the schemes can be classified into two groups: the direct method of field orientation [7] and Theindirect method of field orientation[8][9]. Fig.3 shows the direct method of field-oriented control.

The method requires flux acquisition, which is mostly obtained by computation techniques using machine terminal quantities. The indirect method of FOC was originally proposed by Hasse, and it avoids the requirement of flux acquisition by using known motor parameters to compute the appropriate motor slip frequency w_s, to obtain the desired flux position. Fig.4 shows such an indirect method of control. The scheme is simpler to implement than the direct method of FOC hence, there is an increasing popularity towards the indirect method of FOC. In this method the torque and flux responses for step changes in command torque. The machine torque response is almost instantaneous, and the average torque is controlled.

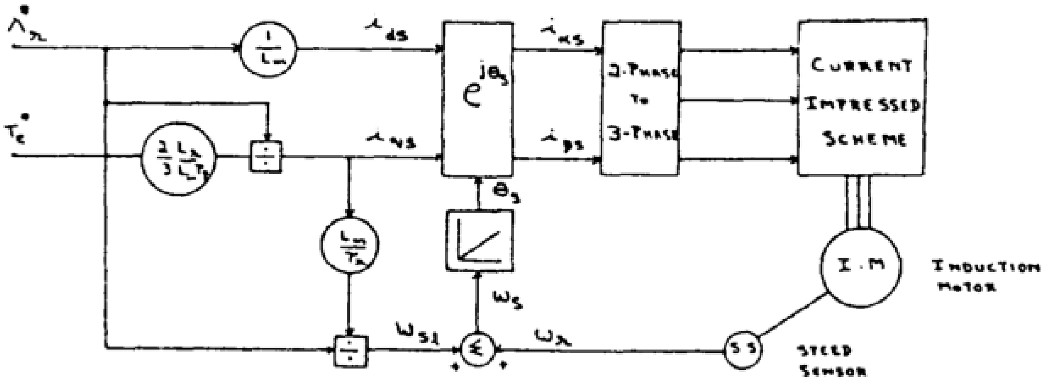

fig. 4 Indirect field oriented control scheme

The high-frequency torque pulsating due to the motor current harmonics and the machine flux is maintained constant during torque transition. Both the direct and indirect methods of FOC are machine parameter dependent unless means are included for directly measuring the rotor flux component. Inductance parameters vary about ± 20 %, whereas rotor resistance changes dramatically (±100%) with temperature. Without the exact knowledge of the machine parameters, optimum decoupling and torque linearization cannot be achieved. Considerable amount of research effort has been directed to developing parameter adaptation schemes for optimum decoupling of field-oriented control. This scheme are based on modified reactive power compensation, estimation of magnetic flux, indirect measurement of instantaneous rotor resistance, and identification of rotor resistance by

Signal injection. Thus far, no standard solution for parameter adaptation has emerged. In most parameter adaptation schemes, the identification is more effective at higher speeds and loaded conditions. Decoupling control can also be achieved by orienting the airgap flux or stator flux. Stator flux orientation provides direct control on the saturation level of the machine. However, implementation of these schemes requires more real-time computations than indirect rotor-flux orientation.

E. Control Of the Wrim

In earlier days, the SCIM was used for essentially constant speed drive, and the WRIM was used for variable-speed drive systems. Although the WRIM is more expensive and less rugged than the SCIM, it has been favored for use in high-power applications in which a large amount of slip power could be recovered. It maybe noted that an attractive feature of WRIM control is that only the slip power is handled by power electronics, which may be only a fraction of the rated machine power. Classically, speed of the WRIM was changed by mechanically varying external rotor circuit resistance**.** The performance can be improved by using a chopper to control the equivalent rotor resistance**.** The static Krameror static Scherbius**[3]** respectively, allow recovery of slip power and have been used for pump and blower drives. The Kramer drive provides subsynchronous speed control. The use of a cycloconverter in the Scherbius method allows bidirectionalpower flow, and hence, the drive can operate in both sub synchronous and super synchronous mode.

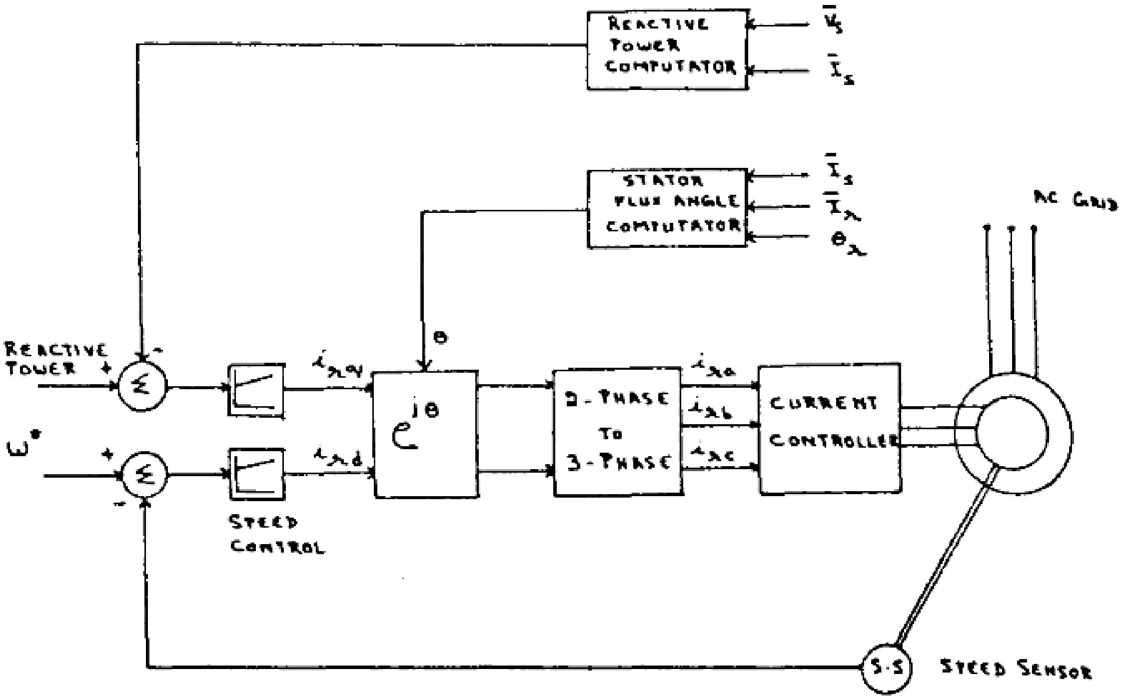

Fig. 5. Field- oriented control of a wound- rotor induction motor

Field-oriented control can also be applied in WRIM's to provide decoupled control of real power and reactive power. These features are extremely beneficial in high-power applications. Fig.5 shows the field-oriented control of a WRIM. In this case, it is more convenient to use stator flux field orientation than rotor flux field orientation. The field-oriented controlof a series-connected WRIM has less parameters involved than the FOC of SCIM's ordoubly fedWRIM's. The machine parameter in question isthe mutual inductance, the variation of which under flux regulation is expected to be small (much less than the variation of resistive parameters with temperature in the SCIM). Hence, the use of parameter adaptation is not required in this case.

IV. SYNCHRONOUS MOTOR DRIVES

The synchronous motor is becoming a strong competitor with the induction motor in the variable-speed drive domain.The main advantages, as compared with induction motors,are the elimination of rotor slip power loss and the natural ability to supply reactive current. In a synchronous machine, the magnetization is provided from the rotor circuit instead ofthe stator. Hence, the machine can be built with a larger airgap without degraded performance. The ability to supplyreactive current also permits the use of natural-commutateddc link converters. However, the manufacturing cost of asynchronous machine is comparatively higher than aSCIMat ratings of500 hp or less. In addition, position sensing isrequired for high-performance control of synchronous motors[4].The open-loop control of synchronous motors using volt/Hertz control technique for flux regulation has beenused in applications such as the textile industry, fiber spinning mills, etc., where high dynamic performance is not of prime concern. In open-loop control, speed should be slowly to avoid pull out (i.e.loss of synchronism).

A hybrid synchronous and induction motor (i.e., a synchronous motor with cage-typehortesseuer windings on the pole faces) isrequired for effective open-loop volt/Hertz control.The most commonly used methods of control for synchronous motors are self control**[3],** and field-oriented control**.** These control techniques can provide flexibility normally obtained in the control of separately excited dc motors. In low-power (<**10 kw)** servo applications, synchronous machines with permanent magnet excitation are very attractive solutions when used in conjunction with self- or field-oriented control mode.

A. Self Control Mode

In the self-control mode, the rotor angle is fed back to generate the stator frequency. The most usual configuration uses a current-fed rectifier-inverter scheme **[3].** Under self-control mode, the angle between the stator mmf and rotor mmf can be controlled at any instant of time; therefore, no risk of pulling out is encountered. The inverter switches are controlled based on the instantaneous position of the rotor to keep the armature mmf Orthogonal to the field mmf.

This mode of operation results in a dc machine (separately excited) like control, with the amplitude of the stator current (dc link current) analogous to the armature current of a separatedexcited dc motor.

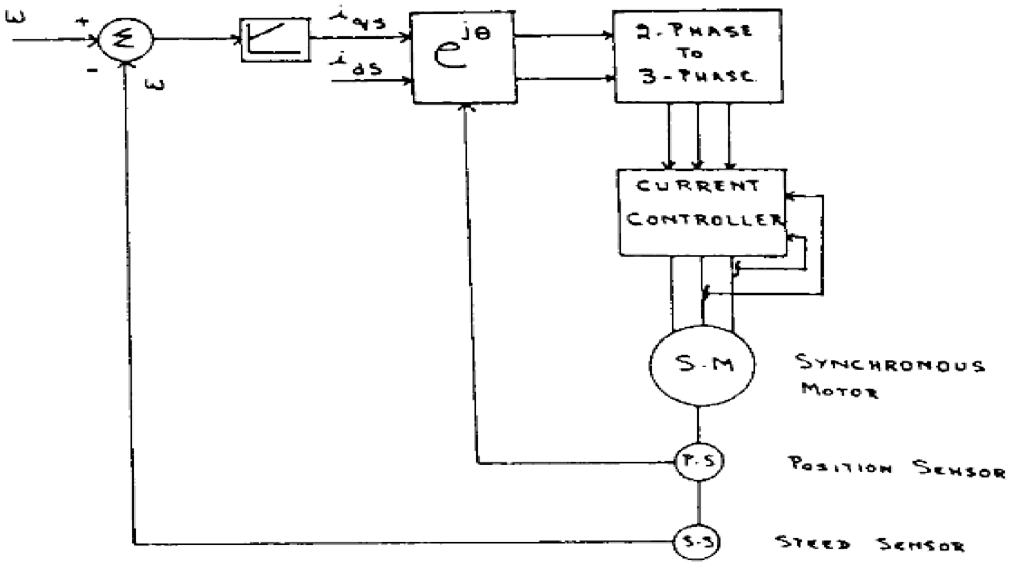

Fig. 6. Field- oriented control of a synchronous motor

B. *Field Oriented Control*

Fig.6 shows the basic configuration for the field-oriented control (FOC) of a synchronous motor. The FOC can provide fast dynamic response with decoupling. In the self-control mode of operation if the inverter is switched to keep the armature mmf orthogonal to the field mmf, it would provide decoupling.

Therefore, the two schem are basically the same, except that the control is executed in polar form (magnitude angle) and rectangular *(d-q)* . However, in self-controlling mode if flux is to be regulated during torque changes, the field current is alsorequired to be adjusted accordingly. Unfortunately, the response of the field current is sluggish due to the large field circuit time constant. On the other hand, in FOC the flux can be regulated quickly during torque transients by the d-component $i_d$of the stator current (i.e. from the stator side). The stator dynamic is comparatively faster than the field circuit dynamic.

V. PERMANENT MAGNET MOTOR DRIVES

In recent years, there has been an emerging growth of permanent magnet synchronous motors (PMSM).This machine, operated in self-control mode, is known as a brushless or electrically commutated dc drive. In the PMSM,the rotor field is supplied by permanent magnets. The mainadvantage when compared with the conventional synchronous machine is the elimination of the field coil, dc supply, andslip rings; hence, lower loss and a less complex motor can be obtained. In PMSM, there is no provision for rotor side excitation control. The control of PMSM is done entirely through the stator excitation control. Field weakening is possible by applying a negative direct axis current (field-oriented control; see Fig.6) to oppose the rotor magnet flux.The PMSM has essentially two different configurations. The surface-mounted magnet machine, is essentially nonsalient with a large airgap and is commonly used in a brushless drive. Because of the large airgap, the armature reaction effect on pole flux is insignificant. Therefore, the variation of airgap flux under stator current change is minimized. This provides ease in flux regulation control. Recently, interior (or buried) magnet machines, have emerged. The machine has narrow airgap and salient pole[10] structure. Torque is contributed by both excitation and reluctance torques. The armature reaction effect is significant in the interior-mounted PMSM. The stator winding in the PMSM's are either fed by rectangular current or sinusoidal current. The rectangular current-fed motors have concentrated windings on the stator, and the induced voltage in the windings is square or trapezoidal. These machines are cheaper and normally used in low-power brushless drives. The sinusoidal current-fed motors have distributed winding on the stator, provide smoother torque, and are normally used in high-power applications.

VI. SWITCHED RELUCTANCE MOTOR (SRM) DRIVES

The principle of the switched reluctance machine (SRM) has been known for over a century. However, in recentyears, this machine has seen a revival of interest for application in low and medium power drives. The machine has saliencies on both the stator and rotor.The rotor is made of laminated steel, which carries no windings or magnets. Concentrated windings are wound onthe stator poles. Currents in the stator windings are switched on and off in accordance with the rotor position to producereluctance torque. This developed torque is a nonlinear function of the rotor position and current. The control techniques of SRM's[11] have not matured yet. However, the control algorithm can be quitecomplex if servo-quality torque smoothness is desired. An absolute position sensor is usually required in an SRM drive, as in the synchronous motor drive, to directly control theangles of stator excitation with respect to the rotor position. Several alternatives for the power converter circuitries can be used for the SRM drive.

VII. CONVERTER TECHNOLOGY

Converter in a drive system is an important component of equipment. The basic converter topology, such as controlled rectifiers, choppers, inverters, and cycloconverters, have been extensively used in industry. New control techniques and new devices [12] for these converters have brought about significant improvement in the drive performance. For example, pulse-width modulation (PWM) of inverters has improved the motor current waveform. Conventional thyristors (SCR) have been traditionally used in most converters. The development of GTO's,power BJT's, and power MOS FET's has eliminated the commutation circuits for the converters and also allowed high-frequency operation. Phase-controlled rectifiers using SCR's and line commutation have been traditionally used for dc motor speed control. However, phase control causes a poor power factor and feeds the lines with harmonics. PWM of the rectifier converter using GTO's, BJT's, or MOSFET's improves the supply power factor and current waveform. These devices are also used in choppers where a high chopping frequency can reduce the ripple in both motor and supply current. The rectifier-dc link-inverter configuration hasbeen popularly used in variable-speed ac drive systems. In low-performance ac drives, the six-step voltage-fed excitation is satisfactory. However, PWM voltage-fed inverters are used if improved performance is required. The current-fed inverter (also known as current source inverter) received a lot of attention for several years. It is rugged and has regeneration capability. In high-performance drives, both current-impressed and voltage-impressed PWM schemes have been used. Power switching devices, such as GTO's, BJT's, and MOSFET's have allowed to increase the inverter switching frequency, resulting in a reduction of inverter size. This has further promoted the use of PWM [13] [14]schemes with extended power range. In high-performance drives, the current control scheme is preferred to the voltage control scheme because of its ability to provide current protection for the drive, to eliminate current unbalance, its independence of stator dynamics, and the fact that the current control provides a more direct capability for controlling motor torque than the voltage control. Some important schemes for current control are discussed here.

A. Bang-Bang Current Control:

In this schemethe motor phase currents are fed back to be compared with the reference command currents. The inverter switches so that the instantaneous phase currents are confined within a certain hysteresis band. Whenever the actual current leaves the band, the appropriate device in the inverter is switched on or off to force the current to return into the inside of the band. The PWM voltage is generated adaptively with this method of control, and consequently, the inverter switching frequency can vary over a wide range and can be excessively high.

B. Linear Current Controller Using a Pulse Width Modulator:

In this scheme the current control loop generates a voltage command that is pulse-width modulated by a fixed frequency triangular carrier wave. Unlike the bang-bang control, the maximum switching frequency is fixed in this scheme.

C. Current Control by Using Current Source Inverter :

In this scheme the quasi-square wave current produces large pulsating torque that causes speed oscillation, particularly in the low-speed range. This problem can be overcome by pulse width modulation of current or programmed dc link current.

The PWM current source inverter using GTO's provides nearly sinusoidal current at both the input line and the output motor. This eliminates the torque pulsation of the motor. In addition, the input power factor can be adjusted close to unity for any power factor condition at the output. The capacitors at the input and output serve to reduce over voltages and harmonic currents. A cycloconverter [3] is a one-stage bidirectional ac-to-ac power converter with four-quadrant capability. It uses the conventional thyristors and are therefore suitable for high power and low-speed applications. Cyclo converters are well established for direct ac-to-ac power conversion. Naturally commutated cycloconverters have limitations on output frequency range, input power factor, and distortion of input and output waveforms. The waveforms can, however, be improved with high pulse number. A forced-commutated cycloconverter comprising bilateral static power switches can overcome many of these limitations. Recently, a new circuit configuration, called the matrix converter, has been developed; it can provide increased output frequency range and low distortion of input and output current. This converter requires bidirectional switches of relatively high voltage rating. High device losses and device cost have not yet made this converter attractive.

Recently, a new class of power converters (the resonant link power converters) have generated a great deal of interest . These converters utilize a high-frequency link to introduce zero voltage or zero current intervals. By switching at the zero crossings of voltage or current, the switching losses of the converter switches and the stretcheson the devices can be greatly reduced. This will permit anorder-of-magnitude increase in the converter switching frequency. The high switching frequency makes the current at the input and output of the converter almost sinusoidal. Theseresonant link converters appear to play an important role inthe next generation of power conversion equipment.

VIII. MODERN CONTROL TECHNIQUES

The conventional linear controllers such as PI, PID [15] have been used in many applications. However, these controllers are sensitive to plant parameter variations and load disturbance. The performance varies with operating conditions, and it is also difficult to tune controller gain both on-line and off-line. The increased productivity and improved product quality demands fast response and parameter-insensitive robust drive systems. The conventional linear control techniques can no longer satisfy the stringent requirement placed on high-performance drive applications. In recent years, many modern control techniques have been proposed; most of them have not yet been applied in practice like Fuzzy logic, hybrid fuzzy plus pid [16] and Genetic Algorithm based controller [17].The availability of high-speed signal processing using microcontrollers has stimulated increased interest in applying modern control techniques to drive systems.

Self-tuning adaptive control techniques has been applied with dc drives. In this method, the controller parameters are tuned to adapt to the plant parameter variations. The identification block tracks the changes in system parameter. This information is used to update the controller parameters through controller adaptation to guarantee a desired closed-loop performance. The model referencing adaptive control (MRAC)[18][19] is also being applied in electric drive systems. In MRAC, the output response is forced to track the response of a reference model (idealized model with fixed plant parameters) irrespective of plant parameters variations.

The controller parameters are adjusted to give a desired closed-loop performance. This adjustment is based on an adaptation algorithm that utilizes the difference between the reference model output and the plant output as its input. Both the self-tuning or the MRAC techniques involve intricate control algorithms. The variable structure control using sliding mode was recently introduced into the field of controlled electric drive systems to compete with the former two adaptive control schemes. With sliding mode control (SLMC)[20], the control system can be designed to provide parameter-insensitive features, prescribed error dynamics, and simplicity in implementation. In SLMC, the drive system is forced to follow a predefined trajectory in the phase plane irrespective of plant parameter variation. The structure and design of the SLMC are relatively simple [21]. In position control drives using the SLMC, the actual position and speed are required as feedback signals. They are easy to obtain, the first-order parameter invariant response for a step change in position command. In speed control drives, the speed and acceleration are required as feedback signals. It is difficult to sense an accurate acceleration signal.

There is intensive research world-wide devoted to sensorless methods. Motor drives without a speed or position sensor have received much research attention in recent years, both for IMs [1], and PM brushless types [2]. Such techniques typically measure stator quantities, usually current, directly via existing transducers normally present in the inverter, and voltage, although not often with a direct measurement. SI methods are also used.

Advantages of such “sensorless” schemes:

a) more compact drive with less maintenance;

b) no cable to machine transducers, easier application particularly to existing machines, reduces electrical noise;

c) transducer cost avoided;

d) suitable for hostile environments, including temperature.

In SI methods the machine is injected with extra, low level signals usually at high frequency. The much higher frequency and low magnitude of the injected signals result in the fundamental behaviour of the machine being little changed. The injected signals may be periodic or alternating in a particular spatial direction.

These signals are modulated by the orientations of the machine asymmetries, and are then processed and demodulated to yield the required measurement. Such asymmetries occur more naturally in SMs. Signal processing can be difficult owing to required frequency tracking, low spectral separation and poor signal to noise ratio. Modern signal processing techniques can help.

IX. CONCLUSIONS

This paper has presented a comprehensive review of electric motor drives and control strategies. Drive technology has seen impressive growth during the last three decades. AC drive technology has been maturing rapidly and will likely overtake dc drive technology in many industrial applications. New high-speed, high-efficiency switching devices, new motor structures, new converter configuration, new control techniques, and new high-speed microcontrollers will contribute to the further development of high-performance motor drives. In recent times, Fuzzy Logic , Genetic Algorithm and Neural Network controllers have generated a good deal of interest for applications to power electronics and electric drive systems. These are non-linear controllers and do, not require a mathematical model of the system. Interest and research sin this area will continue relentlessly.

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