# Design of Modern speed control technologies for research level implementation

Dr. S. K. Bikshapathy[1] S. Rajesh[2] T Satish[3] E Sai Prasanna[4]

*[1]Professor, Dept.of EEE, Siddhartha Institute of Engineering & Technology, Ibrahimpatnam, Hyderabad, Telangana, India.*

*[2]Associate professor, Dept.of EEE, Siddhartha Institute of Engineering & Technology, Ibrahimpatnam, Hyderabad, Telangana, India.*

*[3]Assistant professor, Dept.of EEE, Siddhartha Institute of Engineering & Technology, Ibrahimpatnam, Hyderabad, Telangana, India.*

*[4]Student, Dept.of EEE, Siddhartha Institute of Engineering & Technology, Ibrahimpatnam, Hyderabad, Telangana, India.*

**Abstract:** In recent years, the application of sensorless AC motor drives is expanding in areas ranging from industrial applications to household electrical appliances. As is well known, the advantages of sensorless motor drives include lower cost, increased reliability, reduced hardware complexity, better noise immunity, and less maintenance requirements. With the development of modern industrial automation, more advanced sensorless control strategies are needed to meet the requirements of applications. For the application of variable speed drive, submodule capacitors of the modular multilevel converter (MMC) suffer from large voltage fluctuations at low frequencies. Inherent advantages of adjustable frequency operation could not be fully exploited without adopting a suitable control strategy. The paper gives an overview of trends in advanced control techniques employed for torque, speed and position regulation of variable frequency drives. Estimation issues are also discussed. Adjustable speed AC Motor drives have been used extensively in modern industry and transportation which calls for electrical and mechanical energy conversion with wide output power range applications. Because of its modularity and scalability, the drive system can be extended to many different application areas. More recently, adjustable speed AC motor drive applications are spreading not only in industry applications, but also sky and the marine. In this paper, after summarizing the history of adjustable speed AC motor drives and applications, the main issues of AC drive technologies are reviewed and investigated in the paper.

***Keywords:*** *Electric machine, drive technology, adjustable speed motor drive, AC machine, drive system, Industry applications, transportation application, high speed PM motor.*

## I. INTRODUCTION

Adjustable speed AC motor drives have attracted increasing attention for more than half of the last century as one of the preferred choices of electric energy conversion for the high-power applications [1], for industry application, transport applications and so on. Although the development of higher-voltage and higher-current power switching devices make the converter capable of driving high power, the power converter topologies and motor control methodologies still present great advantages due to the fact that they can achieve high power. Moreover, the high quality of the output voltage waveforms of inverter also makes them very attractive to industry and academia [1]. Power electronics and drive applications are going to spread not only in industry application but also to sky and the marine applications requiring more electrification. The paper is organized as follows: Section 2 presents a brief review of the brief history of adjustable speed AC motor drive technologies and applications in Japan as an example. Then, technical issues of adjustable speed AC motor drives are surveyed and analyzed in Section 3. Finally, Section 4 provides adjustable speed AC motor drives technologies and discusses the development of high speed high power AC motor and application.

## II. BRIEF HISTORY OF ADJUSTABLE SPEED AC MOTOR DRIVE TECHNOLOGIES AND APPLICATIONS

Some significant events in global history of power electronics and motor drive technologies [2-5] influenced Japanese history of motor drive technology. Needs have driven power requirements and manufacture of motor products to meet the demands of each age. Mainly from the latter of 1970s to 2000s, the existence of industrial vitality requiring better performance of drives compared to former days is the reason why progress in motor drive technologies in Japan has been very active [6].

### 2.1 DC drive

·Rapid spread of thyristor DC drive, to large capacity mill drive of metal industry from middle of 1960s.

·Completion of basic drive control technologies (speed and torque control by armature and field current).

·Introducing of digital control by 16 bit micro- processor in around 1980**.**

**2.1.2 AC drive**

- Stage 1:ca.1960-ca.1976:
  ·Practical use of several kinds of thyristor AC drives.
  ·Commercialization of voltage and current source thyristor inverters for process line and energy saving drive from middle of 1960s.
  ·Introduction of general-purpose inverter (transistor inverter), afterwards adopting sinusoidal PWM control and applied to home air conditioner in around 1980s.
- Stage 2:
  ·Realization of the same control performance as DC drive.
  ·R&Ds of slip frequency type vector control from middle of 1970s, commercialization of this control using various AC drives.
  ·Stimulation to digital control and precise speed sensor by demands of sophisticated control theory and calculation.
- Stage 3:
  - · Enthusiastic desire for both performance and cost of high qualified AC drive.
  - · Peak performance of mill drive attained by Cyclo-converter drive of IM in middle of 1980s, remaining solution for reduction of power source capacity.
  - · Introducing of inverts using GTO in order to attain the reduction of power source capacity and reasonable cost [7].
- Stage 4: Introduction of IGBT having the almost same impact as thyristor.
  ·Voltage source inverter as almost universal acceptance for AC drive.
  ·High performance drives, i.e., auto tuning of general-purpose inverter, AC servo driver superior to DC servo in around 1990.

Level inverter and multi-cell cascade inverter realizing direct middle voltage drive, large capacity and high speed drive for oil & gas field applications.

- Stage 5:

·Challenge of new technology for AC drives.

·Introduction of matrix converter in middle of '00s'. ·New applications of PMSM and SWR drives, and R&Ds for their control technology.

**2.2. Transport applications**

In this paper, authors describe three motor drive fields for railway, elevator and automotive as transportation applications, treated mainly with AC drives, because at present, the AC drive is common technology for three fields despite their different progress history [6-7].

An overview of transportation motor drive technologies and products in Japan is shown in Fig.2. Features of Railway Drives in Japan

Railway drives are categorized into DC and AC electricity of overhead wire, or into electric train, locomotive, high-speed railway (Shinkansen in Japan) and super-high-speed railway (Maglev vehicle in Japan). As for drive technologies, DC drive started from series DC motor by resistor control, grew to chopper applications to field or/and armature circuits using power devices. Afterwards, AC drives of IM was substituted for DC drives, and at present, PMSM drives have started [8].

**2.2.1 Features of Japanese development in railway drives**

(1) Leading edge high power devices were applied to develop new drive equipment, for example, power diode for series-0 Shinkansen in 1964, GTO for an electric train in 1982 and for series-300 Shinkansen in 1992, IGBT for an electric train in 1992 and for series-700 Shinkansen in 1999, and SiC diode for a prototype of electric train in 2012.

(2) Strong cooperation between railway companies and electrical manufacturer promoted practical use of new power devices and new drive equipment, eliminating problems of introducing new technologies through discussions, field tests and so on.

**2.2.2 Features of elevator drives in Japan**

Elevator drives are categorized into middle/low speed type and high speed type according to con- struction installation, or into standardized type or not. As for drive technologies, middle/low speed type moved from IM primary voltage control to inverter

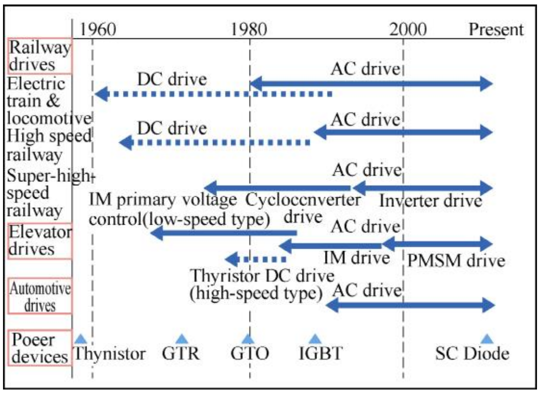


Fig.1 An overview of transportation motor drive technologies and products in Japan

Drive, and high speed type moved from thyristor DC drive to inverter AC drive of IM [12]. In middle/low speed type, flat

PMSM technology was introduced as a key component of machine-room-less elevator after moving to inverter drive of IM [9-10]. Since PMSM drives were wide-spread as standardized types, it was first used in transportation application before elevator drives changed to PMSM drive.

**Background of Japanese progress in elevator drives is as follows:**

(1) Domestic market was the largest in the world at a period from high economic growth to the bubble economy; therefore developments and manufacturing of elevators were very active.

(2) Since many electric manufacturers in Japan competed with each other for developing new products, many advancements in industrial motor drive technologies were introduced.

**2.2.3 Features of automotive drives**

Automotive drives for power train are categorized into electric vehicle and hybrid electric vehicle. Except for small size electric vehicles, motor drive applications were delayed by the influence of slow progress of battery technologies, however grew from hybrid to pure electric vehicle, from large to middle size vehicle and from IM to PMSM drive [11-12]. Products had to endure mass production and durability, and as such, transportation applications were the latest to put in practical use.

**Backgrounds of introducing electric vehicles in Japan were the follows:**

(1) Necessity of power electronics technologies. It is no exaggeration to say that precondition to commercialize electric vehicle has been satisfied by improvement of NiHM or Lithium- ion battery instead of lead acid battery. Moreover, power devices, GTR and IGBT realizing high performance and reliability drive, PMSM motors [13] and are important for small, light and efficient equipment and leading technologies of motor control and analysis.

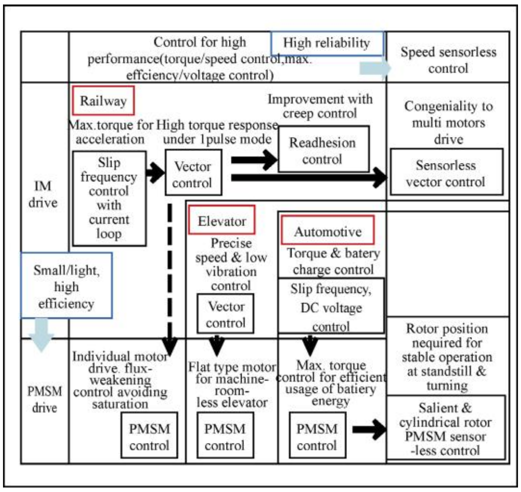


Fig.2. Some technical trends of IM and PMSM drive control methodologies

(2) Japanese automotive companies have been very eager to clear emission controls of oversea countries because of small domestic market, and continued to develop electric vehicle and fuel cell vehicles for long periods.

## III. TECHNICAL ISSUES OF ADJUSTABLE SPEED AC MOTOR DRIVES

In sustainable society, more electrical energy will be consumed for convenience of human activities.

However, greenhouse gases must be decreased for environmental conservation. Hence, motor drive technologies that will result in high efficiency, saving resources, and capability of operation on command is very important [14,15,16].

The following items need to be addressed in the future drive systems:

- Requirement for high efficiency, fewer resources and lower costs make applications of PMSM and SRM desirable. High performance control technology is necessary to use them in any situation.
- Pursuit for high reliability of the whole drive system requires sensorless control of not only speed sensor but also other sensors as the intrinsic solution.
- Recently SiC and GaN are noteworthy as new materials for power semiconductor devices.
- The pros and cons for adopting new devices to AC drives is an interesting subject in near future.
- In industrial drives, a mechanical object is displaced by motor energy, but a person is moved by motor energy in transporting drive. Major metrics for riding circumstances are loudness, vibration, EMI noise and so on. Required drive systems must control such metrics within permissible range for comfortableness.
- In transportation applications, smoothness of acceleration and deceleration is important inevitably, as well as sufficient starting torque, readhesion control against slips and coasting operations.

Table 2 describes some issues for advancement of AC motor drive technologies for spreading many applications. It will be shown as follows; Ultra- high speed drives, low speed and high-accuracy drives by sensorless control, large capacity drives fed by multilevel inverter, ultra-small size motor, high response and torque accuracy, downsizing and efficiency, standardization, and so on.

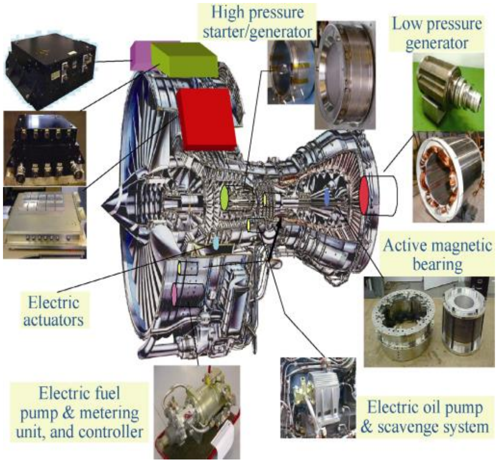


Fig.3. Power optimized aircraft engine

Low-speed and high-accuracy sensor-less controls are based on high frequency injection method, zero-sequence carrier injection, model base method, induced voltage caused by magnetic saturation, etc.

## IV. ADJUSTABLE SPEED AC MOTOR DRIVES

Fig.8 shows some examples of drive systems arranging AC motors and inverters for industrial applications. These are Electric Vehicle, Elevator, Forklift and Textile machine and so on.

We are required to combine with motor, inverter and its control system. But motor speed of these applications is near nominal speed with power supply frequency but not high speed.

We will focus the interest to ultra-high speed drive technology of large capacity motor.

As shown in Fig.9, products of high speed motors show on the *x* and *y* axis shown by both logarithm coordinates *x* axis is motor speed, and *y* axis is the output capacity of motor. The technical difference between ultra-high speed motor and high seed motor is divided by this straight line.

In this side, upper side of this line shows the ultra-high speed drive region, and the other side is high speed drive region.

It is very different technology for the motor capacity. And also it has very different technology for motor speed.

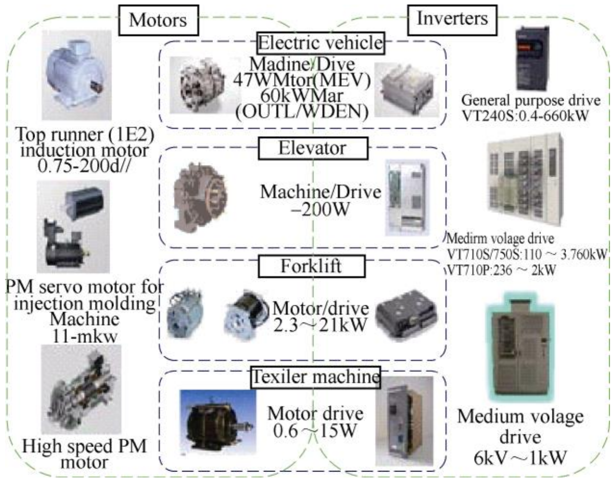


Fig.4. Drive system products-some examples

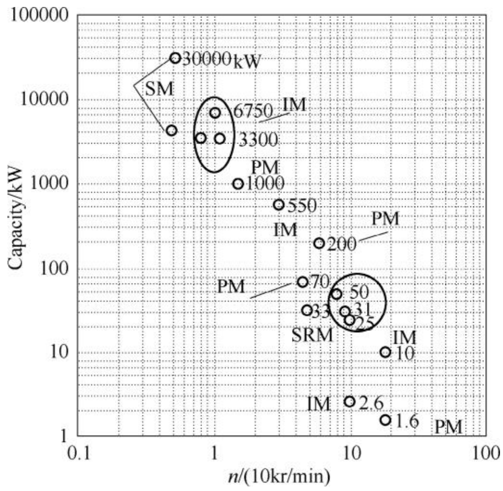


Fig.5 Nominal output power versus rotation speed of some of the prototyped and or manufactured high speed machines

But these rotor surface speeds are very important for centrifugal force to keep safety the parts or materials in the rotor.

Candidate high speed electric machine topologies are Induction machines (IM), Synchronous machines (SM) for large capacity, and Permanent magnet machine (PM), Switched reluctance machines (SRM), Axial flux machines (AFM), Homopolar machines (HM), Bearing-less PM for small and/or median capacity drives. High Speed Electric Machines are widely used in many applications, such as:

·Hand held drilling tool for dentists (10~20W, 400kr/min; 100W, 500kr/min PM),

·Hand held drilling tool for dentists (10~20W,

400kr/min; 100W, 500kr/min PM),

·Vacuum cleaner (1.6kW 100kr/min, SRM),

·Supercharging machine for traction application.

(3kW, 150kr/min, PM).

·Aerospace (192kW 13kr/min SRM).

·Many kinds of compressor (300kW 60kr/min solid-rotor IM, PM, SM etc.).

·Grinding spindle and milling spindles for machine tools (from 24kW to 1kW, from 9krpm to 30kr/min IM, PM).

·Oil/gas industry (8MW, 15kr/min PM 32MW, 6kr/min SM).

·Fly-wheel energy storage systems (150kW, 16kr/min), and others.

Benefits of high speed motor applications are size and weight reduction, and high efficiency of drive system.

Usually, to sustaining the rotor, this side used magnetic bearing for levitation, and this lower side used rolling bearing or sliding bearing. The capacity and speed of these motor and its inverter output voltage are shown here.

## V. CONCLUSION

The use of a Variable Speed Drive for a speed control application usually offers an energy efficient and environmentally friendly solution. The best opportunities for energy savings, with subsequent economic savings, arise through the laws which govern the operation of centrifugal fans and pumps.

Firstly, the history of adjustable speed AC motor drive technologies and applications in Japan as an example are briefly reviewed and analyzed. Then, technical issues of adjustable speed AC motor drives are surveyed and analyzed for future advancement. Finally, section 4 provides adjustable speed AC motor drives technologies and discusses the development of high speed high power AC motor and application.

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