Chapter 1

Introduction to Electric Traction AC Drive System

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Outline

1. Transport Needs
2. History and Development of AC Drive System
3. The Structure Configurations of AC Traction Drive System
4. The Characteristics of AC Drive Compared with DC Drive
5. The Key Technologies of AC Traction Drives
6. The Development Tendency of AC Traction Drives and Control Systems in the Future
7. The Contents of the Course
Transport Needs

- What does transport mean?

What does everyone want?
- Safety
- Availability
- Reliability
- Performances
- Flexibility
- Comfort

(A) — (B) — Cost
Transport Needs

What are we going to talk about?
Electric Drive technology was born in 19\textsuperscript{th} century, which is widely used in industry, agriculture, transport and daily life in 20\textsuperscript{th} century.

If the electric actuating mechanism is driven by DC motor, we call it \textbf{DC drive system}. If the actuating mechanism is driven by AC motor, we call it \textbf{AC drive system}.

According to the requirement of load objects, electric drive can be classified as \textbf{Constant Speed system} and \textbf{Variable Speed system}. 
In 1930’s, people has known that the frequency conversion adjusting speed technology for AC motor is a very perfect electric drive technique.

Question:

Why is not the electric AC drive system widely used in the industry application?
In 1960’s, with the development of power electronics technology and the success of frequency conversion speeder, AC drive system was concerned and interested increasingly again, and became a hot field research of electric drive system.

In the middle of 1970’s, energy saving has been hot issues for humans with the advent of energy crisis across the world.
History and Development of AC Traction Drive System

- Since 1990’s, with the rapid development of high power semiconductor devices and micro electronics technology, and the application of modern control theory and technology, people have made breakthroughs in AC motor drive system for adjusting speed.

- Nowadays, As a excellent drive and control technology, AC motor drive system has been widely used in the industry and railway traction system applications.
The Experimental Records of Heavy-Load Freight Trains in the World
Supper Heave-Load Freight Train in Australia

The cargo is iron ore in this train. The length of this train is approximately 2km.
The Experimental Records of High-speed Passenger Trains in the World

(1) April, 4, 2007, TGV, 574km/h, Paris
(2) December, 2010, CRH380AL, 486.1km/h, Beijing-shanghai, China;
(3) January, 2011, CRH380BL, 487.3km/h, Beijing-shanghai, China;
(5) 1988, ICE, 406km/h, Germany;
(6) 2004, KTX, 352.4km/h, South Korea;
(7) 1988, TAV, 319km/h, Italy.
From Oct., 1964 to Dec, 2012, Japanese has constructed and opened five Shinkansen. The total mileages are 2048.8km, and the highest operating speed is 270～300 km/h.
France government has constructed and opened 4 high-speed railway lines. And the highest operating speed is 270~300km.
Germany governmen has constructed and opened 4 high-speed railway line. The total mileages are 917km, and the highest operating speed is 250~300km.
Electric traction drive system is adopted for the conversion of electrical energy into mechanical energy.

\[ P = F \times V \]

Mechanical energy

Power source

Single-phase
25kV/50Hz catenary

How to drive locomotive?
Electric traction drive system is adopted for the conversion of electrical energy into mechanical energy.
Electric Railway Traction AC Drive Systems

The Structure Configurations of DC Traction Drive System

AC-DC traction system for DC motor drive
DC Traction Drive Locomotives in China

Electric Railway Traction AC Drive Systems
Electric Railway Traction AC Drive Systems

The Structure Configurations of AC Traction Drive System

AC-DC-AC traction system for AC motor drive

Transformer

Pulse Rectifier

Capacitor

Inverter

AC motor

Gear box

Wheel

Traction Converter

Power line

25000V
High-speed AC Traction Drive EMUs in China

CRH2 high-speed Electric Multiple Units

The maximum operation speed: 350km/h
High-speed AC Traction Drive EMUs in China

CRH3 high-speed Electric Multiple Units

The maximum operation speed: 350km/h
High-speed AC Traction Drive EMUs in China

CRH1 high-speed Electric Multiple Units  The maximum operation speed: 250km/h
CRH5 high-speed Electric Multiple Units

The maximum operation speed: 250km/h
HXD1 high-power 6-axis locomotive

The maximum operation speed: 120km/h
Power: 9600kW
HXD2 high-power 6-axis locomotive

The maximum operation speed: 120km/h
Power: 10000kW
High-power AC Traction Drive freight locomotives in China

**HXD3 high-power 6-axis locomotive**

- The maximum operation speed: **120km/h**
- Power: **7200kW**
The Characteristics of AC Drive Compared with DC Drive

- **Advantages:**
  1. Better traction performance: better speed adjustment features, larger starting torque;
  2. High power factor and lower harmonics pollutions;
  3. Larger output power, smaller size and weight of AC motor;
  4. Better dynamic performance and higher adhesion availability.

- **Disadvantages:**
  1. More complicated drive system structure;
  2. More sophisticated control system.
There are four technologies for Traction system.
The Energy Flow of Traction Drive System

- Power Grid
- Pantograph
- Transformer
- Converter
- Motor
- Rail

- High voltage Devices
- Main Breaker
- Transformer
- Rectifier controller
- Inverter-motor controller
- Vehicle controller

- Rectifier
- DC-link
- Inverter
- Traction Drive
- Motor
- Gear box
- Wheels
The Topology of AC Traction System Units for CRH2 EMU

Electric Railway Traction AC Drive Systems

25kV 50Hz

S1a, S1b, S2a, S2b, S3a, S3b, S4a, S4b, S5a, S5b

P + u1

C1 + u2

n

T1a, T1b, T1c

T2a, T2b, T2c

T3a, T3b, T3c

T4a, T4b, T4c

M

3~

4台

S1, S2, S3, S4, S5, S6, S7, S8, S9, S10

i1

i2

i3

i4
The Topology of AC Traction System Units for CRH3 EMU

25kV 50Hz

Transformer Two AC-DC Converters DC-Link DC-AC Inverter Traction Motor

$U_{ab1}$ $i_{N1}$ $i_{ab2}$ $i_{N2}$ $u_{ab1}$ $u_{ab2}$ $i_2$ $i_1$ $L_2$ $C_2$ $C_d$ $U_d$ $M$ 3~
The Topology of AC Traction System Units for CRH1 EMU

Electric Railway Traction AC Drive Systems

Diagram:
- 23kV 50Hz input
- Transformer (T1a, T1b, T1c)
- Filters (L1, L2)
- Capacitor (C1, C2)
- Inverter (T2a, T2b, T2c)
- Motor (M, 3~)

Diagram shows the topology of the AC traction system units for CRH1 EMU, including the input voltage, transformer, inverter, and motor connections.
The Topology of AC Traction System Units for CRH5 EMU

Electric Railway Traction AC Drive Systems
The Key Technologies of AC Traction Drives

Electric Railway Traction AC Drive Systems

Traction Inverter-Motor Drive

- 1. Tractive characteristics curve, capacity, parameters calculation and design;
- 2. Field-oriented control (FOC) of traction motor;
- 3. Direct torque control (DTC) of traction motor;
- 4. PWM schemes (asynchronous modulation, synchronous modulation and hybrid modulation) for traction inverters;
- 5. Flux observer method for FOC and DTC methods;
- 6. DC-link capacitors voltage balancing schemes for three-level traction inverters
1. Transformerless Control Technique

CRH2 Transformer

Transformerless AC-DC-AC Traction Drive system
The Development Tendency of AC Traction Drives and Control Systems in the Future

2. Speed Sensorless Control Technology

Advantages:
1. Improving the reliability of traction drive system;
2. Reducing the size of traction motor (20%~30%);
3. Saving Manufacturing cost and maintenance cost;

In 1998, Simens “Combino” streetcar

Guangzhou Metro line 3 in China
2. PMSM Gearless Direct Drive Technology

R117 Traction Permanent Magnet Synchronous Motor (PMSM) in Japan

PMSM Gearless Drive system, Simens

Gear drive system
1. Introduction to AC Electric Traction Drives system;
2. The Fundamental of Electric Traction Drives Design;
3. The Fundamental of Variable Voltage Variable Frequency (VVVF) for Induction Motor;
4. The Operating Principle and Control Design of Four Quadrant PWM Rectifiers;
5. The Operating Principle and Modulation Scheme of Three-phase PWM Inverters;
6. Field Oriented Control of Induction Traction Motor;
7. Direct Torque Control of Induction Traction Motor.
1. Introduction to AC Electric Traction Drives System

(1) History and Development of AC Traction Drive System;

(2) The Structure Configurations of AC Traction Drive System;

(3) The Characteristics of AC Traction Drive System Compared with DC Traction Drive;

(4) The Key Technologies of AC Traction Drives;

(5) The Development Tendency of AC Traction Drives and Control Systems in Future;
2. The Fundamental of Electric Traction Drives Design

(1) Traction characteristic Design of Electric Traction Drives;
(2) Capability Calculation and Parameters Design of Traction Converter and Induction Motor;
3. The Fundamental of Variable Voltage Variable Frequency (VVVF) for Induction Motor

(1) The Equivalent Circuit of Induction Motor;
(2) Electromagnetic Torque Characteristics;
(3) Constant Flux Control Design;
(4) Constant Power Control Design with Weakening Flux;
(5) Scalar Control of AC Induction Motor;
4. The Operating Principle and Control Design of Four Quadrant PWM Rectifiers

(1) The Operating Principle Analysis of Two-level Single-phase Four Quadrant PWM Inverter;
(2) The Operating Principle Analysis of Three-level Single-phase Four Quadrant PWM Inverter;
(3) Control Concept and Objects of Single-phase Four Quadrant PWM Inverter;
(4) Dual-loop Controller Design of Single-phase Four Quadrant PWM Inverter;
(5) Neutral-point Voltage Balance Scheme of Three-level Single-phase PWM Inverter;
5. The Operating Principle and Modulation Scheme of Three-phase PWM Inverters;

(1) The Operating Principle Analysis of Two-level Three-phase PWM Inverter;
(2) The Operating Principle Analysis of Three-level Three-phase PWM Inverter;
(3) Design Rules of Sinusoidal Pulse Width Modulation;
(4) Concept and Principle of Space Vector Pulse Width Modulation;
(5) Design Rules of Space Vector Pulse Width Modulation Scheme;
6. Field Oriented Control of Induction Traction Motor

(1) The Basic Concepts and Principle of Field Oriented Control;
(2) Rotor Flux Observer Design of Induction Traction Motor;
(3) Design of Rotor Field Oriented Controller;
(4) Design of Stator Field Oriented Controller;
(5) Parameters Design of Field Oriented Controller.
7. Direct Torque Control of Induction Traction Motor

(1) The Basic Concepts and Principle of Direct Torque Control;
(2) Design of Direct Torque Controller;
(3) Stator Flux Observer Design of Induction Traction Motor.