電動機械 (Electric Machinery) (EE382000)
課程簡介 (Course introduction)

一、 課程說明 (Course Description)

本課程旨在介紹機電能量轉換原理、各式電機之結構、操作原理、運轉特性以及固態控制。另外，亦介紹電力系統之組成、輸配、應用、用電安全、電源品質、備用電源及一些特殊設備之電源系統等。供同學通盤了解電力工程之有關事務 (與電動機械實驗配合進行，欲修電動機械實驗者請修電動機械課程)。

This course introduces the following topics for various electric machines: electro-mechanical energy conversion principle, structures, operation principle, running characteristics, power electronic control, etc. In addition, some basic power engineering concepts are also introduced, such as power system configuration, transmission and distribution, electricity applications, electric safety, power quality, standby power and some special electric power systems. From this course the students can generally understand the basic electric power engineering affairs. The students are suggested to take this course if they want to participate the course of "Electric machinery laboratory" offered in the followed semester.

二、指定用書 (Text Books)

1. 講義 (Lecture notes).
2. P. C. Sen," Principles of Electric Machines and Power Electronics," 3rd Edition, John Wiley & Sons, 2014.

三、教學方式 (Teaching Method)：面授或線上教學 (Oral teaching or on-line teaching)。

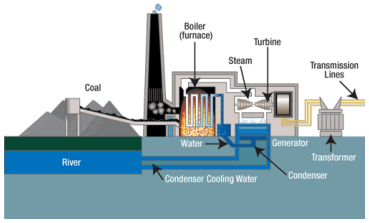
四、教學進度 (Syllabus)：

1. 機電能量轉換及機電整合簡介 (Introduction to electro-mechanical energy conversion principle and mechatronics)。
2. 電力系統概要：發電、輸配電、電力系統暫態、用電安全、備用電源、特殊設備電源系統、電力品質等(Introductory power system: generation, transmission and distribution, electric transients, electric safety, power quality, standby power and some special electric power systems)。
3. 電力電子概要：功率半導體概要、電源供應器概要、馬達驅動器概要等(Introductory power electronics: power semiconductor devices, switching power supplies, motor drives)。
4. 電動機械 (Electric machinery)：
   (1) 磁路分析、永久磁鐵磁路分析 (Magnetic circuit analysis, permanent-magnet magnetic circuit analysis)。
   (2) 變壓器 (Transformers)。
   (3) 步進馬達之結構、驅動及應用 (Stepping motors: Structures, driving control and applications)。
   (4) 直流馬達及發電機 (DC motors and generators)。
   (5) 同步馬達及發電機 (Synchronous motors and generators)。
   (6) 感應馬達及發電機 (Induction motors and generators)。
   (7) 直流無刷馬達及其於週邊設備之應用 (Brushless DC motors and their applications)。
   (8) 開關磁阻式馬達及其他特殊馬達 (Switched-reluctance machines and other special machines)。
   (9) 馬達之 SoC 固態速度控制實作實驗 (步進馬達及直流馬達) (Solid-state stepping motor driving control experiment, solid-state DC motor speed control experiment (optional))。

五、成績考核 (Evaluation)：作業(20%)、期中考(40%)、期末考(40%)

(Exercise 20%, mid-term test 40%, final test 40%)。

電動機械 (Electric Machinery)- Introduction to Electrical Power Engineering



用戶 (Users)

Generator

Transformer (升壓)

Transformer (降壓)

G

Transmission line

Distribution line

電燈 Lighting

M

馬達 Motor

電熱 Heater

Renewable and distributed power sources (Micro-grid system)

Interconnected operation via proper synchronization and management controls (Anti-islanding, LVRT)

M

\+

DCV

\-

電力電子設備: Motor drives, home appliances switching power supplies, computers, etc.

電力工程有關領域：

電力系統：電力之產生、輸配、應用。

電動機械：電磁設備裝置 - 變壓器、發電機、馬達。

電力電子：以功率半導體元件組裝之裝置及系統。

Islanding: (en.wikipedia.org/wiki/Islanding)

Islanding is the condition in which a distributed generator (DG) continues to power a location even though electrical grid power is no longer present. Islanding can be dangerous to utility workers, who may not realize that a circuit is still powered, and it may prevent automatic re-connection of devices. Additionally, without strict frequency control the balance between load and generation in the islanded circuit is going to be violated, leading to abnormal frequencies and voltages. For those reasons, distributed generators must detect islanding and immediately disconnect from the circuit; this is referred to as anti-islanding.

A common example of islanding is a distribution feeder that has solar panels attached to it. In the case of a power outage, the solar panels will continue to deliver power as long as irradiance is sufficient. In this case, the circuit detached by the outage becomes an "island". For this reason, solar inverters that are designed to supply power to the grid are generally required to have some sort of automatic anti-islanding circuitry.

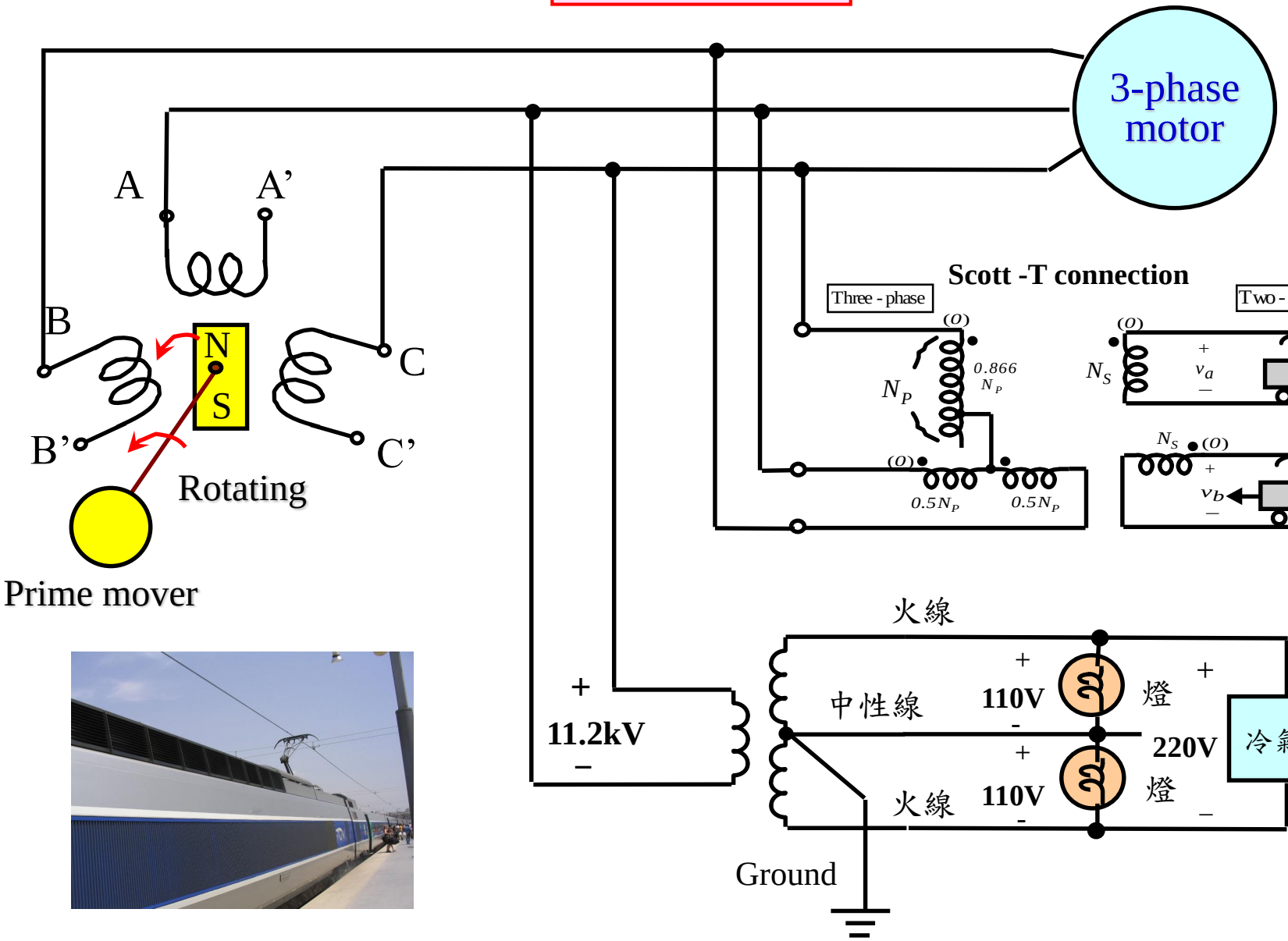
Low voltage ride through (LVRT) (en.wikipedia.org/wiki/Low_voltage_ride_through)

In electrical power engineering, **fault ride through** (**FRT**), sometimes **under-voltage ride through** (**UVRT**), or **low voltage ride through** (**LVRT**), is the capability of electric generators to stay connected in short periods of lower electric network voltage (cf. voltage dip). It is needed at distribution level (wind parks, PV systems, distributed cogeneration, etc.) to prevent a short circuit at HV or EHV level from causing a widespread loss of generation. Similar requirements for critical loads such as computer systems and industrial processes are often handled through the use of an uninterruptible power supply (UPS) or capacitor bank to supply make-up power during these events.

Generation
發電

Transmission and distribution
輸配電

Applications
應用



電動機械課程概要
(Electric Machinery course outline)

■ 課程目的

電動機械 (Electric Machinery) 主要介紹藉電磁作用做能量轉換之裝置，含運動型 (線型及旋轉型) 電機、靜止型電機 (變壓器)。

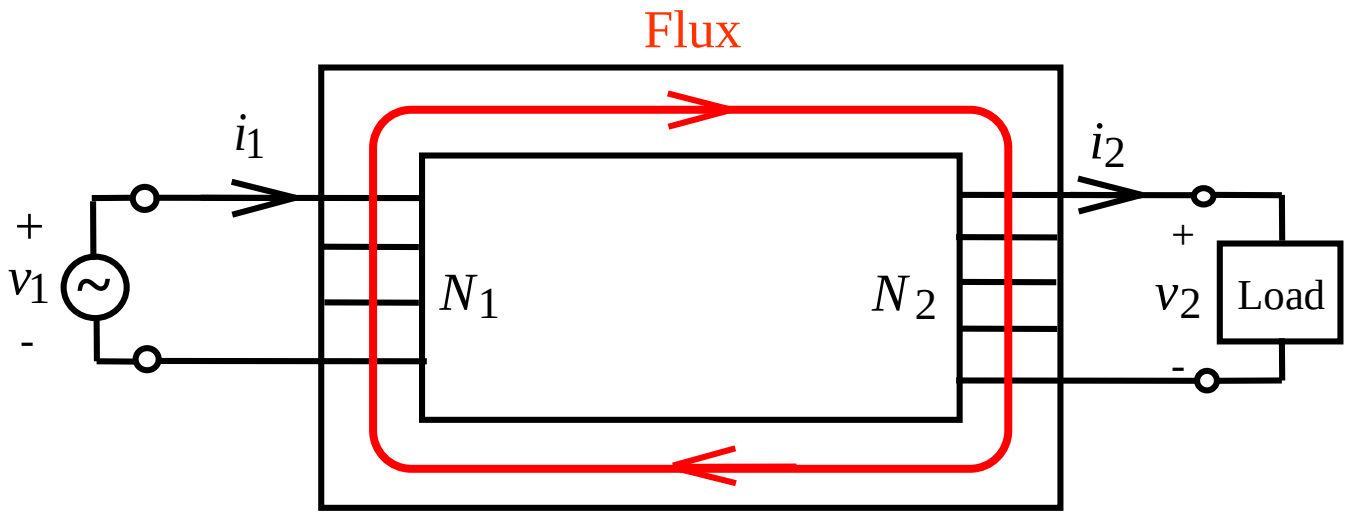
(1) 運動 (線型及旋轉型) 電機：

發電機 (Generator)：　電能 ← *磁能* ← 機械能

電動機(馬達)(Motor)：電能 → *磁能* → 機械能

(2) 靜止電機：

變壓器(Transformer)： 電能 → 磁能 → 電能



變壓器之主要功能：

- ☒ 變壓或變流：$N_1 / N_2 = v_1 / v_2 = i_2 / i_1$ 。
- ☒ 阻抗轉換 (Impedance transformation)。
- ☒ 隔離 (Isolation)。

Electric machine applications

1. Static machines:

(1) Inductors: Power passive filters; Signal filters; Energy storage component; Super-conducting energy storage system; Lifting systems.

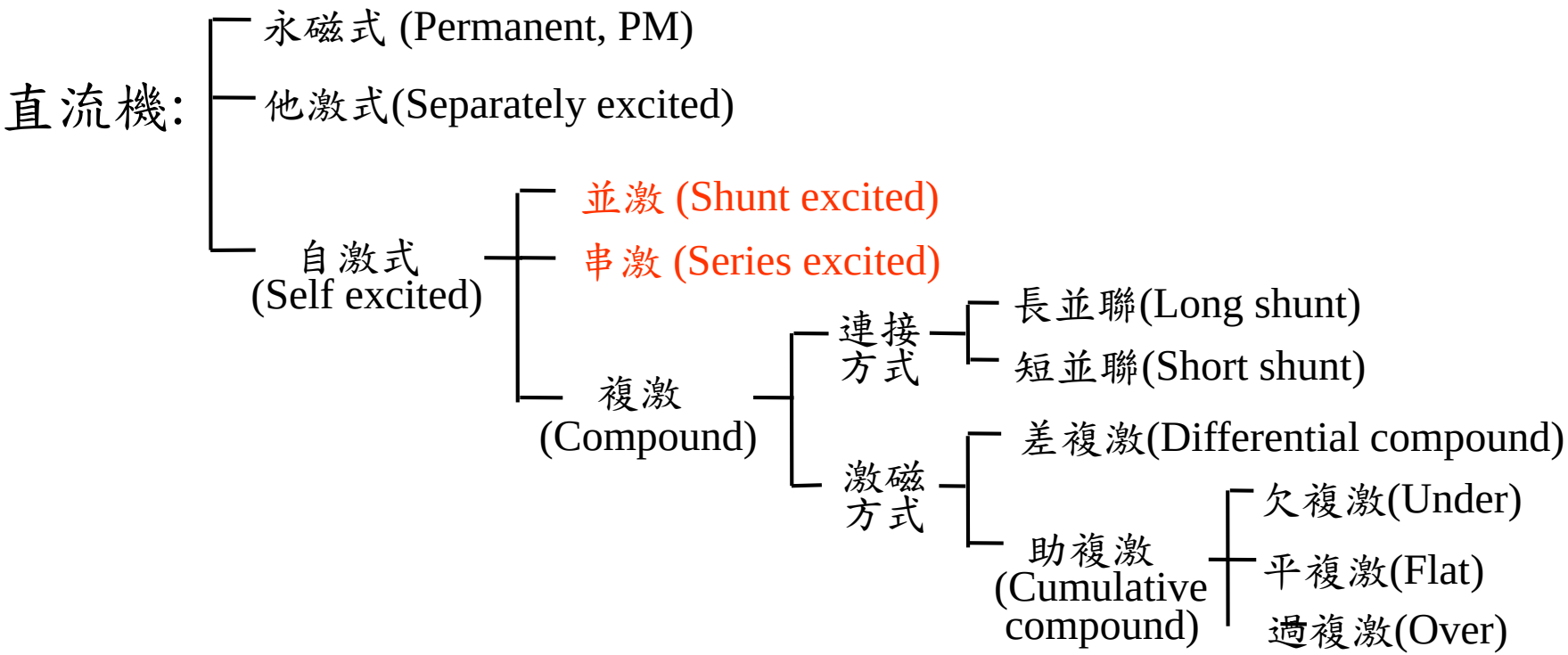
(2) Transformers: Voltage/current transformations; Impedance transfer; Galvanic isolation.

2. Motional machines (Rotary/linear):

(1) Types: (a) DC machines. (b) AC machines: single-phase/ three-phase; Synchronous machines and induction machines. (c) Special machines: Stepping motors; Brushless DC motor (BDCM); Voice coil motor (VCM).

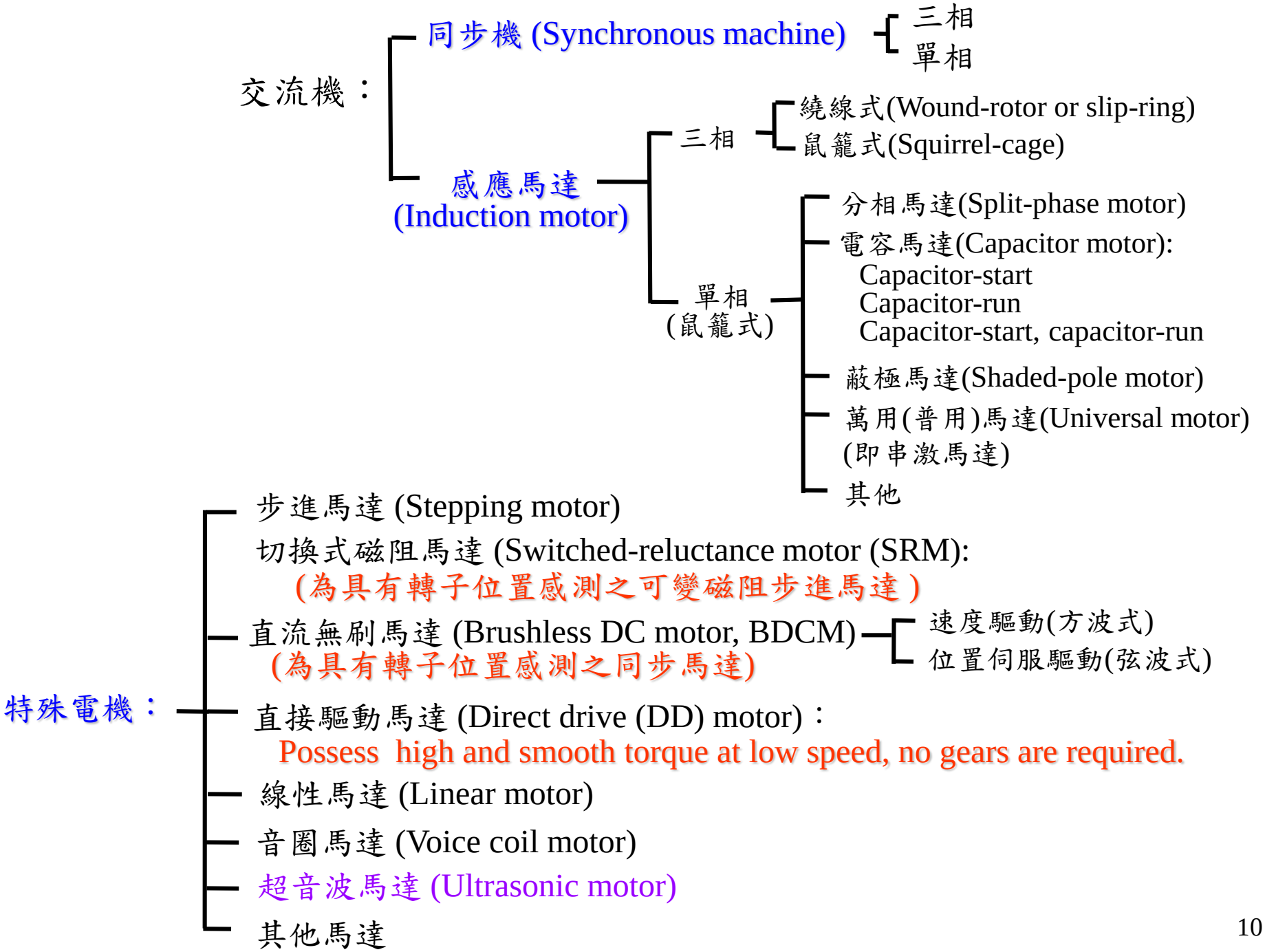
(2) Air-conditioners; home appliances; Cooling fans; Pumps; Blowers; Elevators/Escalators/Moving sidewalks; Robotics/ Automation equipments; Electric bicycle/Electric scooter/ EV/E-bus; Rail trains; Electric tools; Green generators; Wind generators, Traditional generators; Flywheels; Solenoids/ Relays/Valves/Pistons/Sterling engines. .

旋轉電機（發電機與電動機）



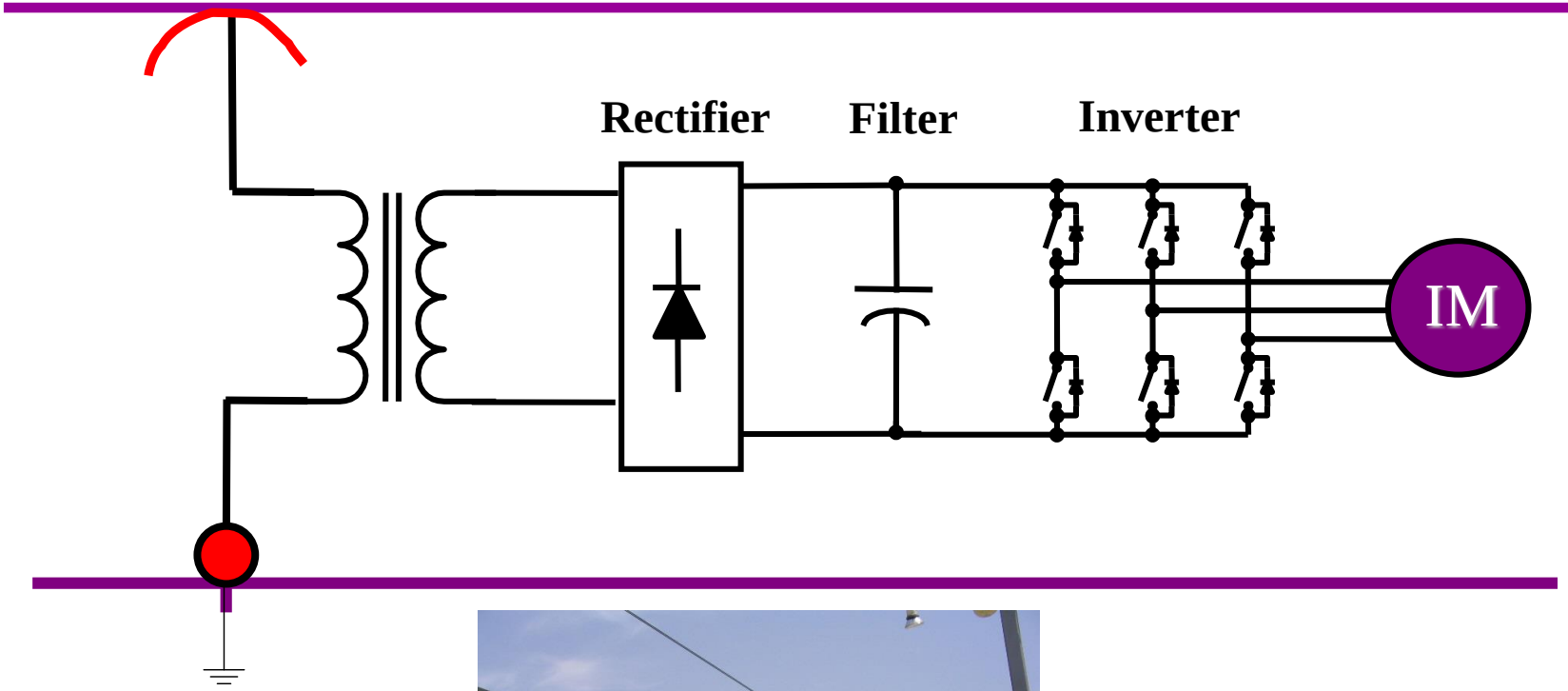
馬達驅動控制性能追求之對象：

- 並激馬達：IM, BDCM (PMSM)
- 串激馬達：SRM

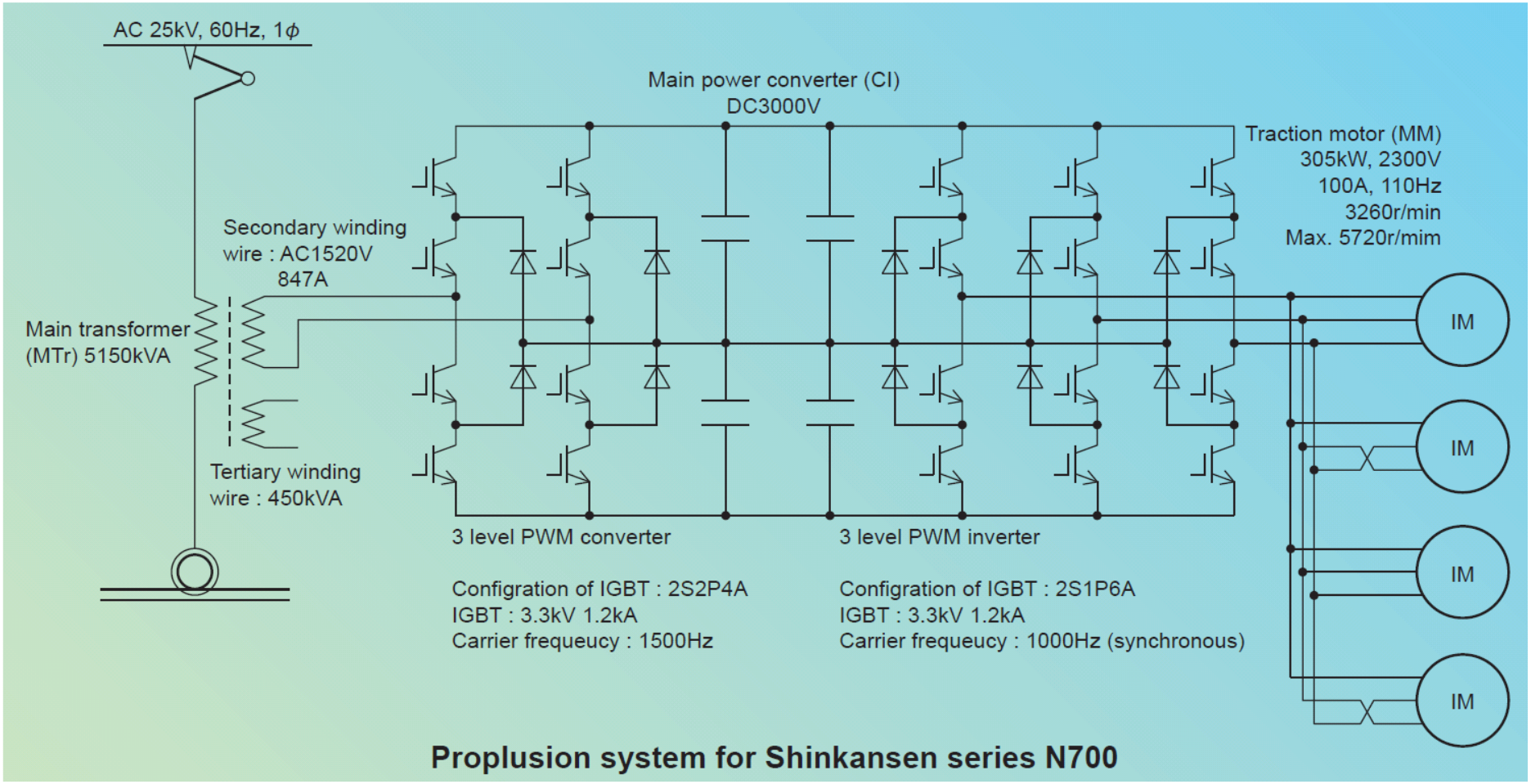

交流機：
同步機 (Synchronous machine)
三相
單相
感應馬達
(Induction motor)
三相
繞線式(Wound-rotor or slip-ring)
鼠籠式(Squirrel-cage)
單相
(鼠籠式)
分相馬達(Split-phase motor)
電容馬達(Capacitor motor):
Capacitor-start
Capacitor-run
Capacitor-start, capacitor-run
蔽極馬達(Shaded-pole motor)
萬用(普用)馬達(Universal motor)
(即串激馬達)
其他
特殊電機：
步進馬達 (Stepping motor)
切換式磁阻馬達 (Switched-reluctance motor (SRM):
(為具有轉子位置感測之可變磁阻步進馬達)
直流無刷馬達 (Brushless DC motor, BDCM)
速度驅動(方波式)
位置伺服驅動(弦波式)
(為具有轉子位置感測之同步馬達)
直接驅動馬達 (Direct drive (DD) motor)：
Possess high and smooth torque at low speed, no gears are required.
線性馬達 (Linear motor)
音圈馬達 (Voice coil motor)
超音波馬達 (Ultrasonic motor)
其他馬達

Rail train powering system (軌道車輛馬達驅動供電系統)

DC source or single-phase AC source

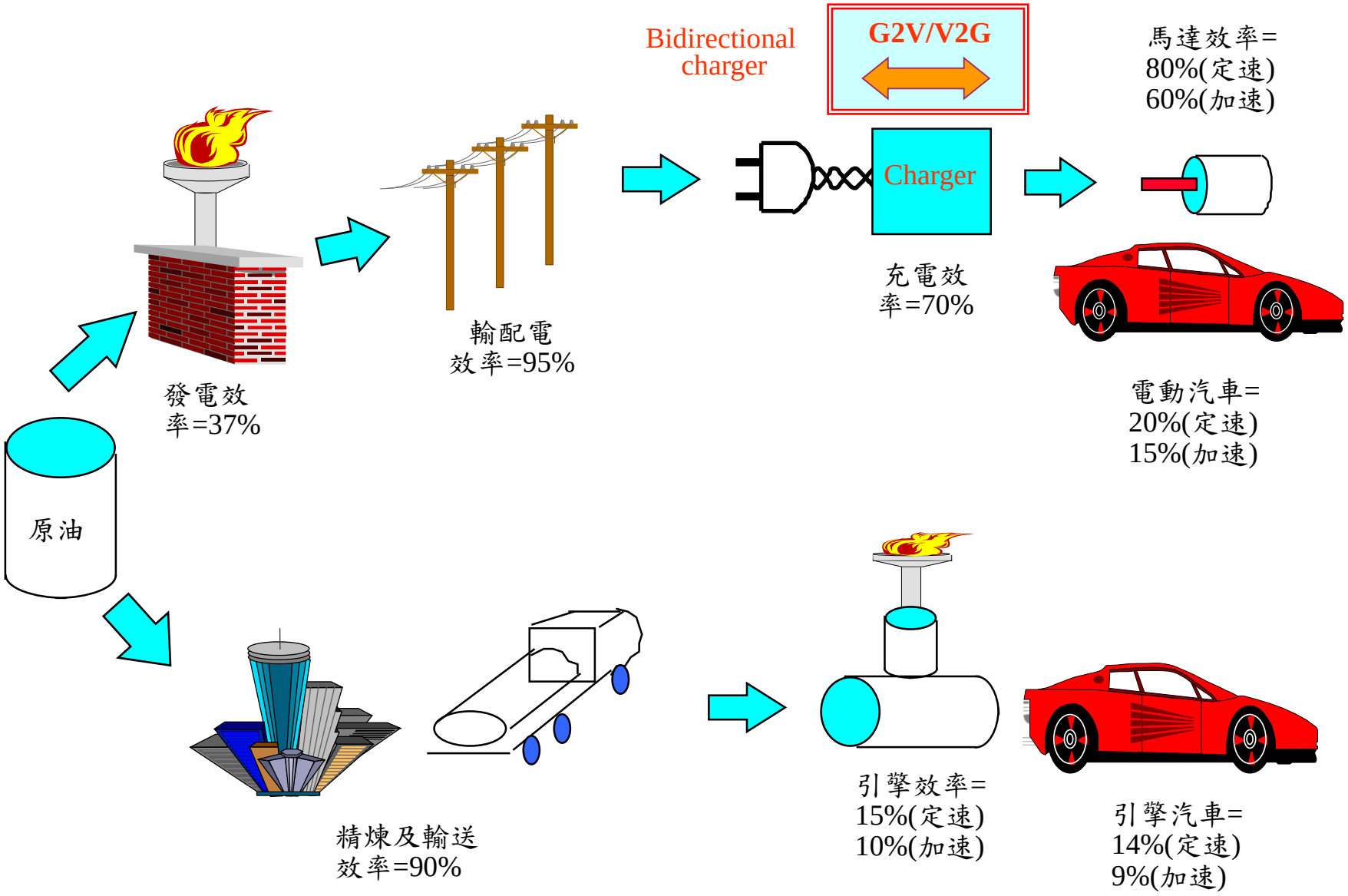


Shinkansen series N700



Proplusion system for Shinkansen series N700

電動汽車與引擎汽車轉換效率比較



Electric Vehicles

Electric vehicles are transportation devices whose propulsion systems (EV inverter) and/or auxiliary functional systems are primarily controlled by conversion of electric power to mechanical power and often include other electrical to electrical conversion components.

On-highway applications

- Electric cars
- Buses
- Fleet and delivery vehicles
- Semi-trailer trucks

Off-highway applications

- Agricultural
- Construction
- Mining
- Material handling
- Marine equipment

Small task oriented vehicles

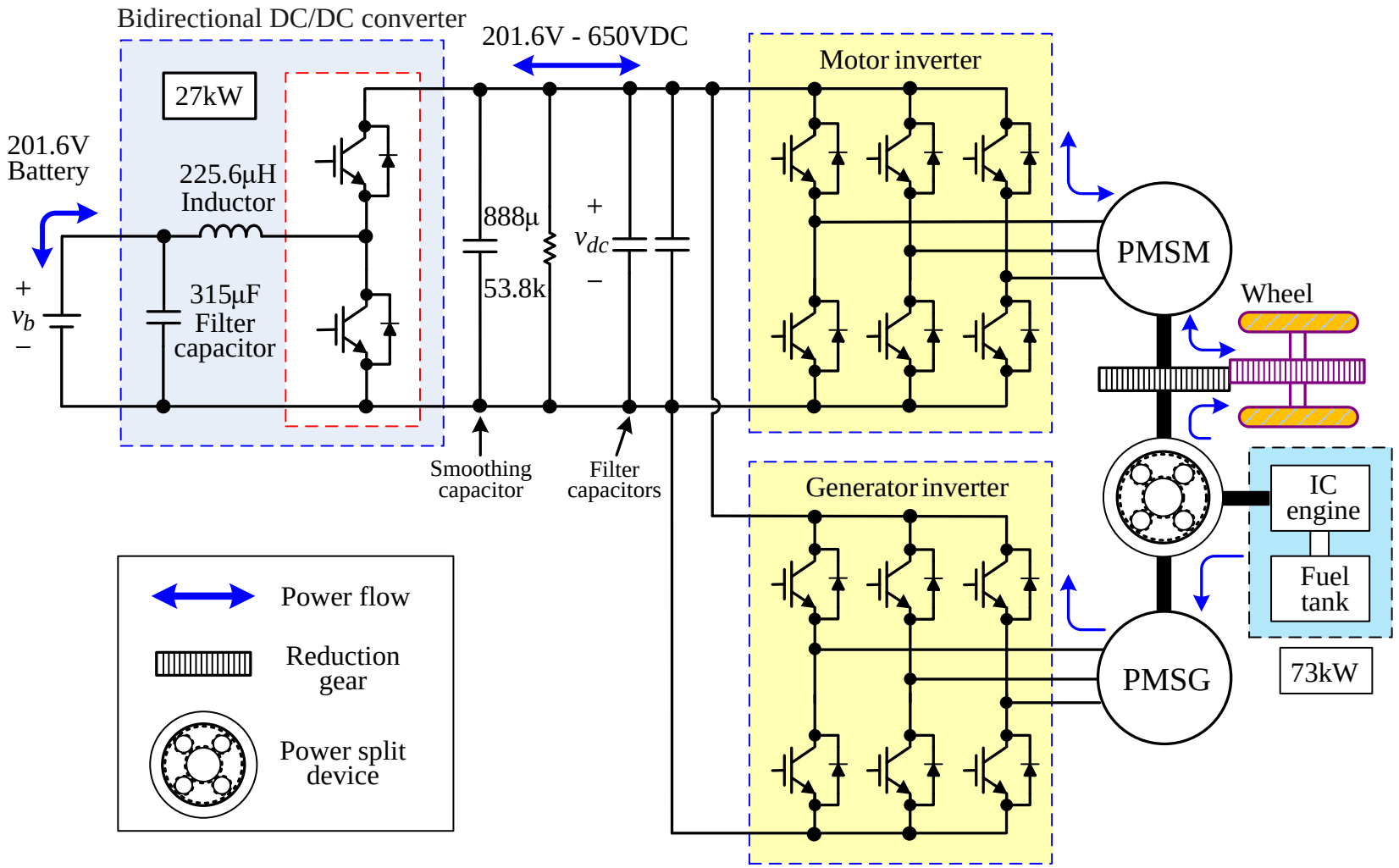
- Carts
- Utility task vehicles
- All-terrain vehicles

Personal transport devices

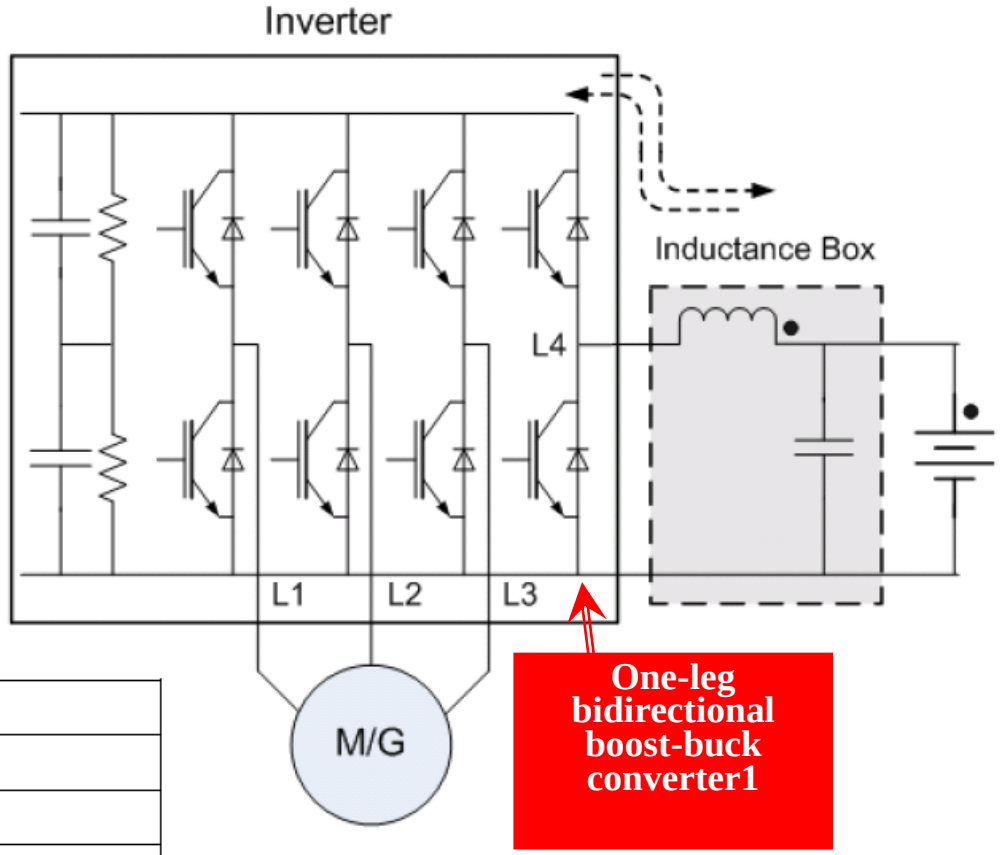
- Electric bicycles (pedelec)
- Electric scooters
- Somatic control (self-balancing)
- Electric wheelchairs
- Electric skateboards

(TI C2000TI C2000™MCUs for EV Powertrain)

Power control unit (PCU)



Siemens ELFA Drive System for Hybrid Electric Vehicles

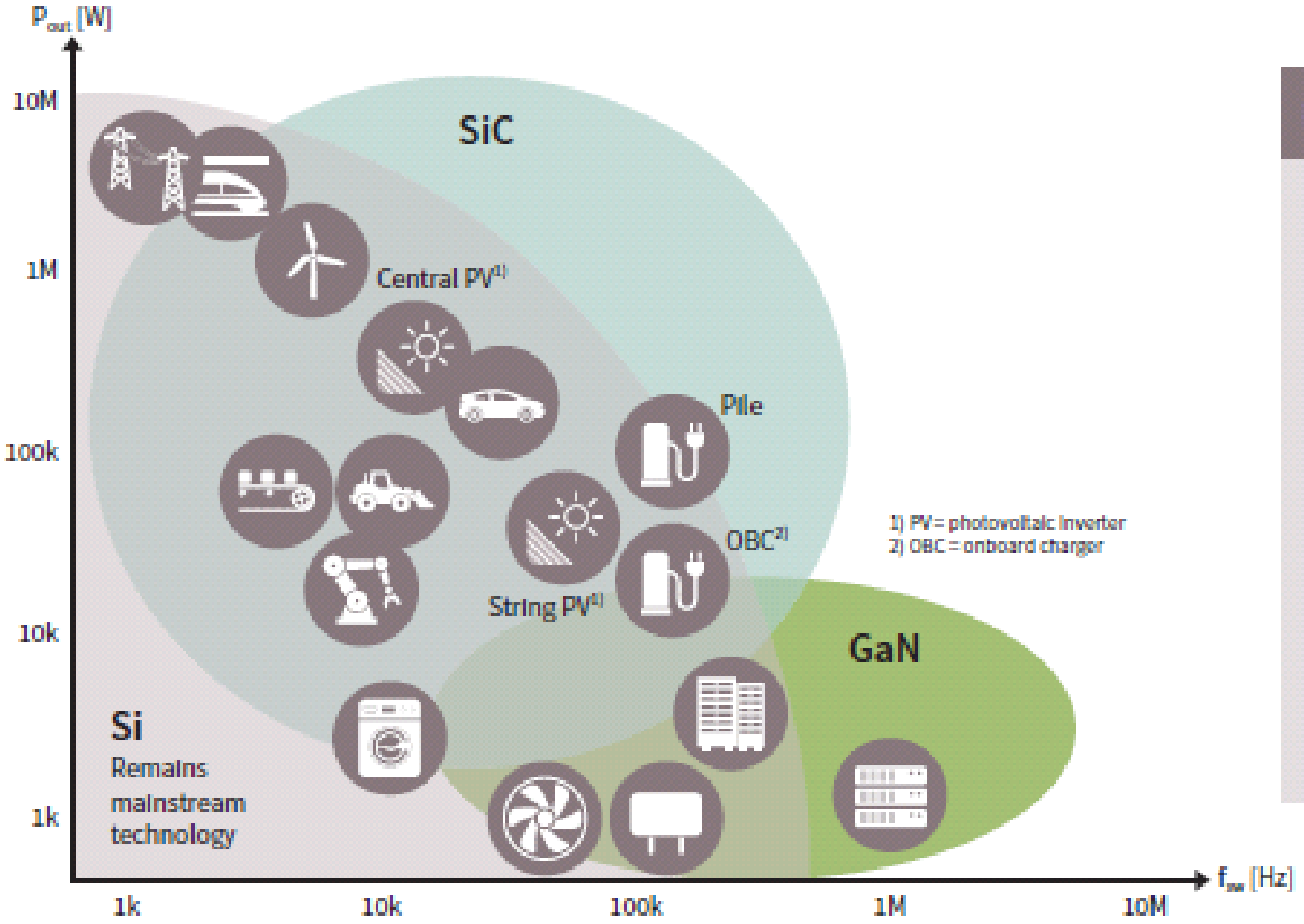


Type	Characteristics
Rated DC Voltage	650 V
Operating DC Voltage	300 – 700 V
Rated Current	250 A
Rated Power @ 650 V	200 kW
Max. Current (10 s)	350 A
Dimension (L x W x H)	411 x 454 x 183 mm
Ambient Temperature	-25^{0}C to 50^{0}C
Max. Switching Frequency	10 kHz
Cooling Media	Water Glycol
Weight	30 kg

Infineon's technology trifecta for power designs of today and tomorrow

CoolMOS™ 7 – CoolSiC™ – CoolGaN™

Infineon has the solution for your applications



Key features

Silicon (Si)

- Mainstream technology

Silicon carbide (SiC)

- Reaching tipping point
- Targeting voltage classes ranging from 600 V to 3.3 kV
- High power

Gallium nitride (GaN)

- Lower cost than SiC
- Targeting voltage classes ranging from 100 V to 600 V
- Medium power

Impact of SiC and RC-IGBT on Drive and Power Supply

Fuji Electric Contributions to xEV

Fuji Electric
Innovating Energy Technology

2 in 1 IPM

Production

Buck boost converter

Company T : HEV

Module

Production

Inverter

IPM

14 in 1 IPM

Production

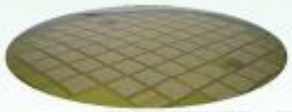
2 Inverters with buck boost converter

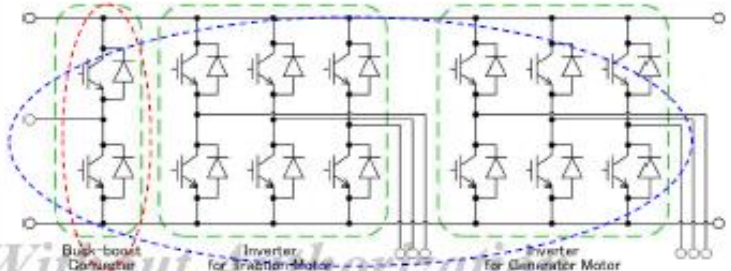
Company H : HEV/PHEV

Power chip for double side cooling system

Production
Power chip by Fuji

Company D : HEV





Application Examples of SiC Devices

Fuji Electric
Innovating Energy Technology

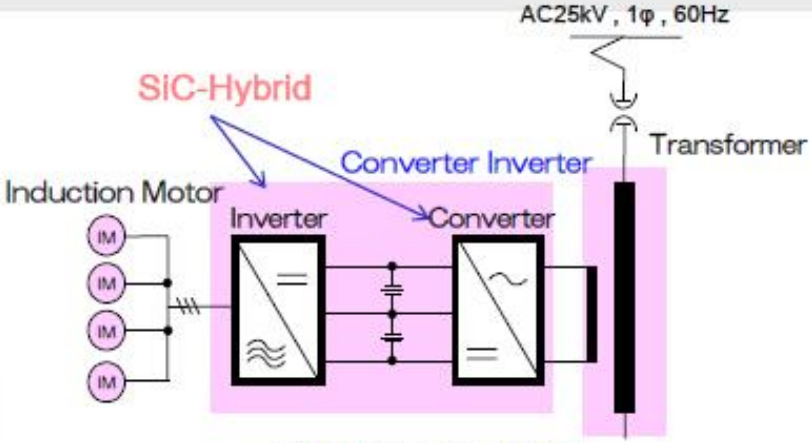
	CY2012	2013	2014	2015	2016	2017	2018	2019
Discrete SiC-SBD			★ Power Supply 650V SiC-SBD		★ EV charger 1200V SiC-SBD			
SiC-SBD Hybrid Module		★ General purpose INV 600V,1200V SiC Hybrid Module		★ Traction propulsion 3300V SiC Hybrid Module	★ Servo, Robot 1200V SiC Hybrid Module	★ UPS 1200V SiC Hybrid Module	★ HEV Racing Car 1200V SiC Hybrid Module	
All-SiC Module		★ PCS 1200V All-SiC Module	★ Mega solar PCS 1200V All-SiC Module			★ IP6x INV 1200V Trench All-SiC Module	☆ Premium INV ☆ APS and Inverter for traction 1200V Trench All-SiC Module	

Next Gen. Shinkansen Use Hy-SiC Module

Fuji Electric
Innovating Energy Technology

- Rectifiers and inverters in N700S propulsion systems utilize SiC-Hybrid modules.
- Trial operation started in April, 2018

N700S Test Train



Driving System for Trains

3.3kV-1.8kA Rated

190×140mm
SiC-Hybrid Module

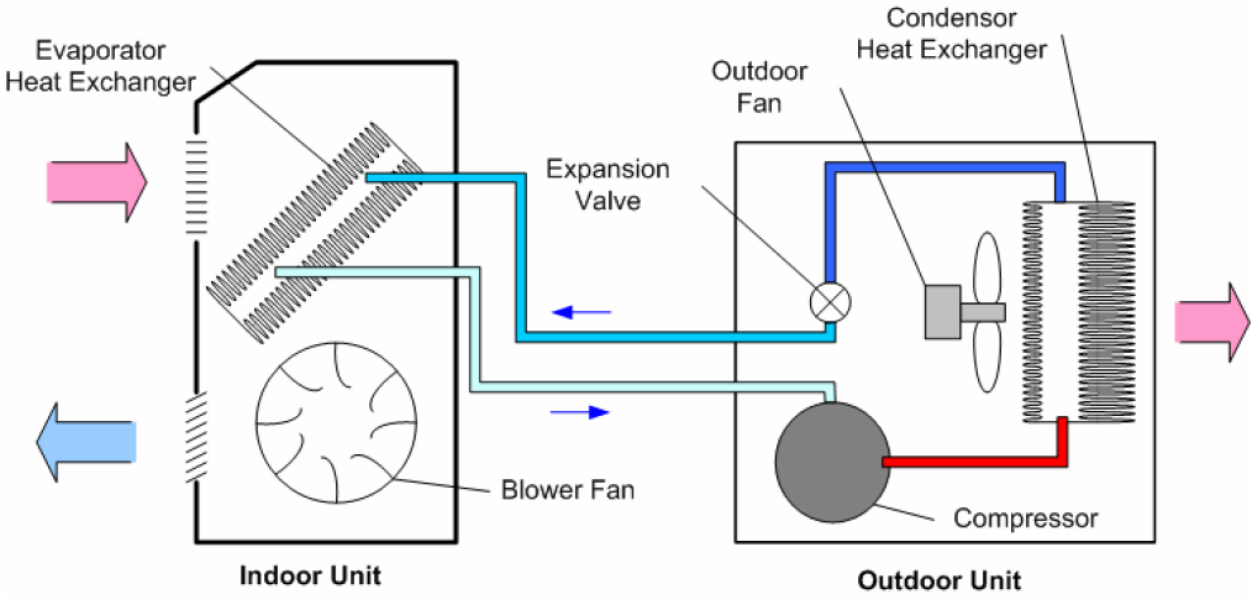
Converter Inverter

Comparison with conventional N700A

Volume : ▲10%

Weight : ▲13%

Home air conditioner trends



Trends:

- Compressor motor: Induction motor >> Permanent-magnet synchronous motor (PMSM) (Specifically Interior PMSM (IPMSM))
- Vector control (brushless control)
- Sensorless control.
- Square-wave type PMSM >> sinewave type PMSM.
- Front-end switch-mode rectifier (SMR)>> provide boostable and well-regulated DC-link voltage with good line drawn power quality.
- Common digital control environment for: Outdoor compressor PMSM, outdoor condenser fan motor, front-end switch-mode rectifier (SMR).
- DSP or ASIC + microcontroller, or FPGA + microcontroller.

www.irf.com/technical-info/whitepaper/mce_digitalpfc_ac.pdf

DCF886

18V 無碳刷衝擊起子機(單速)

- +57%續航力
- 無碳刷省能，耐用馬達
- 專利One Touch快插式夾頭
- 165Nm

★ DCF886P2W 無碳刷衝擊扳手起子機

電壓	18V
電池	XR超鋰電
夾頭尺寸	6.35mm
每分鐘空載轉速	0-2800 RPM
每分鐘衝擊數	0-3200 BPM
最大扭力	165Nm
LED	3顆LED燈,20秒延遲
重量(不含電池)	0.9kg
長度x高度	140x228mm

DCF895

18V無碳刷衝擊起子機(三速)

- 三段扭力調整 (56/100/170牛頓米)
- 單手夾頭
- 電備三顆超亮LED燈，20秒延遲自熄設計，有效提高工作方便性

電壓	18V
電池	XR 超鋰電
扭力	170Nm
轉速調整	3段
每分鐘空載轉速	0 - 2850 / 1900 / 950 RPM
每分鐘衝擊數	0-3300/2400/1300 BPM
重量(不含電池)	0.97kg
長度x高度	132x205mm

DCD790

18V無碳刷電鑽調扭起子機

- 高效無碳刷馬達運轉次數提升57%
- 輕量緊湊設計,可用範圍更廣
- 15段扭力調整
- 20秒延遲LED，防陰影投射角度

電壓	18V
電池	XR超鋰電
功率	360W
夾頭尺寸	1.5-13mm
轉速調整	2段
每分鐘空載轉速	0-600/2000 RPM
最大扭力	60/23Nm
最大鑽孔能力—木材/金屬	38/13mm
重量(不含電池)	1.2kg
LED	有
長度x高度	182 x 227mm

DCD795

18V無碳刷震動電鑽調扭起子機

- 高效無碳刷馬達運轉次數提升57%
- 輕量緊湊設計,可用範圍更廣
- 15段扭力調整
- 20秒延遲LED，防陰影投攝角度

電壓	18V
電池	XR 超鋰電
功率	360W
夾頭尺寸	1.5-13mm
轉速調整	2段
每分鐘空載轉速	0-600/2000 RPM
每分鐘衝擊數	0-10200/34000 BPM
最大扭力	60/23Nm
最大鑽孔能力— 木材/金屬/混凝土	38/13/13mm
重量(不含電池)	1.24kg
LED	20秒延遲
長度x高度	198 x 245mm

DEWALT 得偉

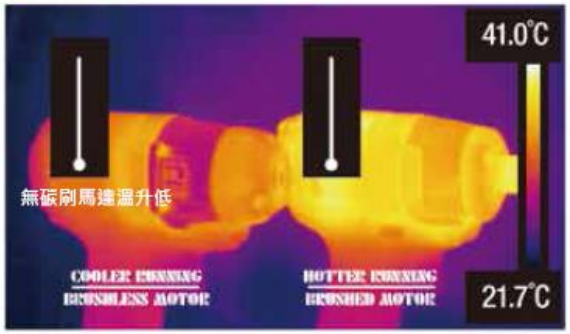
BRUSHLESS MOTOR

GET MORE DONE!™

無碳刷馬達
電子式的控制能量轉換成有效的動能，可以提升工具的使用時間及工作效率

碳刷馬達
機械式碳刷系統，運轉時將產生溫度，能量易被削減並減少機器的使用時間

無碳刷馬達比碳刷馬達多
57% 工作時間



CORDLESS DRILLS 18 V

Einhell Germany AG

QUICK STOP-FUNCTION
enables tools to be changed quickly and easily

2-SPEED METAL GEAR BOX
The 2-speed metal gear box delivers plenty of power in the low speed range for screwdriving work and high speeds for fast drilling

ADDITIONAL HANDLE
Comfortable working and less strain on the joints during operation

METAL DRILL CHUCK WITH LOCK FUNCTION
Safe fixation of the drill bit

Cordless Drill
TE-CD 18 Li Brushless

BRUSHLESS MOTOR
More power and prolonged operation

INTEGRATED LED
Well illuminated work area even in poor lighting conditions

BELT CLIP
The driver can be kept securely on the belt even in difficult working positions

POWER X-CHANGE LITHIUM-ION BATTERY
The rechargeable battery can be used in all the devices from the Power X-Change family

BRUSHLESS*ENERGY* – MORE EFFICIENT WORK.

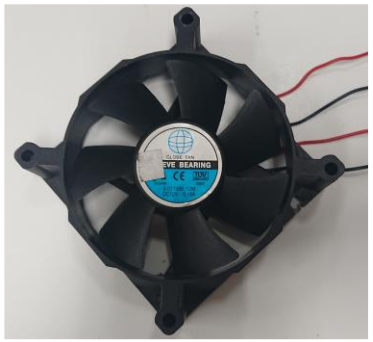
- MORE POWER
- LONGER OPERATING TIMES
- LONGER SERVICE LIFE
- MORE COMPACT DESIGN
- MAINTENANCE-FREE

+25 % more power*

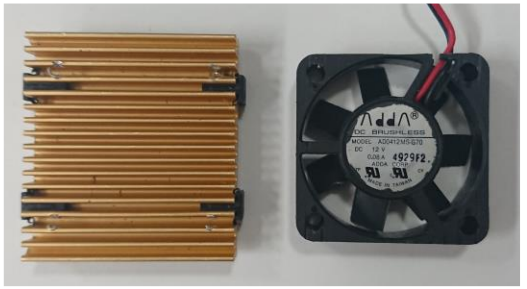
+50 % more operating time*

+100 % more servicelife*

Peripheral cooling fans

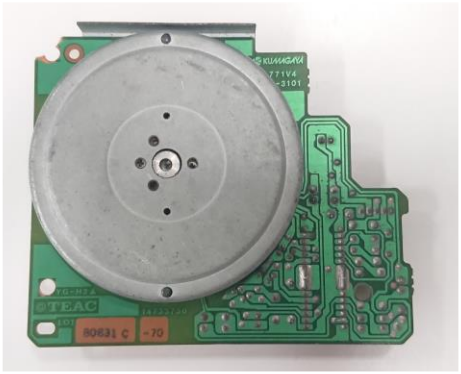


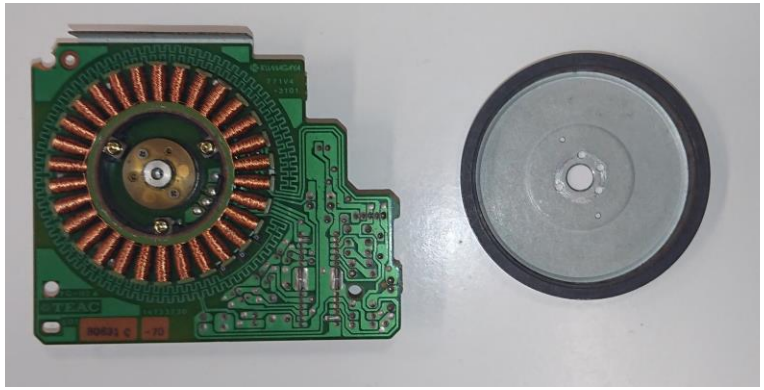
CPU cooling fans



Picture provided by the manufacturer

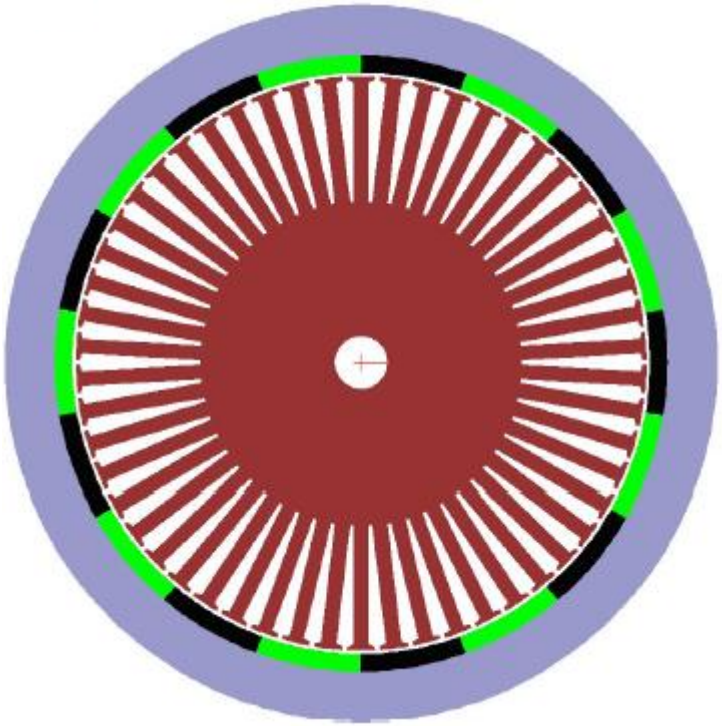
Phonomotors

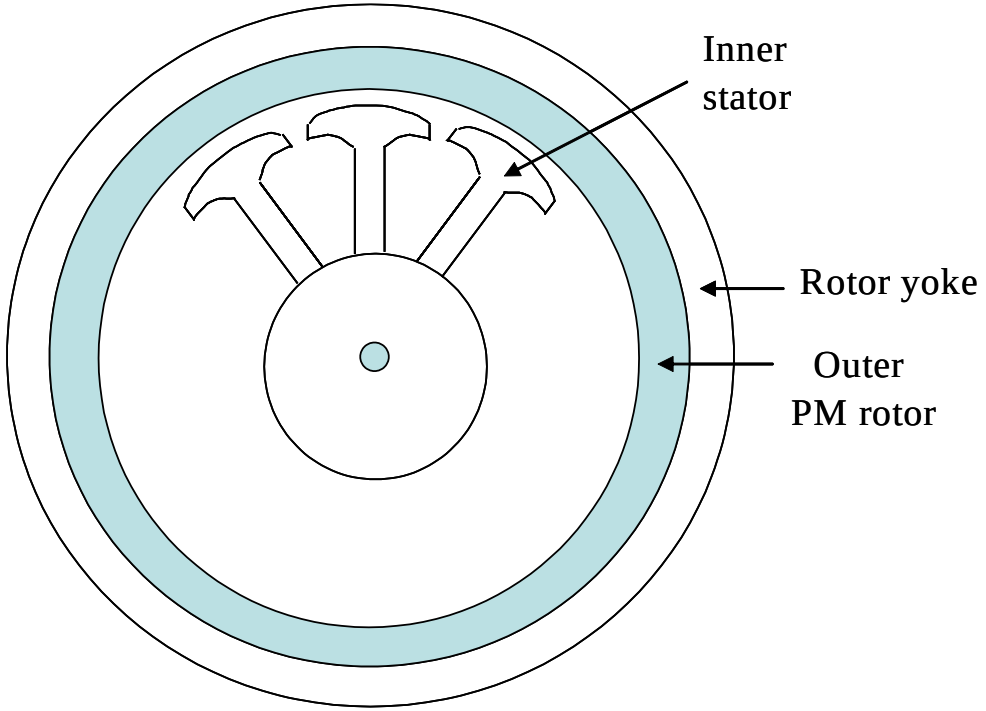




外永磁轉子 (Outer rotor)、內電樞定子馬達

- **外永磁轉子(Outer rotor)、內電樞定子，電樞繞組採集中式(Concentrated)**，具繞組繞製較簡易、銅損較小、可薄型化、散熱較不易、轉矩漣波較大等特點。由於具有較大之氣隙處半徑力臂，有較大之轉矩產生能力，但需有降低轉矩漣波(Ripple torque)及噪音之對策考量。常用於散熱扇、電動車輛、電梯、升降梯、磁碟機主軸驅動等，需馬達為扁平薄型化之場合。



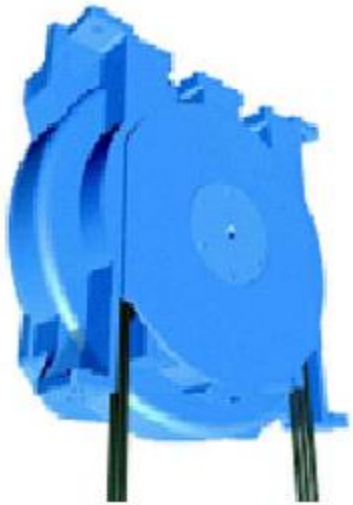


www.osti.gov/energycitations/servlets/purl/885638-y9YVQx/885638.PDF

Elevator traction motors

Key features of motors:

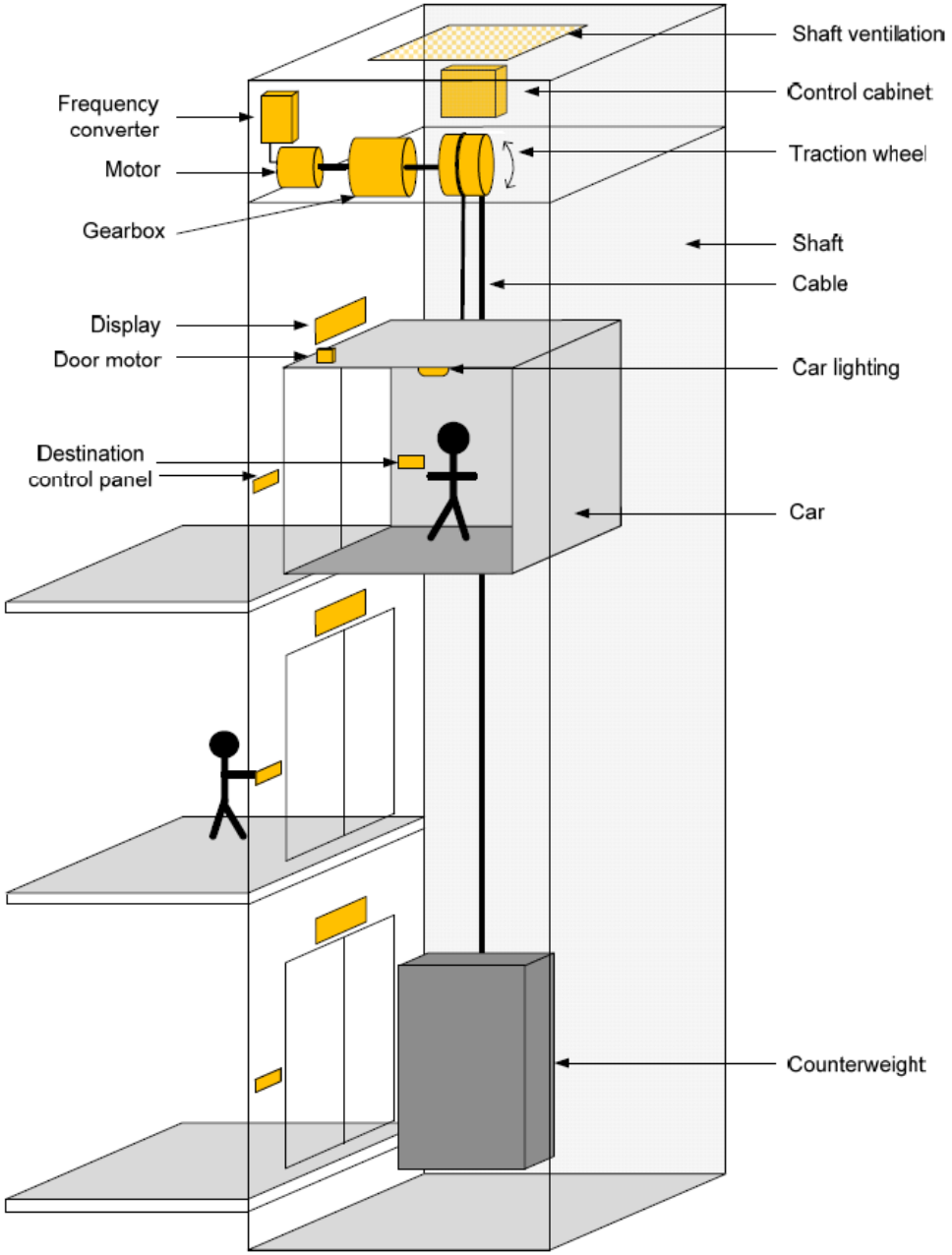
- ☒ Motor drive must have high reliability.
- ☒ Higher torque for accelerating elevator car and smaller ripple torque to yield comfortable ride.
- ☒ Compact and *thin* motor structure for meeting the machine room-less requirement.
- ☒ Motor type: concentrated armature winding PMSM: the used PM should posses high long-term resistance to demagnetization. The temperature coefficient and aging effect should be considered.



3.7kW, 93rpm

Mitsubishi Electric ADVANCE, vol.103, pp. 2-4, 2003.

Typical conventional traction lift (Elevator)



https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/e4_publishable_report_en.pdf

Figure 2-2. Simplified representation of a typical conventional traction lift installation (source: Fraunhofer ISI)

Typical moving walk (Escalator)

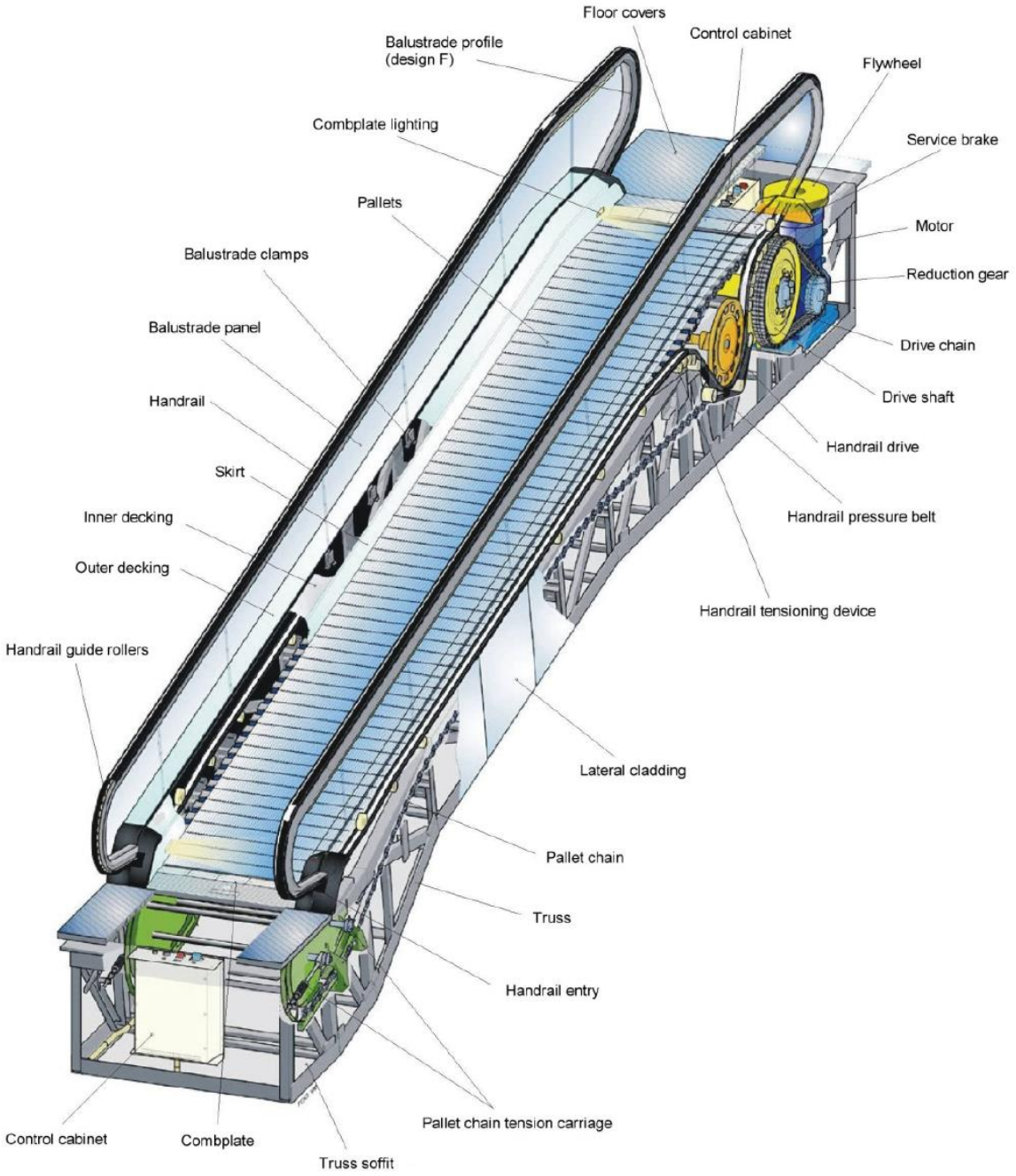
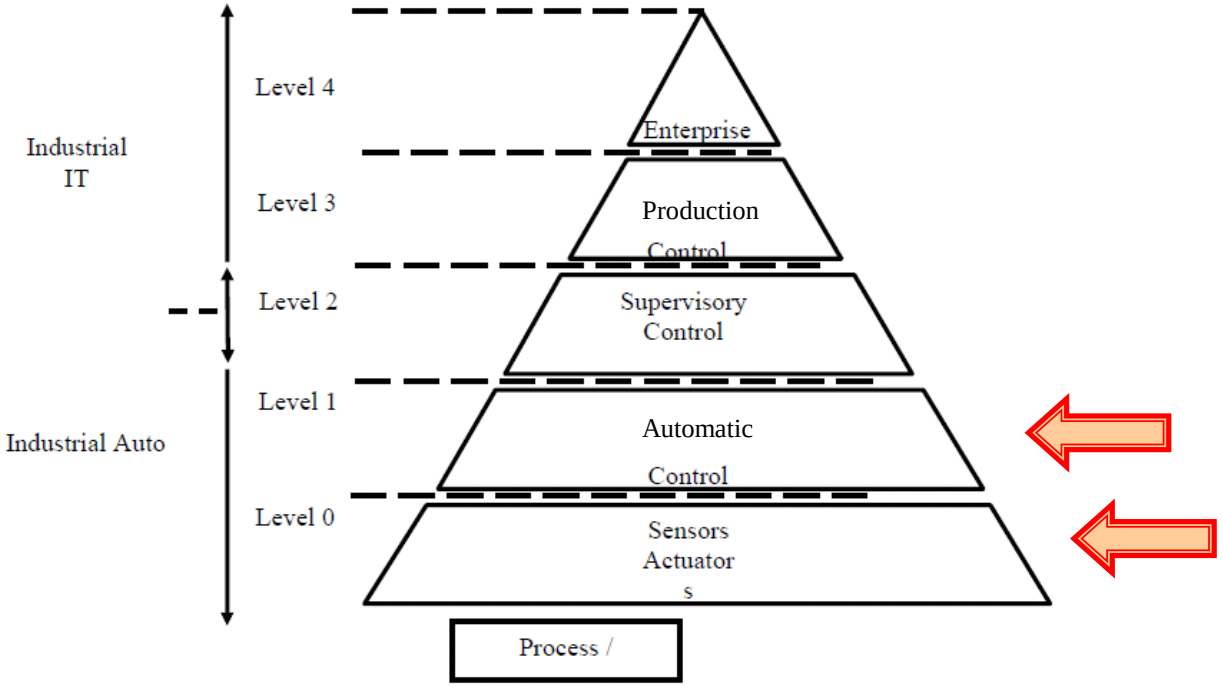


Figure 2-8. Typical moving walk configuration (source: Schindler)

Architecture of Industrial Automation Systems

The Architecture of Elements: The Automation Pyramid Industrial automation systems are very complex having large number of devices with confluence of technologies working in synchronization. In order to know the performance of the system we need to understand the various parts of the system. Industrial automation systems are organized hierarchically as shown in the following figure.



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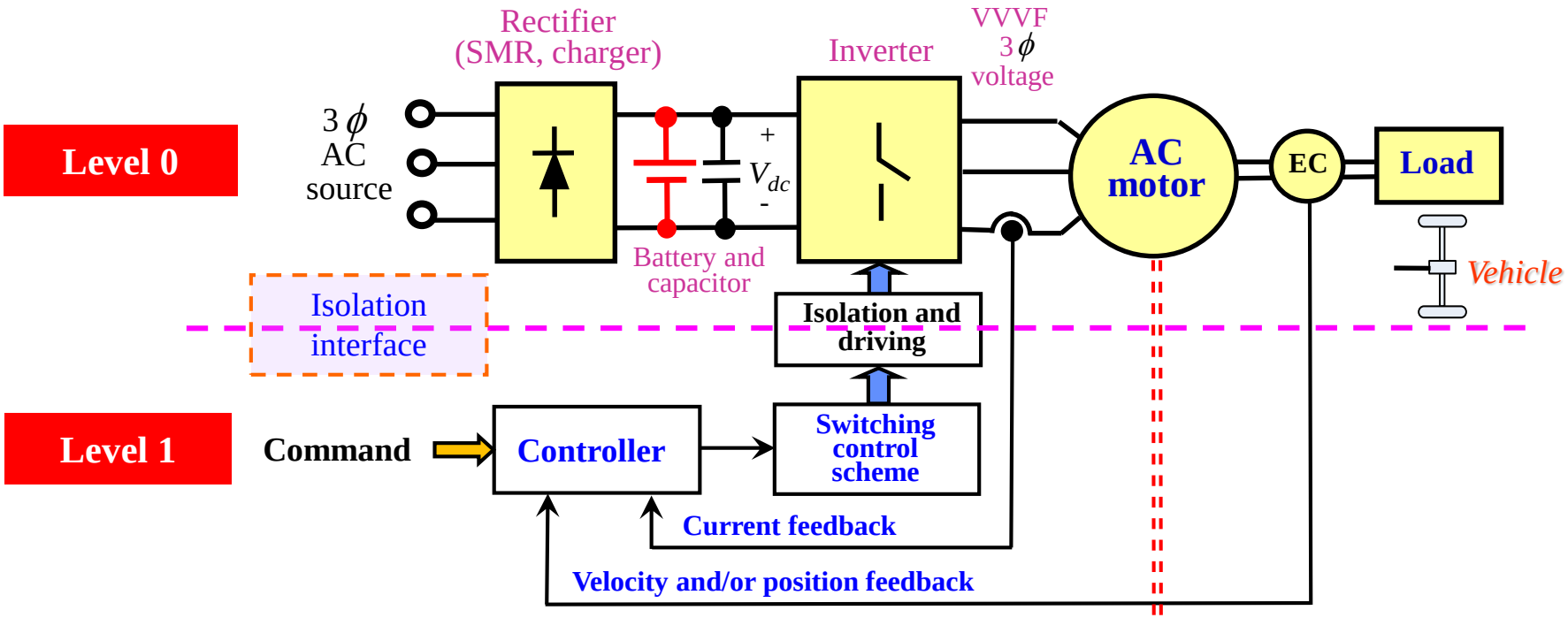
- ***Sensors and Actuators Layer:*** This layer is closest to the processes and machines, used to translate signals so that signals can be derived from processes for analysis and decisions and hence control signals can be applied to the processes. This forms the base layer of the pyramid also called ‘level 0’ layer.
- ***Automatic Control Layer:*** This layer consists of automatic control and monitoring systems, which drive the actuators using the process information given by sensors. This is called as ‘level 1’ layer.

Supervisory Control Layer: This layer drives the automatic control system by setting target/goal to the controller. Supervisory Control looks after the equipment, which may consist of several control loops. This is called as ‘level 2’ layer.

Production Control Layer: This solves the decision problems like production targets, resource allocation, task allocation to machines, maintenance management etc. This is called ‘level 3’ layer.

Enterprise control layer: This deals less technical and more commercial activities like supply, demand, cash flow, product marketing etc. This is called as the ‘level 4’ layer.

Motor drive research fields: Level 0 + Level 1



- **DCM and stepping motors: Education courses and experiments.**
- **Research:**
  - **Synchronous motors: (1) PMSM: Wind generator, prime-mover emulator, EV drive, cooling fan, air-conditioners, etc. (2) SynRM: EV drive, wind generator, flywheel drive, industrial drives, etc.**
  - **SRM: EV drive, wind generator, cooling fan, flywheel drive, industrial drives, etc.**
  - **IM: Wind turbine emulator and EV motor drives.**

Traditional aircraft power system

- In a traditional airplane, the jet engine is designed to produce thrust and to power the pneumatic, hydraulic, and electrical systems (Figure 4).

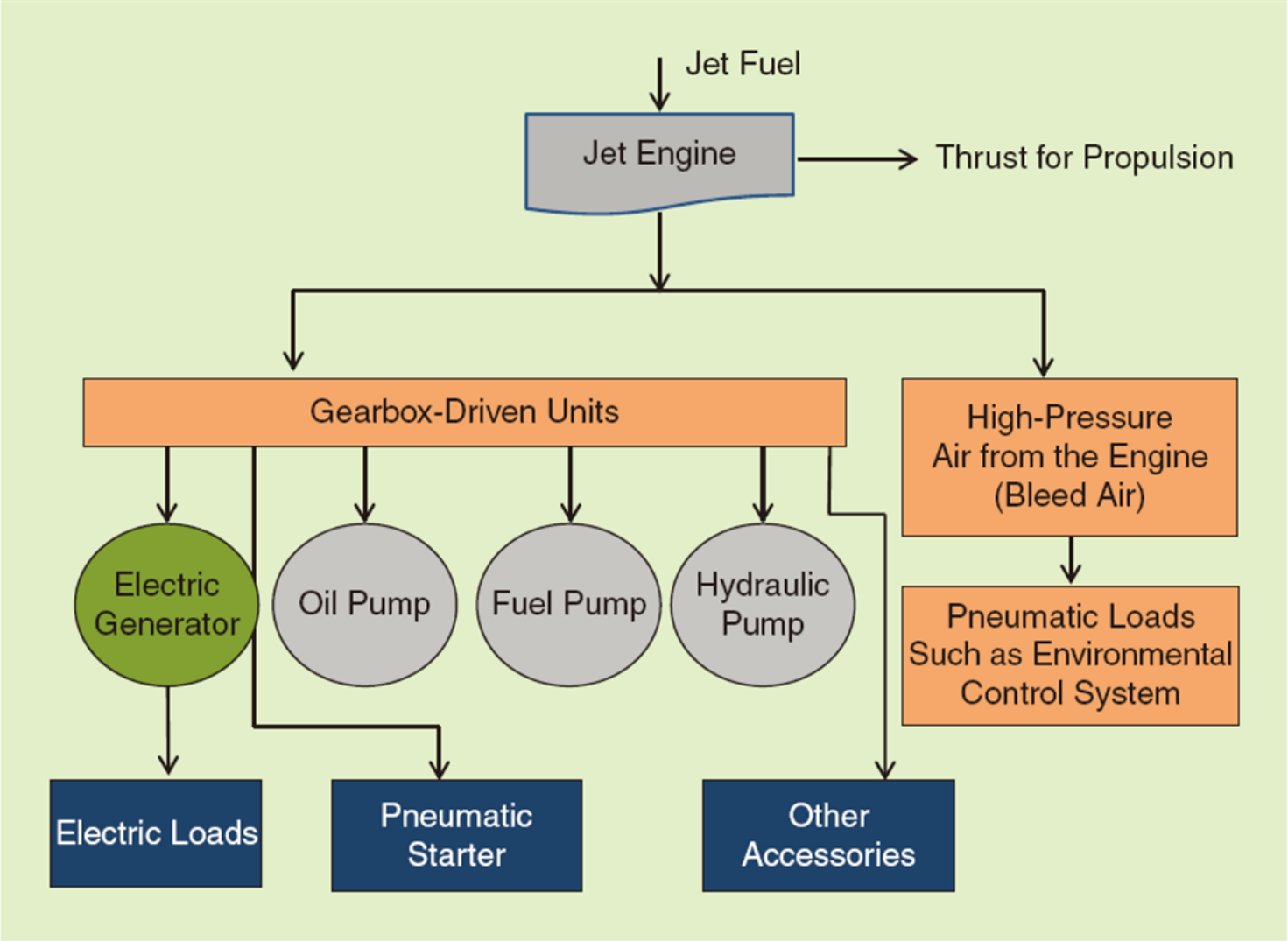
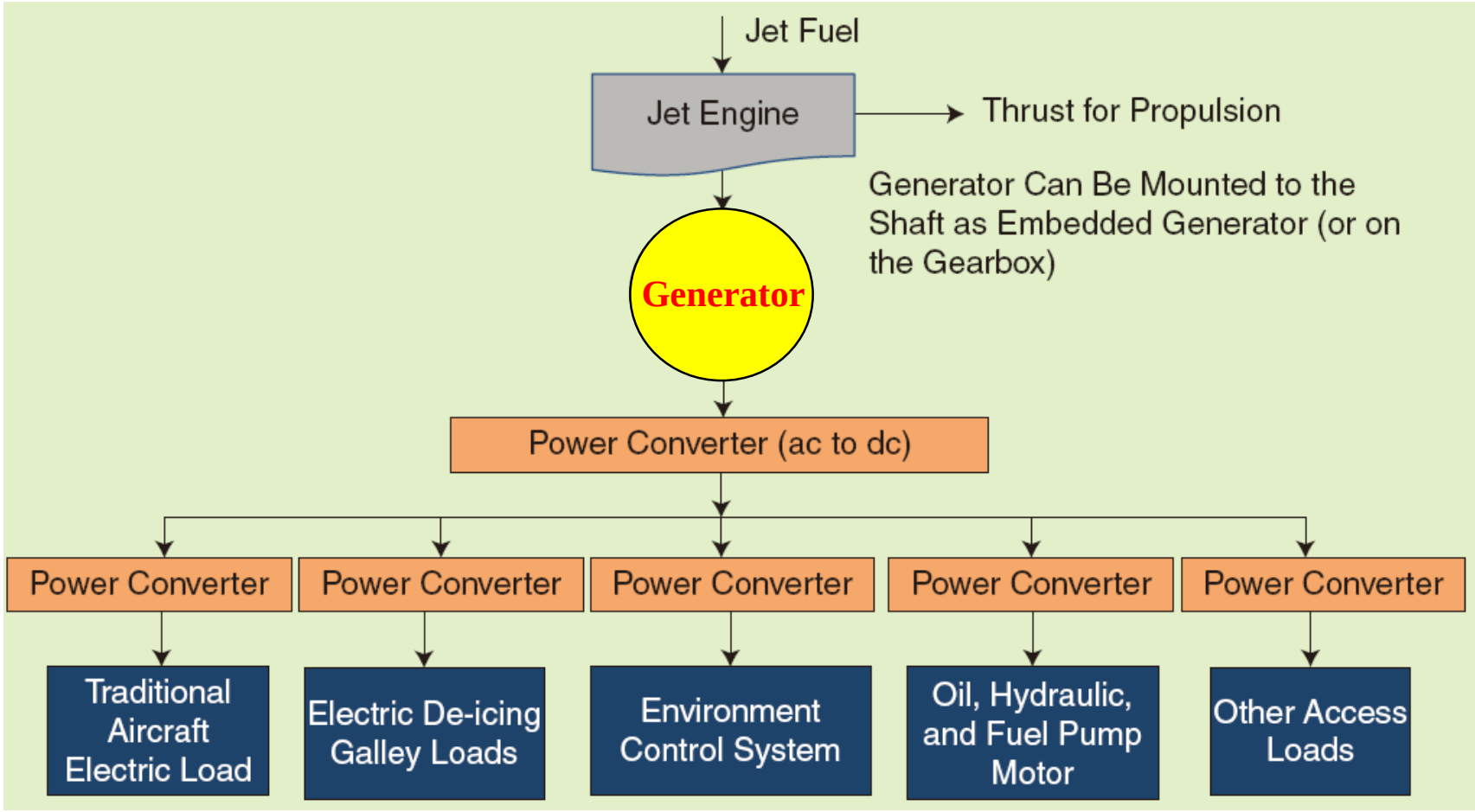


Figure 4. A traditional aircraft system.

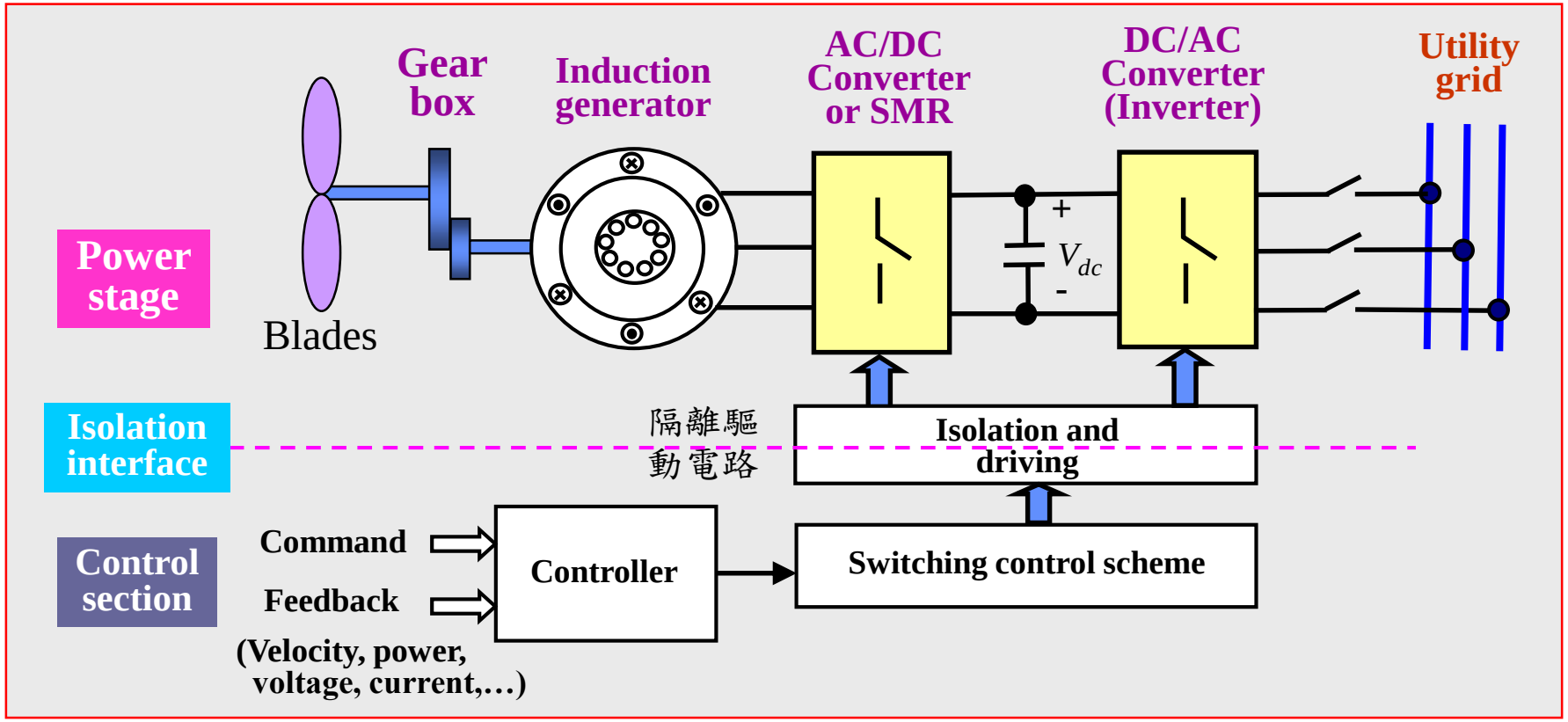
More electric aircraft (MEA) power system

- In an MEA system, the jet engine is optimized to produce the thrust and electric power. The electric machine is used for starting the engine and generating electric power. Most of the loads are electrical, including the de-icing and environmental control systems. The fuel, hydraulic, and oil pumps are all driven by the electric motors.



風力發電系統(Wind generator system)簡介

- 為一含*風渦輪機、機械、電動機械、電力系統、電力電子轉換器、控制器、感測與轉換*等之整合系統，唯有各組成子系統本身之適當設計、系統組件間之妥善搭配、適當之總體操作及管理控制，始可得優良之運轉性能。



- Requirements: Reliable (particularly for offshore WG), higher efficiency, smaller volume and low weight, low cost, miniaturization, low vibration and acoustic noise, etc.

Incorporated operation of EV to grid, microgrid and BESS

Interconnected operations of EV to grid, microgrid and BESS