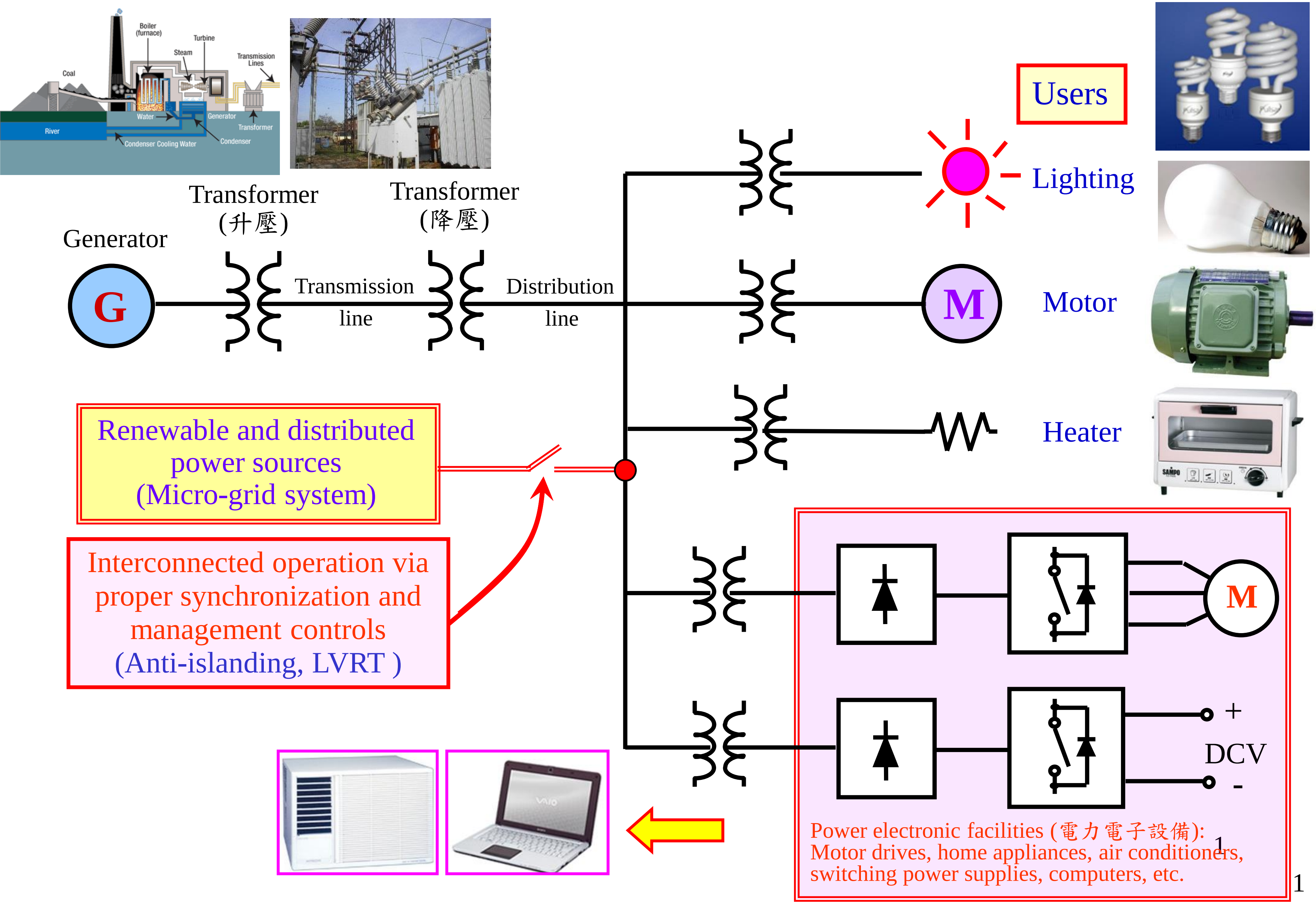
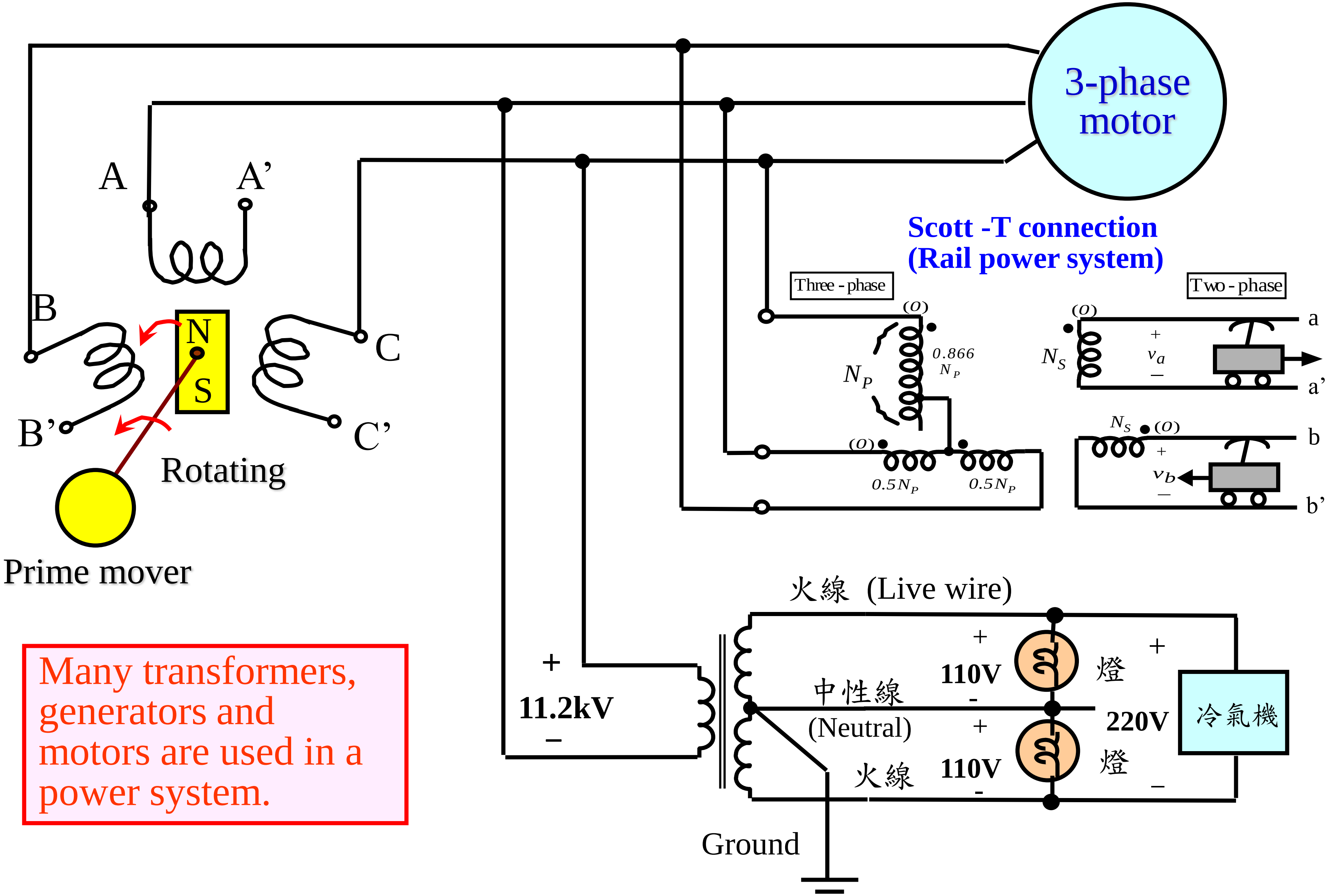
Configuration of power system



Generation → Transmission and distribution → Applications



Many transformers, generators and motors are used in a power system.

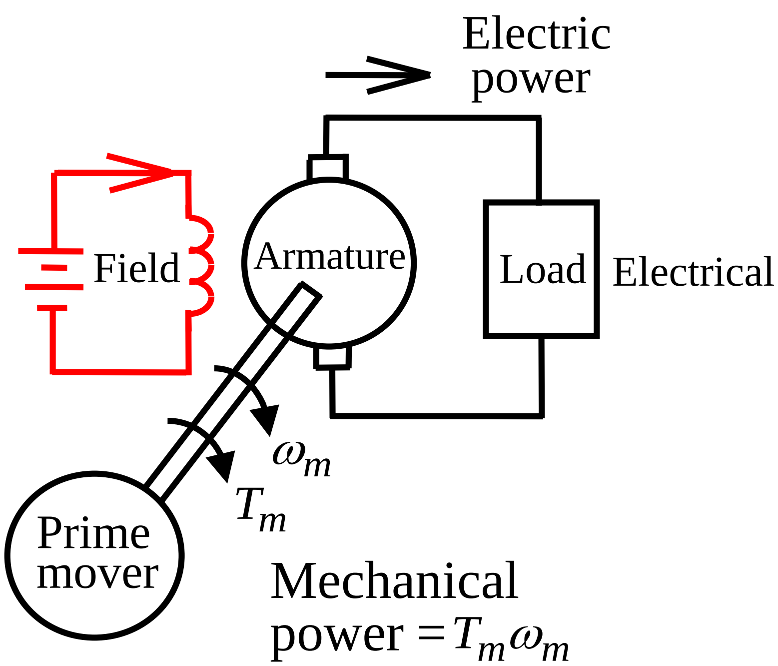
(1) Moving devices (Rotary and linear electric machines):

Motor: Electric energy >> Magnetic energy >> Mechanical energy

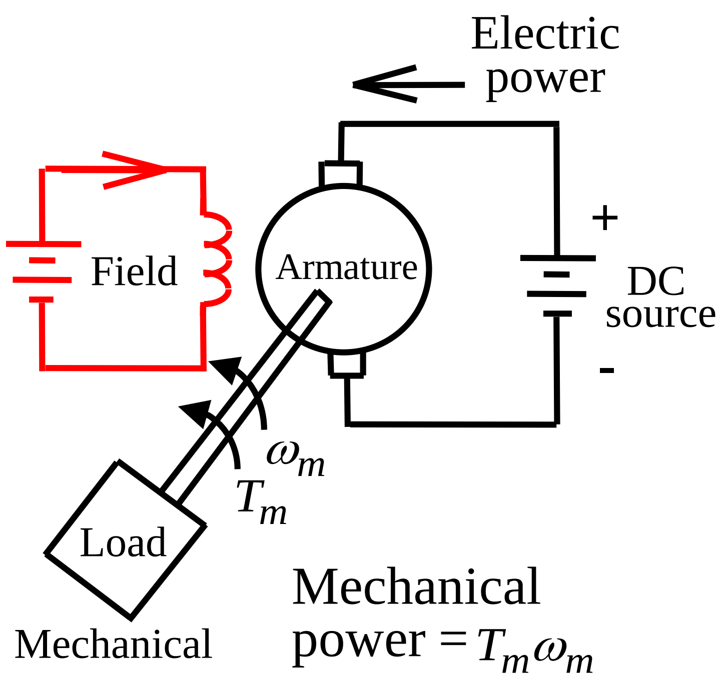
Generator: Mechanical energy >> Magnetic energy >> Electric energy.

- Motor and generator have the same structure, only the operation is different.

DC generator



DC motor



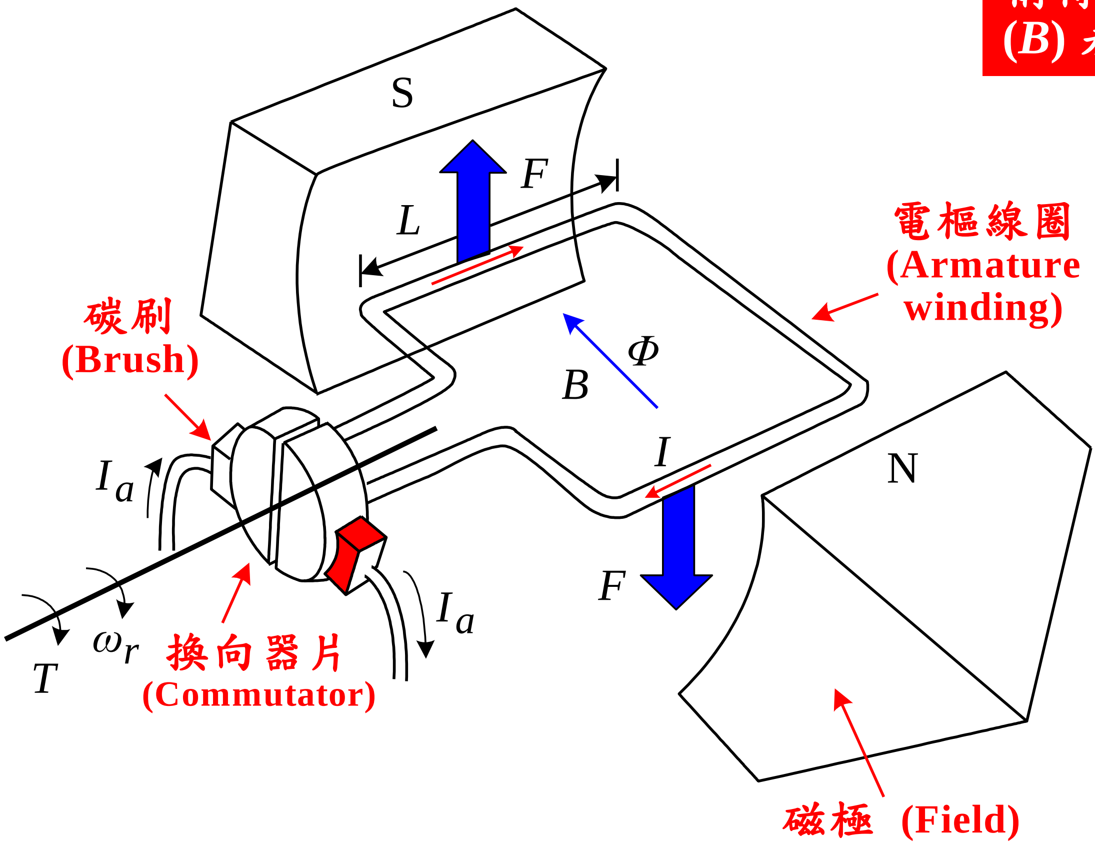
- **Generator: $e = B\,l\,v$**
- **Motor: $f = B\,l\,i$**

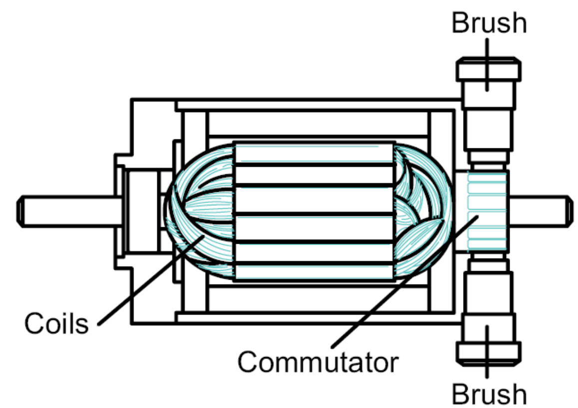
Structure and developed torque of a DC motor (with brush)

- Torque generating capability of a DC Motor is the best among all motors, since the flux and armature conductor current are kept in quadrature in nature.

唯有直流有刷馬達，其固有之結構特徵使其導體電流 (*l i*) 與磁場 (*B*) 永保垂直

$$T = K_a \Phi I_a$$

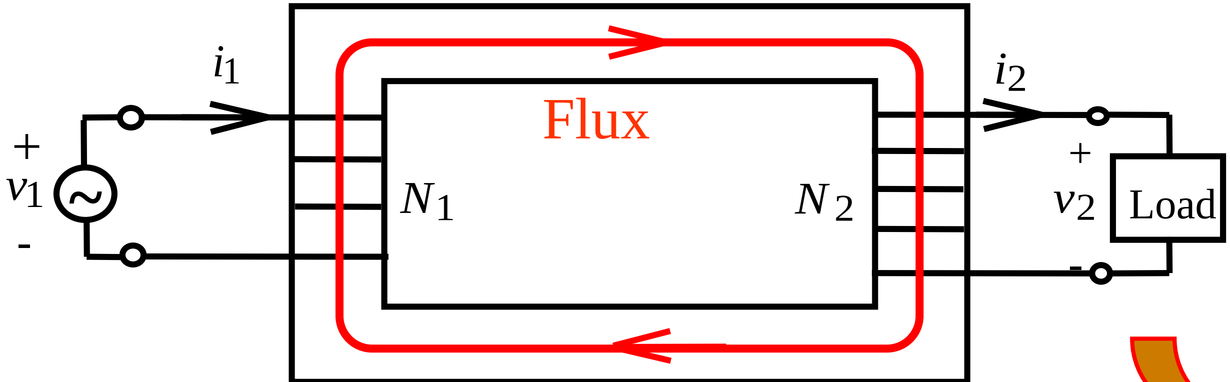




(2) Static machines:

(a) Transformers

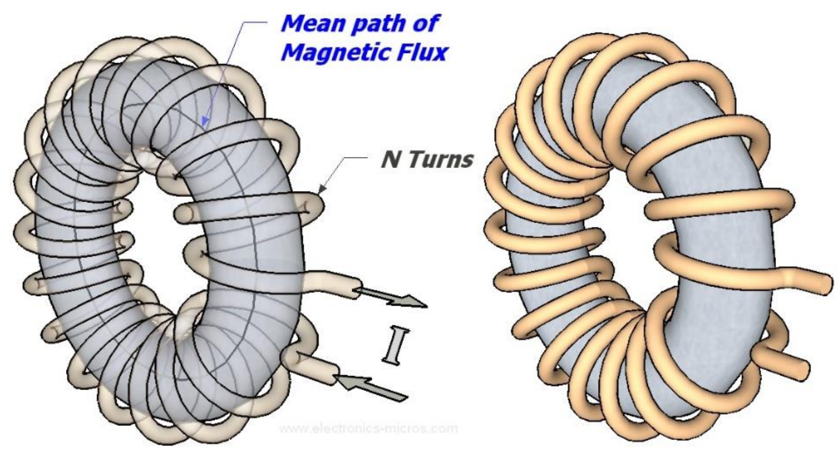
Electric energy >> Magnetic energy >> Electric energy



$$N_1 / N_2 = v_1 / v_2 = i_2 / i_1$$

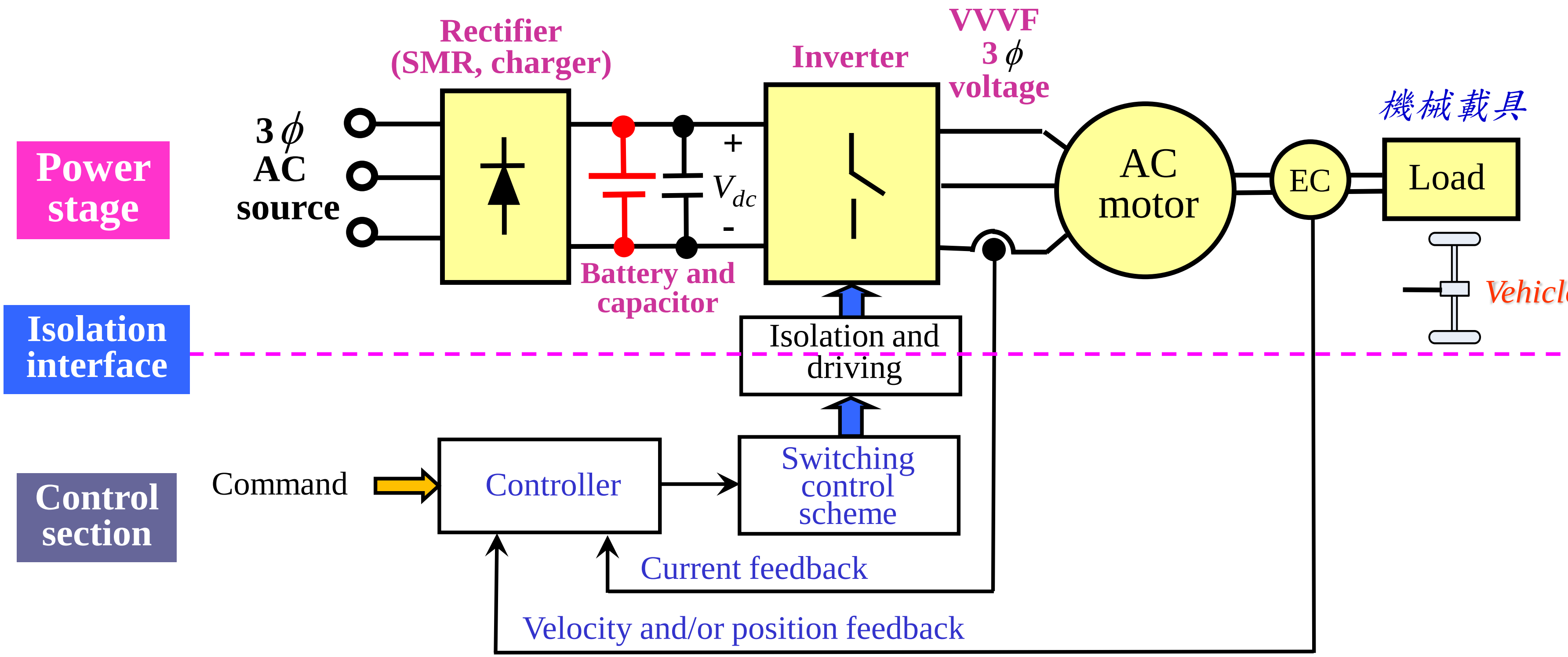
- Basic functions: (1) Voltage (current) transformation; (2) Impedance transformation); (3) Isolation.

(b) Inductors: Energy storage components



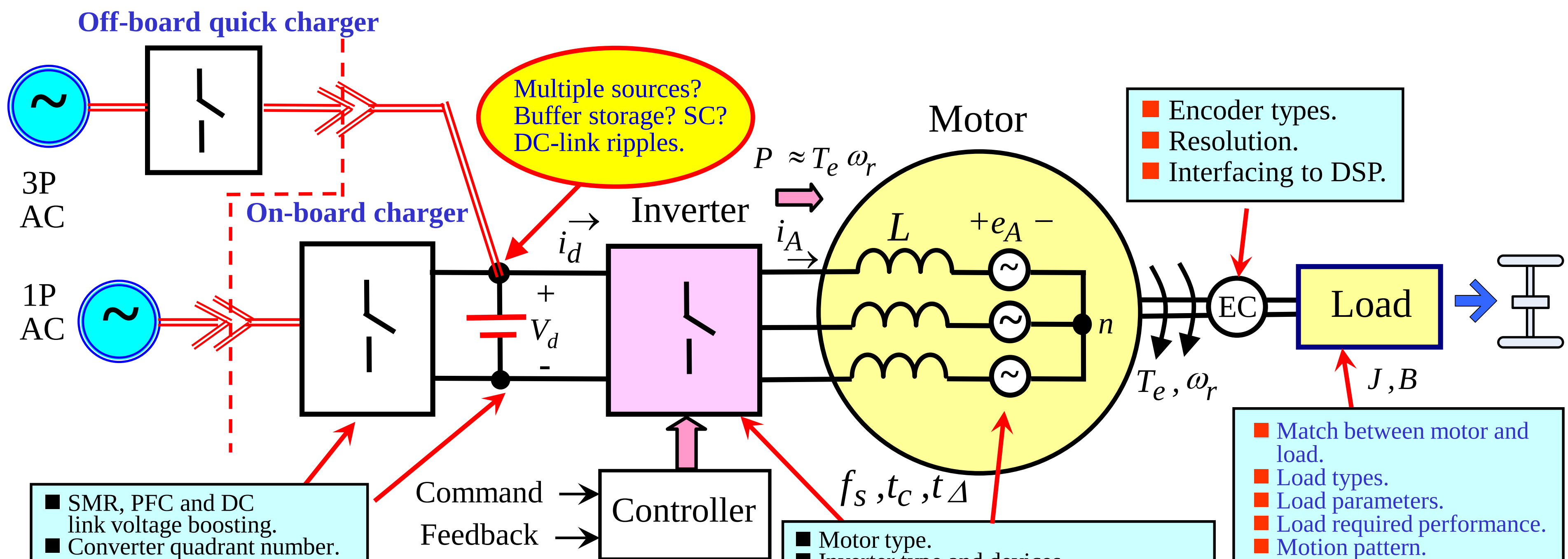
馬達驅動系統 (Motor drive)

為一含*馬達、機械載具、轉換器、控制器、感測與轉換*等之整合系統，唯有馬達本身之適當設計與驅動系統組件間之妥善搭配，始可得優良之運轉控制性能。
(Motor drive is an interdisciplinary mechatronic system including motor, mechanical load, power converter, controller, transducing and sensing schemes. The proper design of motor and the proper match between the constituted components should be made for yielding good driving performance.)



- Requirements: Reliable, low cost, miniaturization (smaller volume and weight), higher efficiency (energy saving), low vibration and acoustic noise, etc.

Some key issues of EV motor drives (EV馬達驅動系統一些關鍵事務)



- Match between motor and load.
- Load types.
- Load parameters.
- Load required performance.
- Motion pattern.
- Speed range, constant torque, constant power.
- *EV,PHEV: Charger, V2G,G2V,V2H operations.*

- SMR, PFC and DC link voltage boosting.
- Converter quadrant number.
- Front-end DC/DC converter for inverter.
- PAM and/or PWM controls.
- Dynamic braking.
- Inrush current.
- Storage types and controls.
- Battery sources.
- Battery charging.
- Super-capacitor buffer.
- Renewable or distributed sources.

- Motor type.
- Inverter type and devices.
- Match between inverter, motor and load
- Voltage utilization.
- Dynamic and regenerative braking.
- Field-weakening.
- Harmonic effects.
- Gate driving signal isolation.
- Interfacing and sensing.
- Current changing rate and response.
- Neutral isolation or not.
- Reflection due to unmatched impedance.
- Power module, SOC promotion.

- Miniaturization.
- Cost effective.
- Reliability.
- EMI problems.
- Grounding and shielding.

- PWM control, harmonics.
- Random switching.
- Dynamic modeling and estimation.
- Feedback sensing, transducing, signal conditioning and filtering.
- Dynamic control: (current, speed and/or position).
- Tuning control for specific motor.
- Digitization of control scheme.
- Common DSP for multiple power stages.
- Acoustic noise and vibration reduction.

- Motor ripple current: $$i_A \approx \frac{v_{A1} - e_{A1}}{Z_{A1}} + \sum_{h=2}^{\infty} \frac{v_{Ah}}{Z_{Ah}} \overset{\Delta}{=} i_{A1} + i_{Ah}$$
- Motor current changing rate: $$\frac{di_A}{dt} \propto \frac{V_d - e_A}{L}, \quad e_A \propto \omega_r$$

Classification of commonly used motors

■ Classifications of rotary electric machines (旋轉電機分類)

直流機 (DC machines):
- 永磁式 (Permanent-magnet, PM)
- 他激式(Separately excited)
- 自激式 (Self excited)
  - 並激 (Shunt excited)
  - 串激 (Series excited)
  - 複激 (Compound)
    - 連接方式
      - 長並聯(Long shunt)
      - 短並聯(Short shunt)
    - 激磁方式
      - 差複激(Differential compound)
      - 助複激 (Cumulative compound)
        - 欠複激 (Under-compound)
        - 平複激 (Flat-compound)
        - 過複激 (Over-compound)

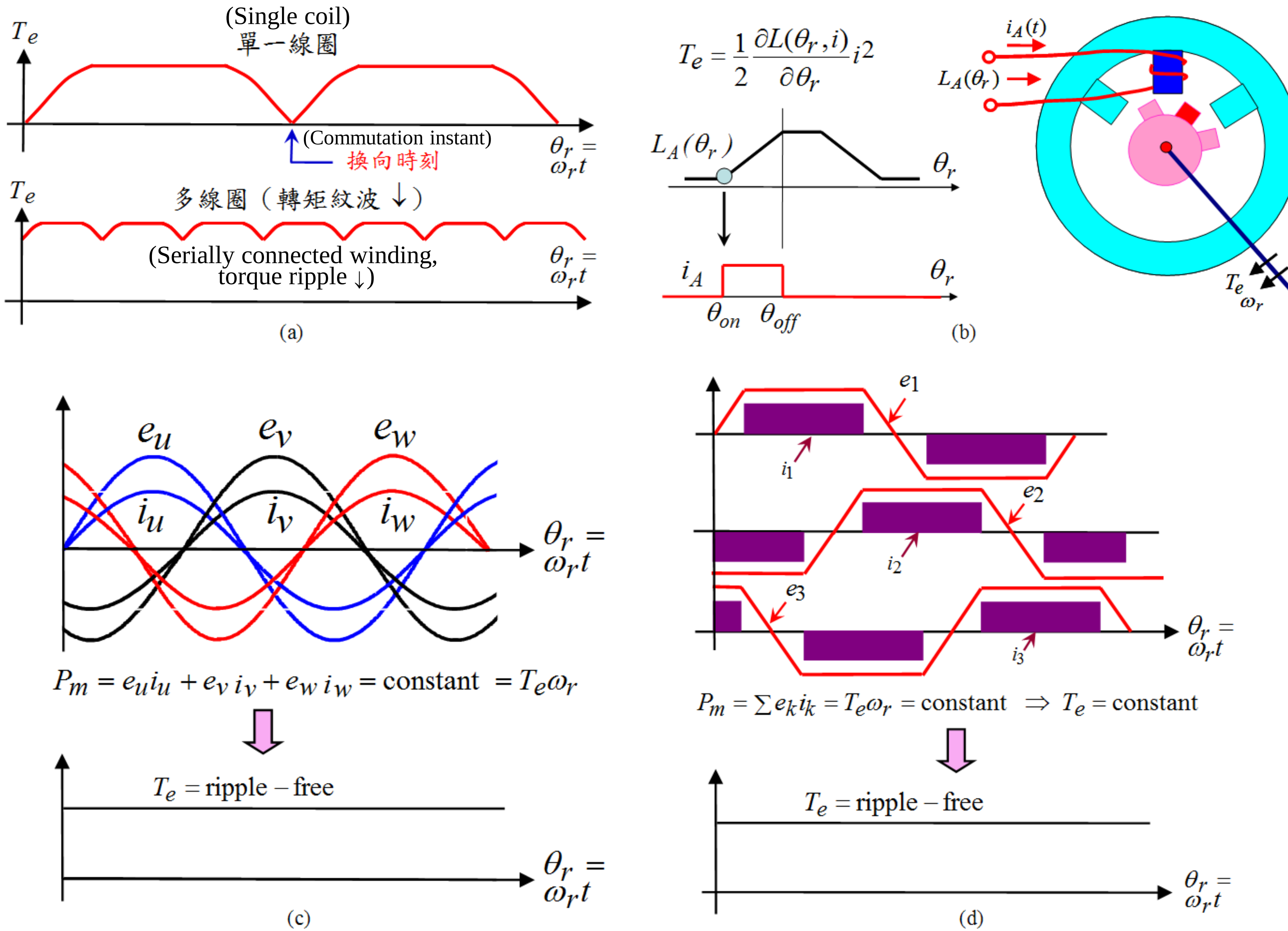
DC motors to be pursued
(直流馬達驅動控制性能追求之對象)：

- ■ Shunt motor：IM, BDCM (PMSM)
- ■ Series motor：SRM

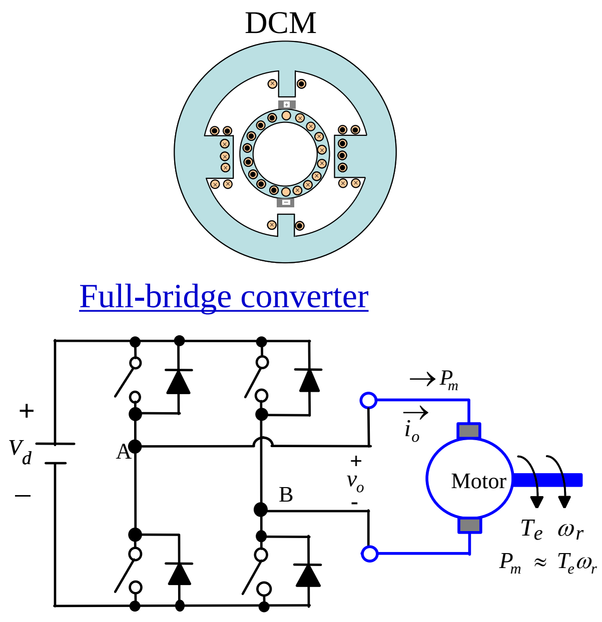
- 交流機 (AC machine)：
  - 同步機 (Synchronous machine)
    - 三相 (Three-phase, 3P)
    - 單相 (Single-phase,1P)
  - 感應馬達 (Induction motor)
    - 三相 (3P)
      - 繞線式(Wound-rotor or slip-ring)
      - 鼠籠式(Squirrel-cage)
    - 單相 (1P) (鼠籠式) (Squirrel-cage type)
      - 分相馬達(Split-phase motor)
      - 電容馬達(Capacitor 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, i.e., Series modtor)
      - 其他

- 特殊電機 (Special machines)：
  - 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) (為具有轉子位置感測之同步馬達)
    - 速度驅動 (方波式)
    - 位置伺服驅動 (弦波式)
  - 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 (Others)

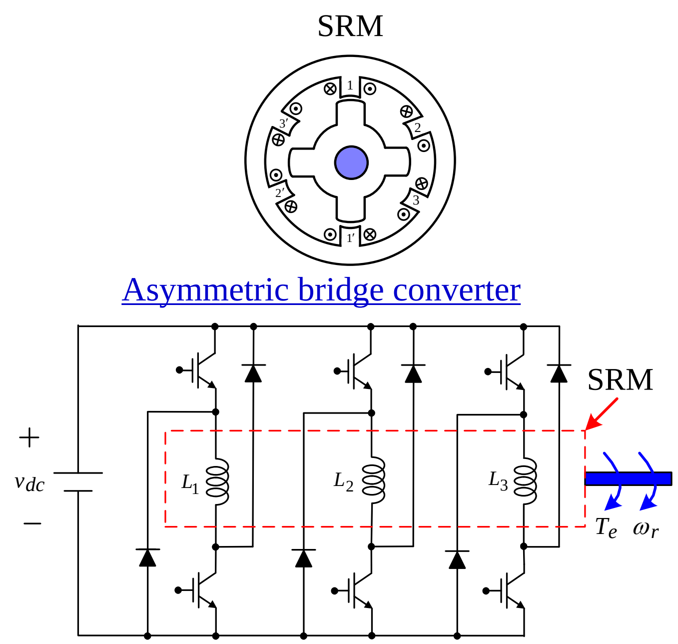
Idealized developed torque characteristics of some typical motors: (a) Brush DC motor; (b) switched-reluctance motor; (c) three-phase sine-wave permanent-magnet synchronous motor; (d) three-phase square-wave permanent-magnet synchronous motor



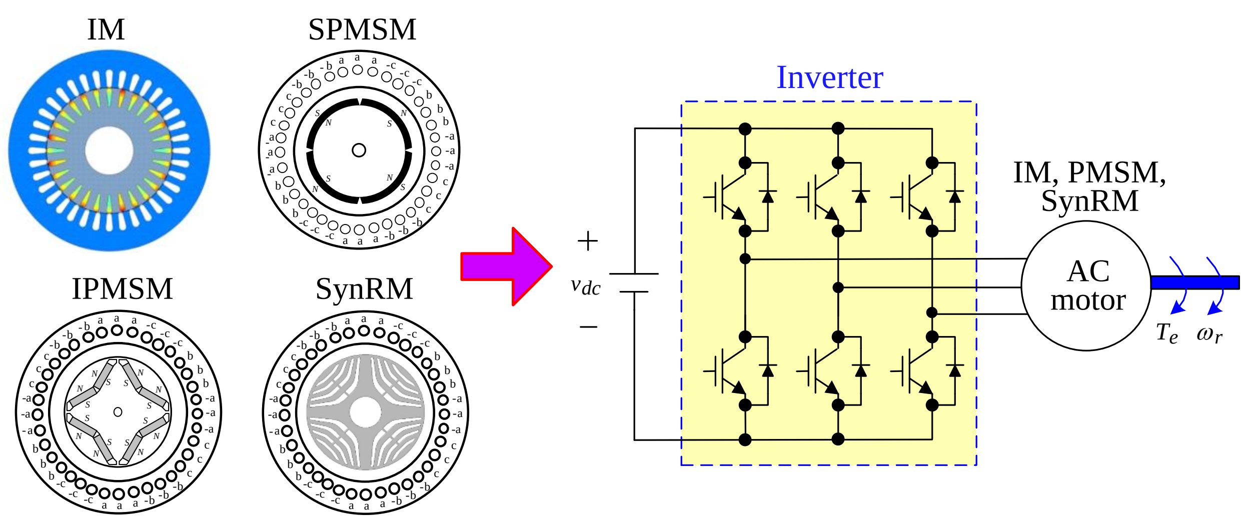
Commonly used motors and their converters: (a) DCM and full-bridge converter; (b) SRM and asymmetric bridge converter; (c) three-phase motors and inverter



(a)



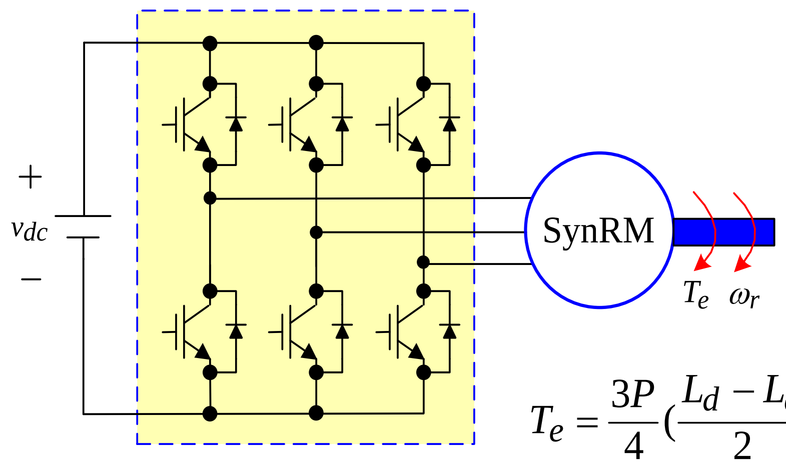
(b)

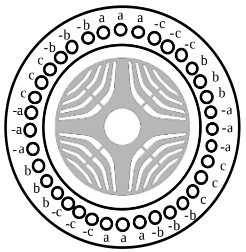


(c)

Synchronous reluctance motor

(Slotted stator with distributed armature winding + slotted rotor)



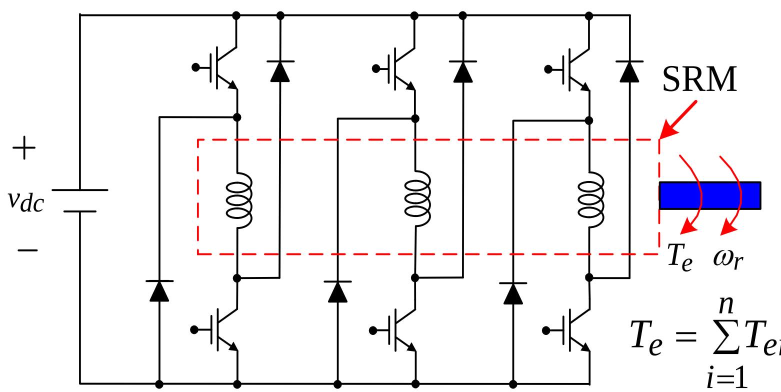


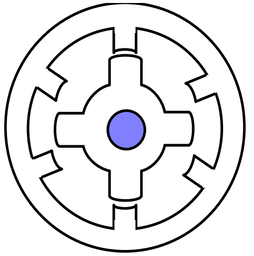
$$T_e = \frac{3P}{4}\left(\frac{L_d - L_q}{2}\right)\hat{I}_{as}^2 \sin 2\beta$$

Switched-reluctance motor

(Salient stator with concentrated armature winding + toothed rotor)

Asymmetric bridge converter

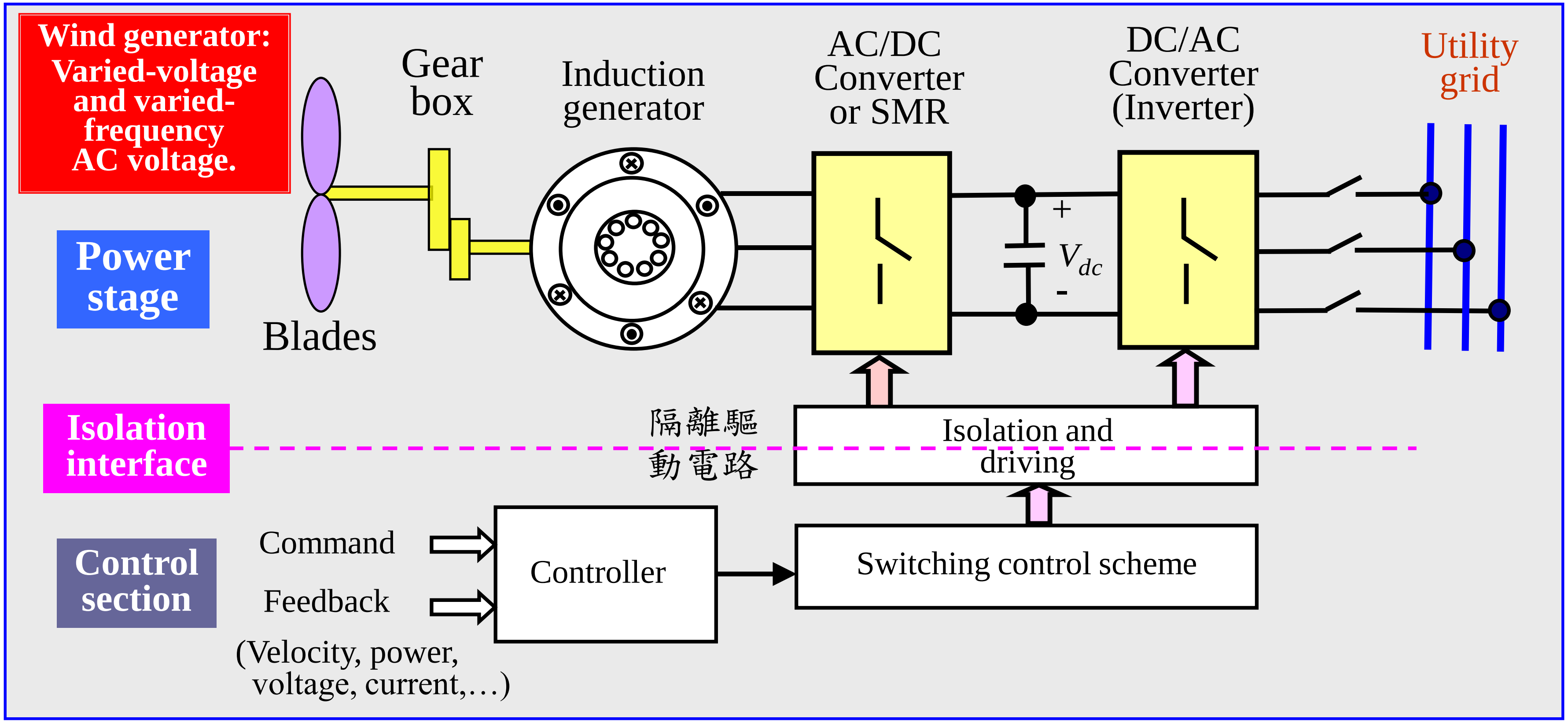




$$T_e = \sum_{i=1}^{n} T_{ei}, \quad T_{ei} = \frac{1}{2}\frac{\partial L(\theta_r, i_i)}{\partial \theta_r} i_i^2$$

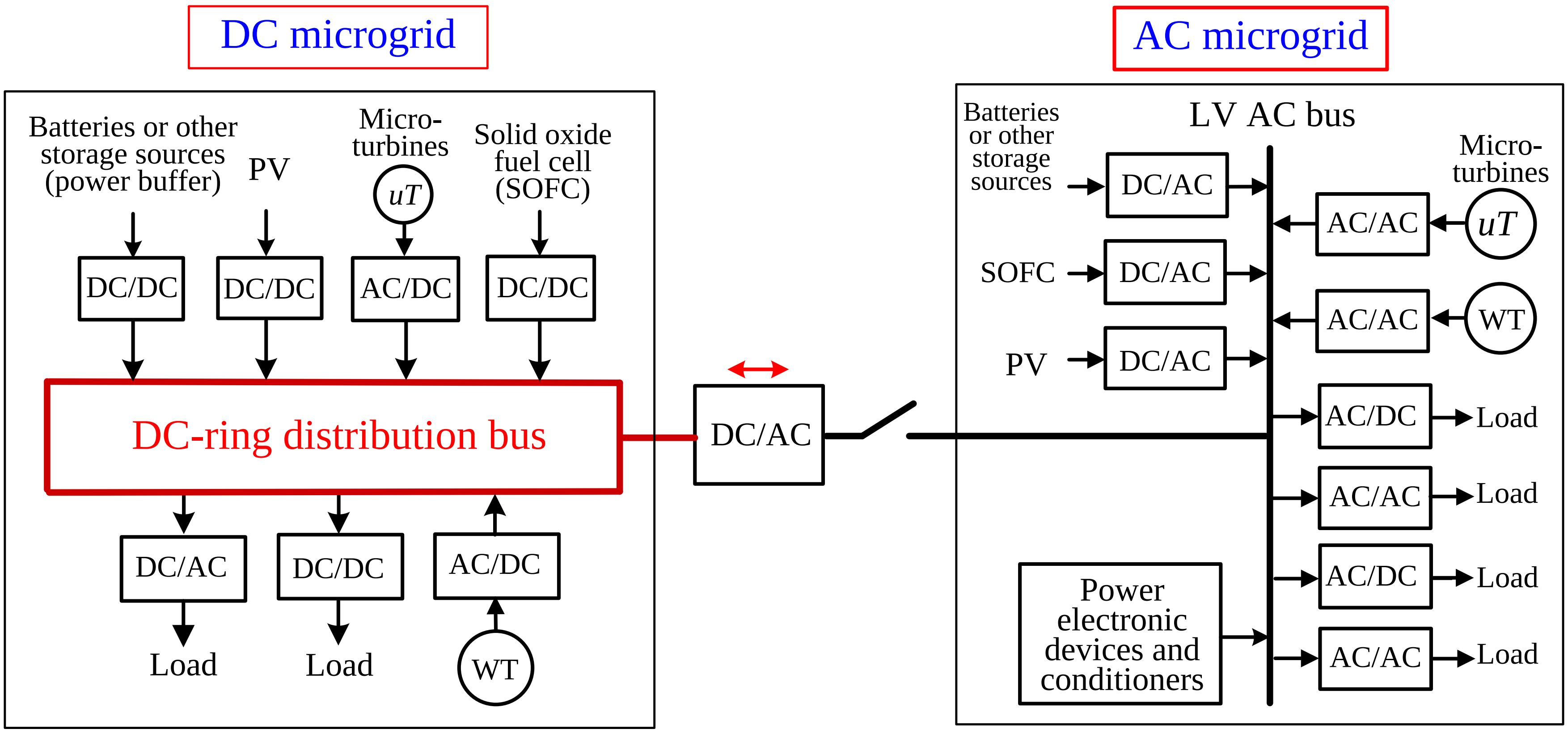
風力發電系統 (Wind generator system)

- 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。
(The generator and its followed power converter must be properly chosen, and the control must also be properly conducted.)



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

Typical micro-grid or distributed power system configuration

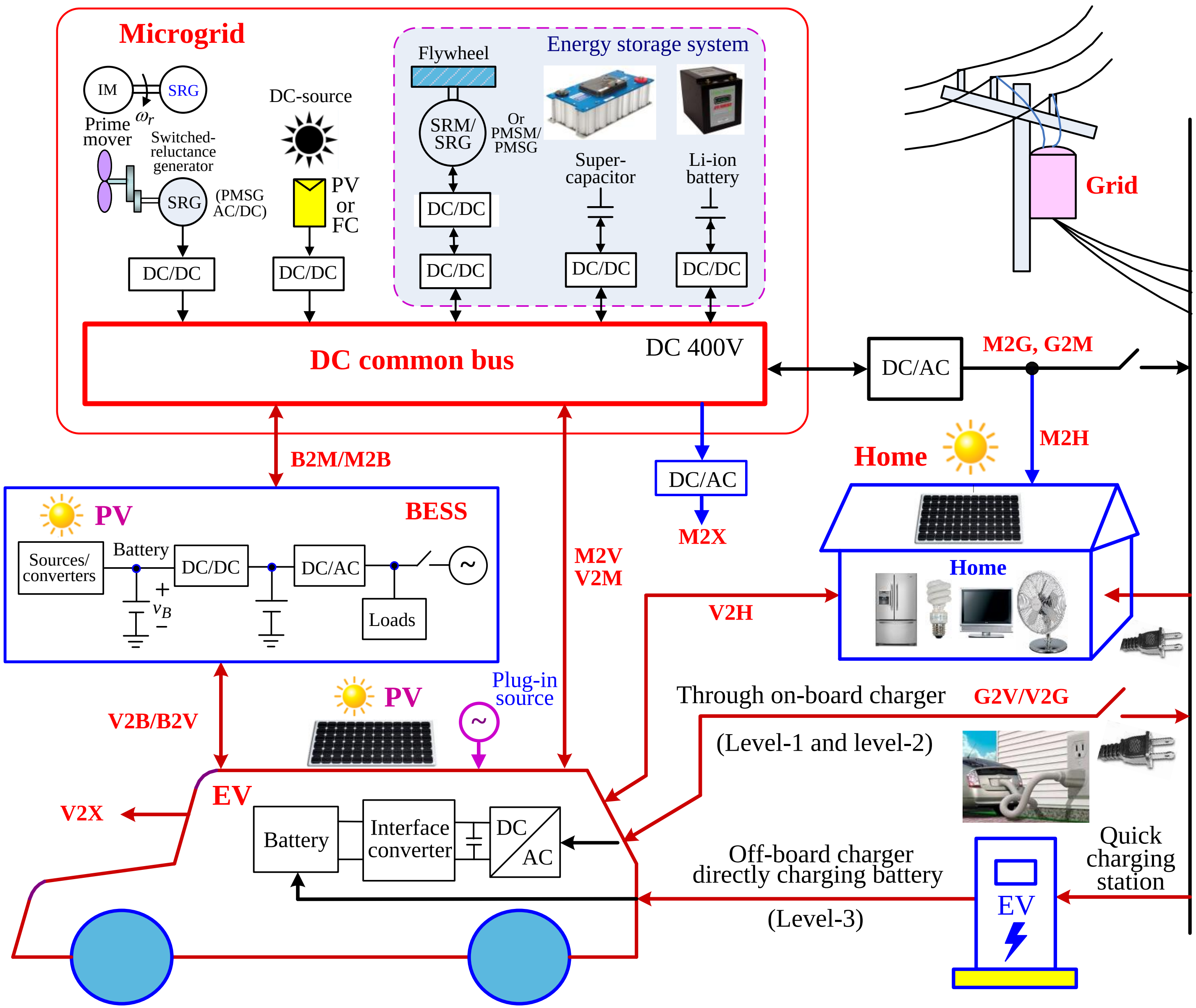


<u>Advantages of DC microgrids</u>

- High network quality
- Higher power transfer capacity
- Lower disturbance injected in the AC main public network
- Simplification of converters connecting the DG to the network
- Simplification the converters powering the loads

- APF
- SVC
- Dynamic voltage restorer
- DSTATCOM
- Solid state transfer switch

Interconnected operations of EV to grid, microgrid and BESS



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).

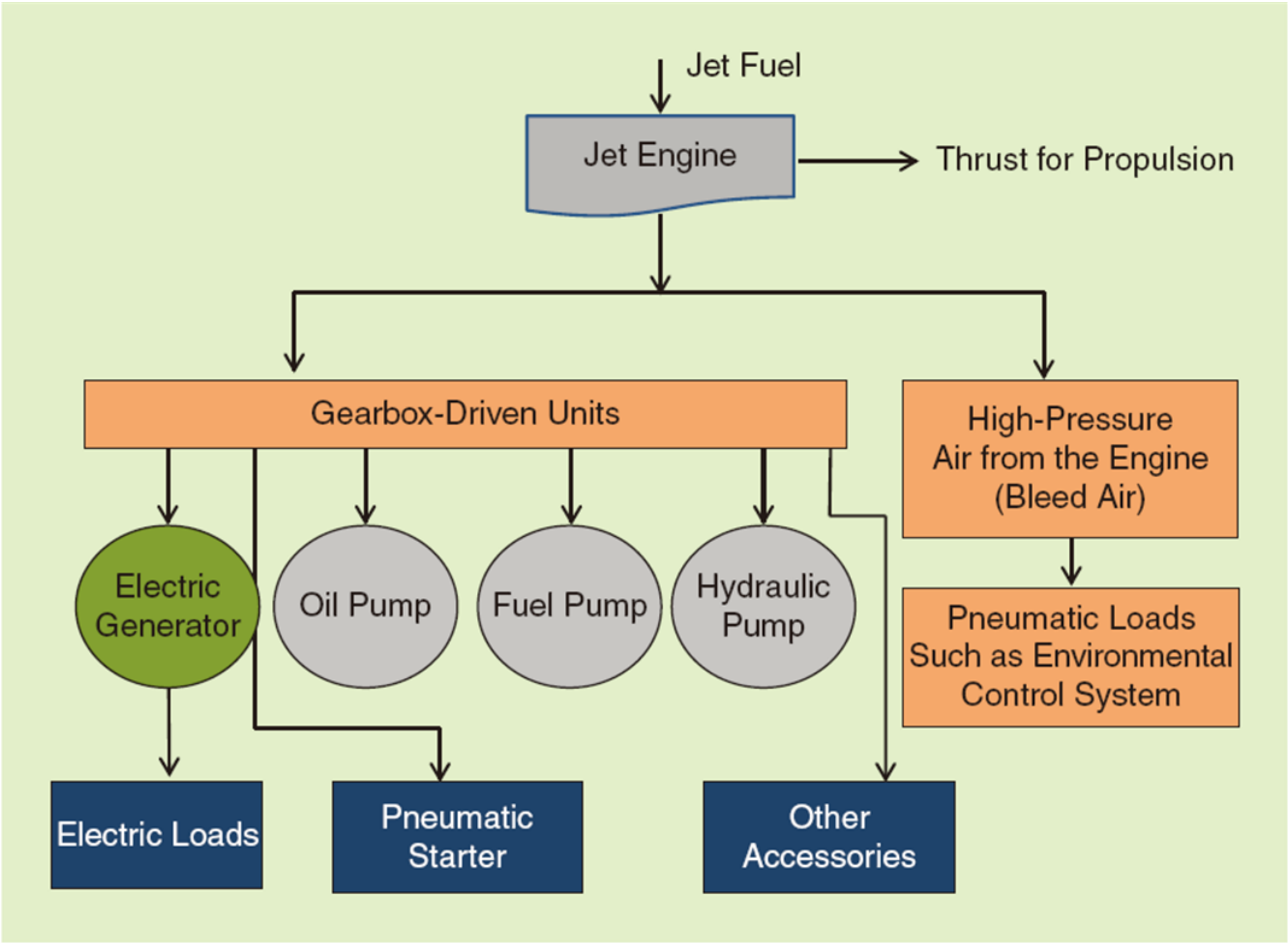
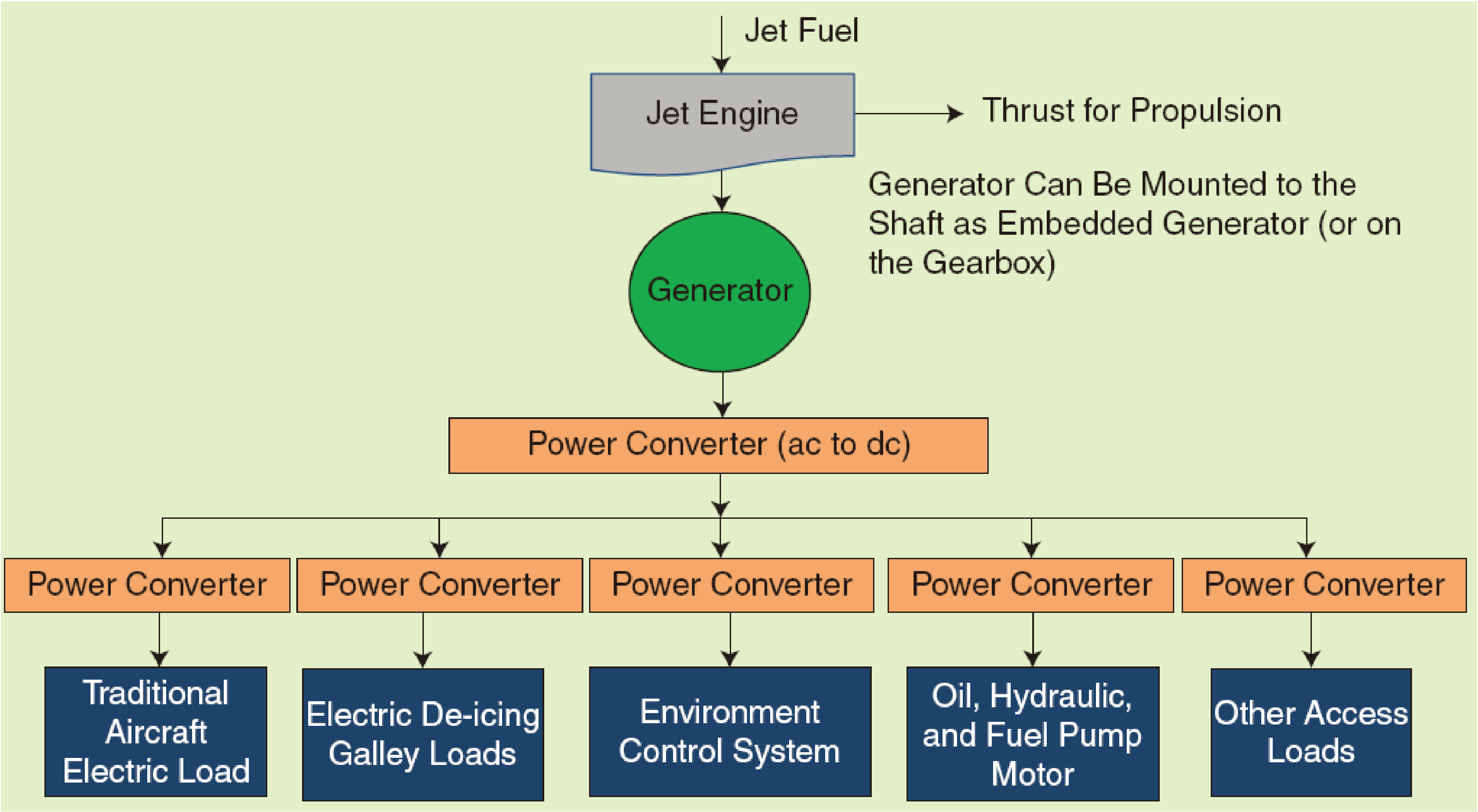


Figure 4. A traditional aircraft system.

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.



Different types of electrical power generation systems in More Electric Aircraft (MEA)

- In an MEA, the thrust for aircraft propulsion is fully provided by the jet engine. In addition, the jet engine driving a generator is responsible for proving the required power for all of the electrical loads.
- The different types of electrical power generation systems currently being used in airplanes (Fig. 3).

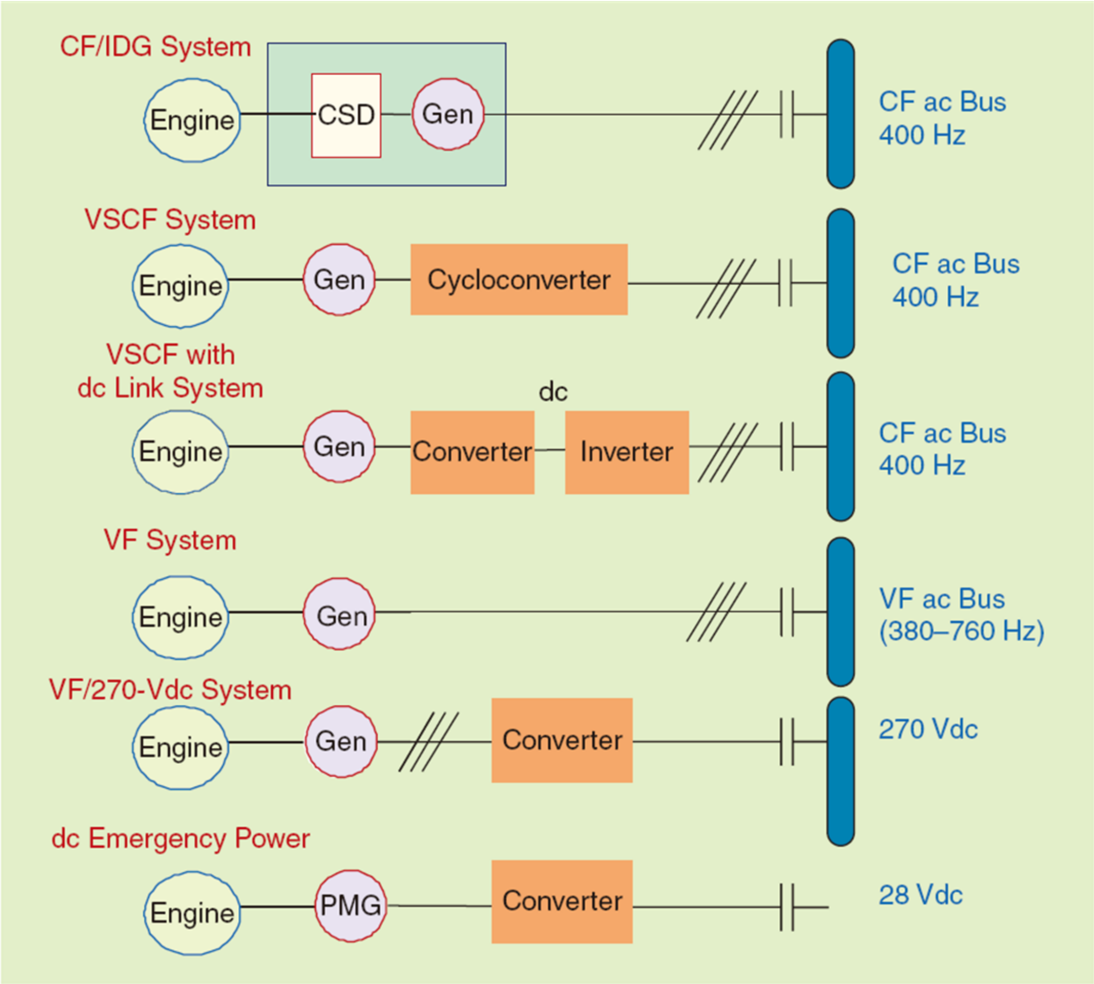


Figure 3. Electrical power generation strategies in aircraft (K. Rajashekara, "Converging technologies for electric/hybrid vehicles and More Electric Aircraft systems," in *Proc. SAE Power Systems Conf.*, Fort Worth, TX, Nov. 2–4, 2010, Paper No. 2010-01-1757).

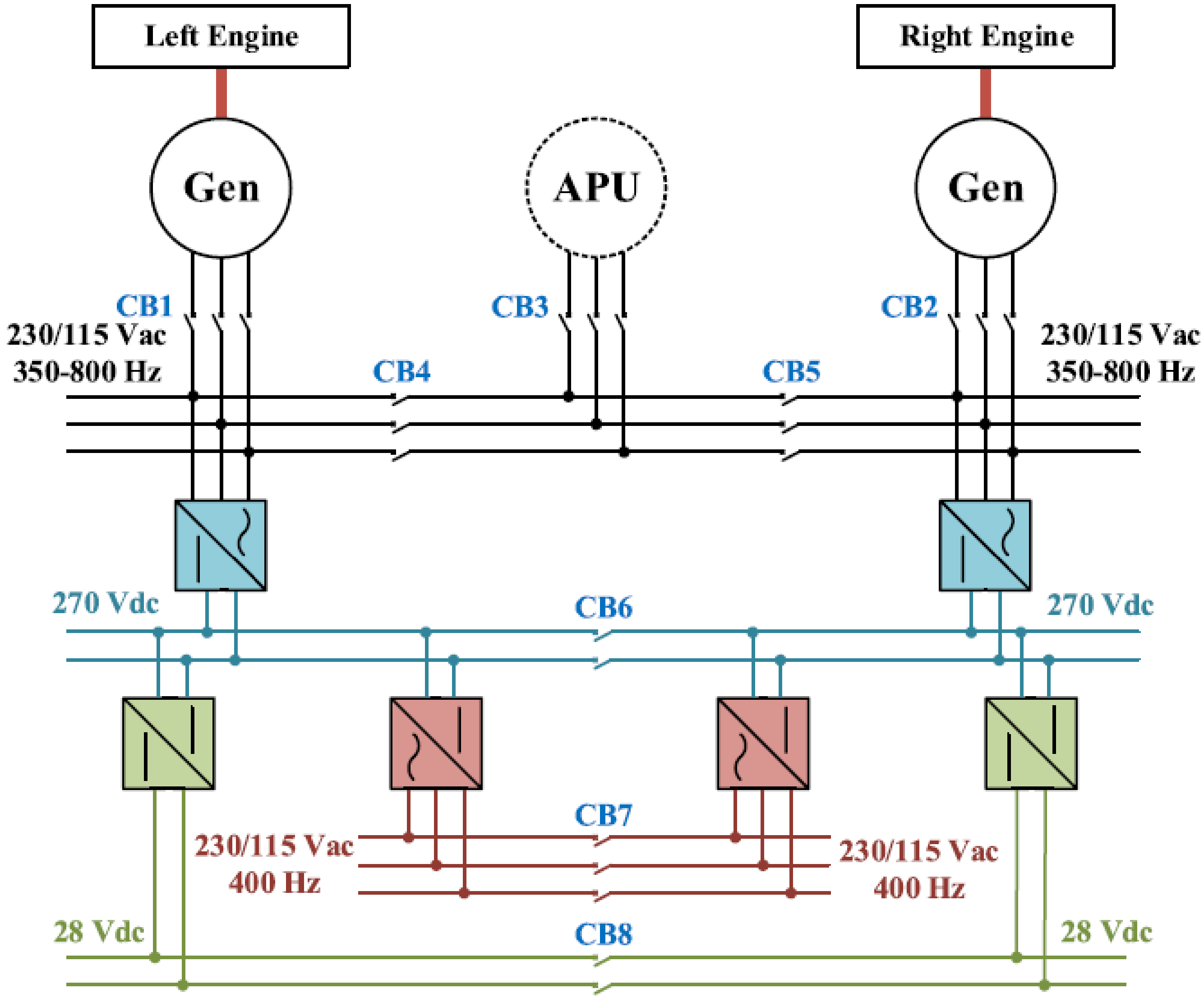


FIGURE 5. EPS with primary dc 270 V bus (HVDC EPS). Different loads are connected to corresponding busses.

[*] "Electric Power Systems in More and All Electric Aircraft: A Review", IEEE Access, vol. 8, 2020..

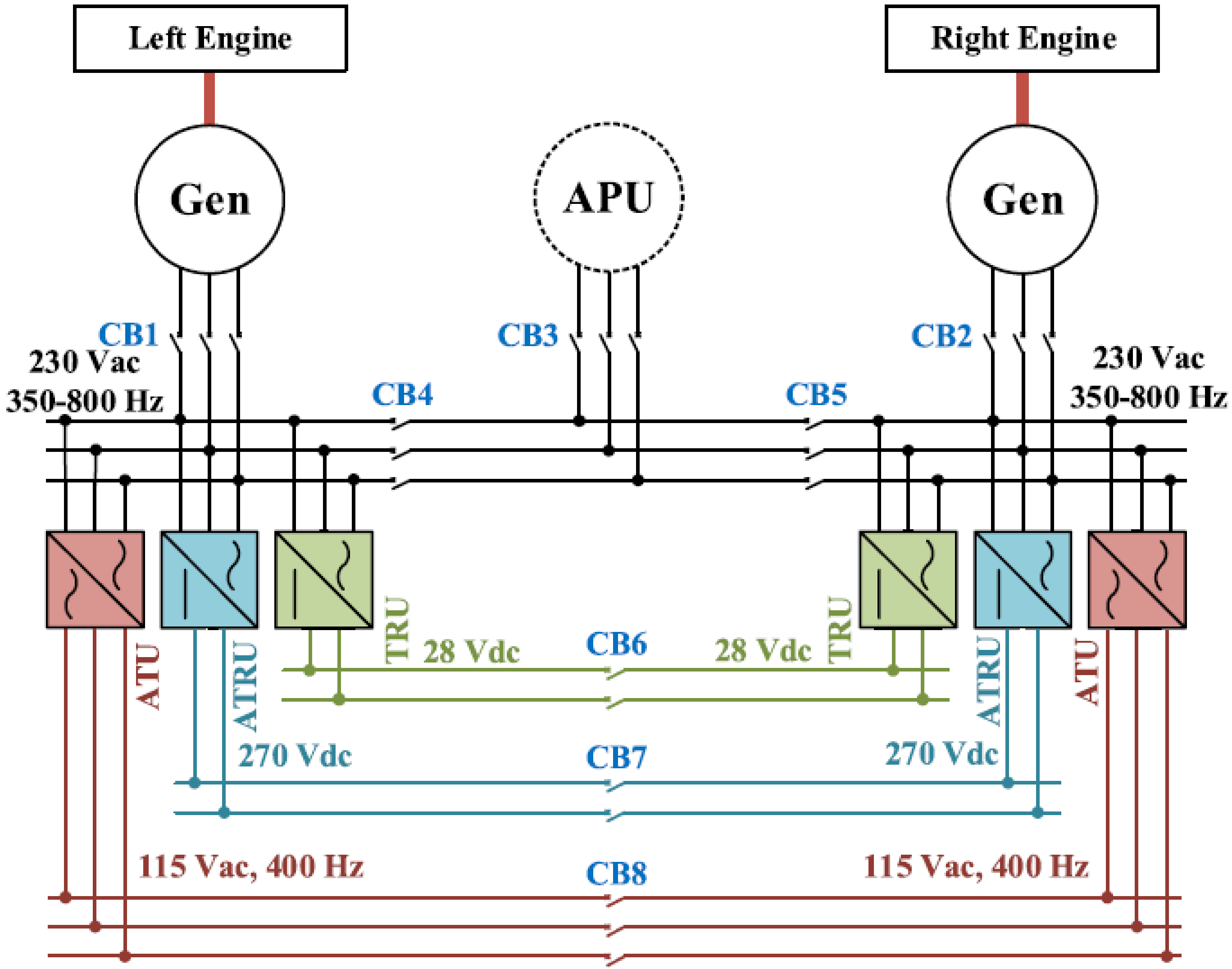
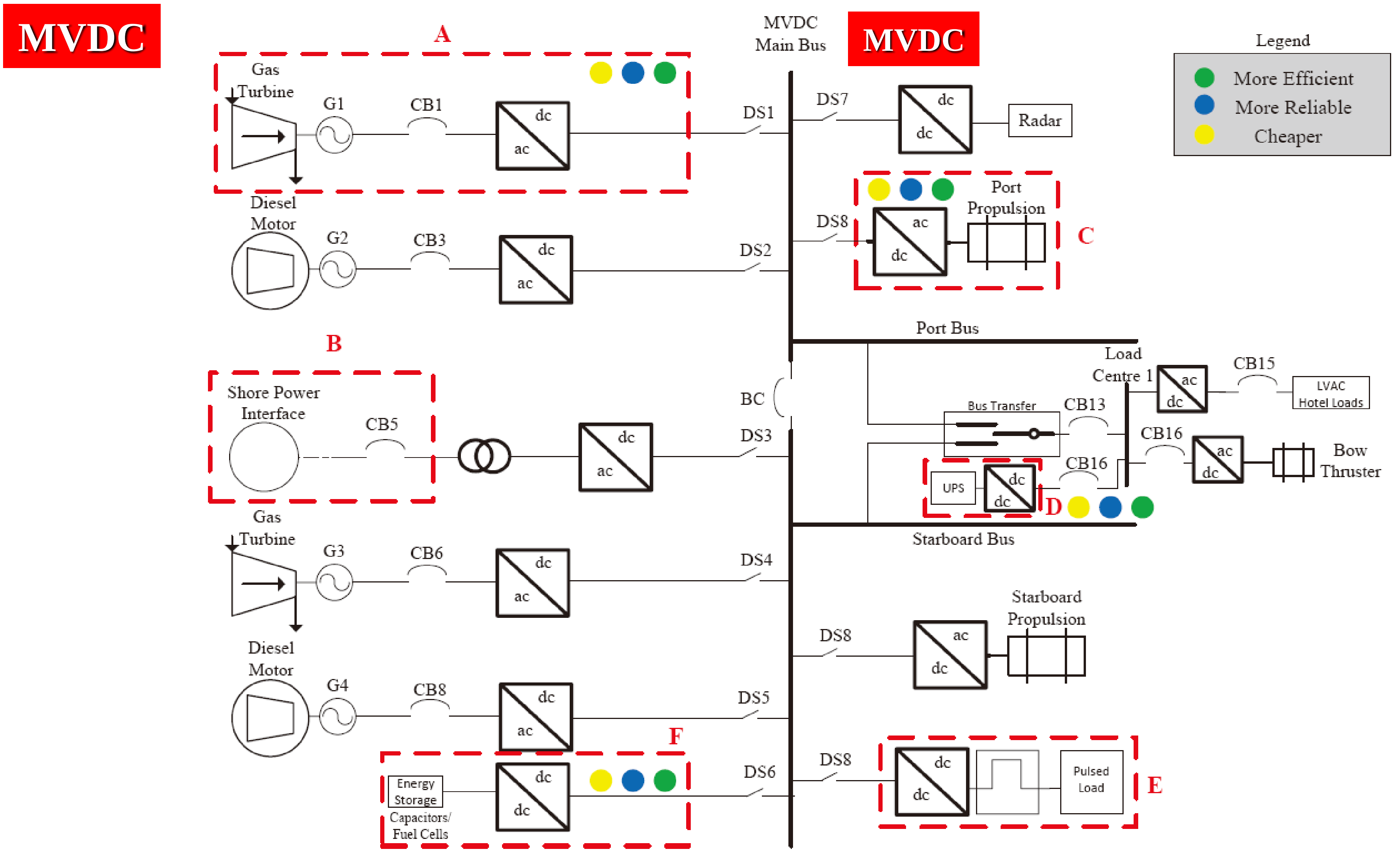


FIGURE 6. EPS with primary ac 230 V with variable frequency 350-800 Hz bus. Different loads are connected to corresponding busses.

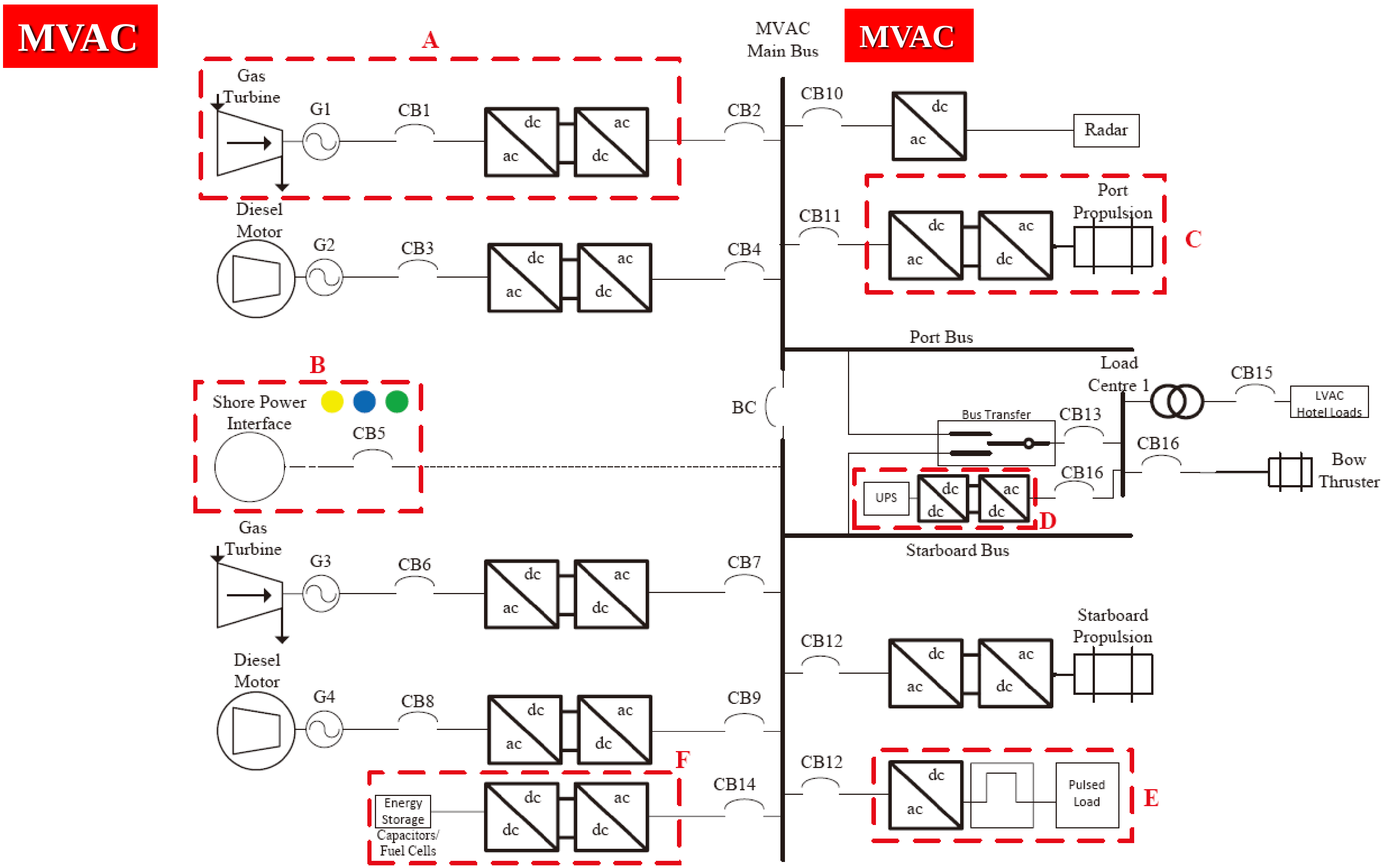
Power architectures of a typical all electric ship



(a) Main distribution bus is medium voltage dc.

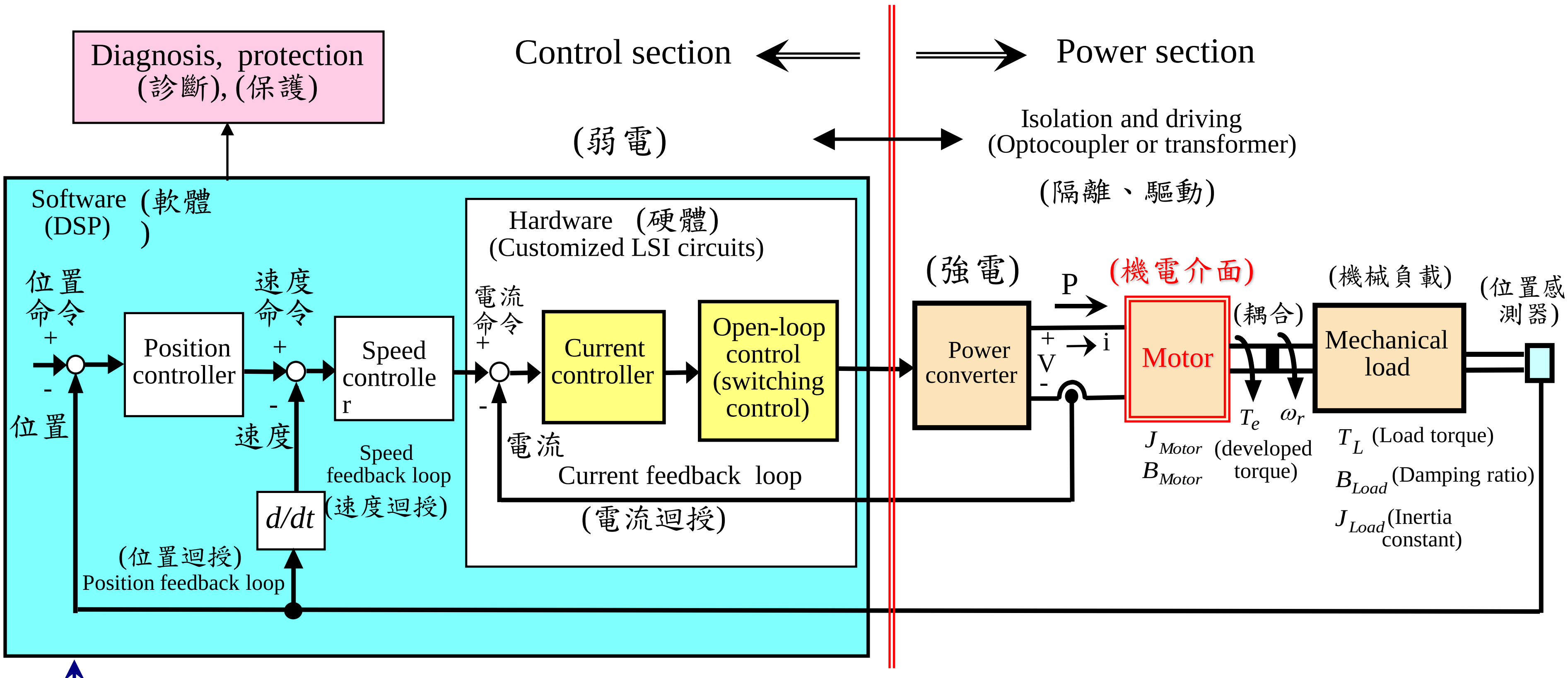
[*] Aditya Shekhar, Laura Ram'ırez-Elizondo, and Pavol Bauer, "DC Microgrid Islands on Ships," IEEE 2017 ICDCM.

Power architectures of a typical all electric ship (AES)



(b) Main distribution bus is medium voltage ac.

馬達驅動系統 (Motor drive system)



感應馬達有關控制策略:

- 多迴路迴授 (Multi-loop control)
- 框轉換及解耦控制(向量控制)
  (Transformation and decoupling (vector) control)
- 向量控制之補償
- 磁通準位及弱磁控制
- 增壓控制(Voltage boosting control)
- 估測迴授變數避免使用感測元件 (Sensorless)
- 系統參數估測 (Parameter identification)
- 適應控制 (Adaptive control)
- 最佳控制 (Optimal control)
- 韌性控制 (Robust control)
- 智慧控制 (Intelligent control)

永磁同步馬達有關控制策略:

- 多迴路迴授 (Multi-loop control)
- 框轉換及直流無刷控制(解耦控制或向量控制)
  (Transformation and brushless control
  (decoupling or vector control)
- 換相移位(Commutation shift)控制
- 激磁控制(Excitation control)及弱磁控制(Field-weakening)
- 增壓控制(Voltage boosting control)
- 估測迴授變數避免使用感測元件 (Sensorless)
- 系統參數估測 (Parameter identification)
- 適應控制 (Adaptive control)
- 最佳控制 (Optimal control)
- 韌性控制 (Robust control)
- 智慧控制 (Intelligent control)

Selection affairs of AC servo motor drive (交流伺服馬達驅動器之選擇)

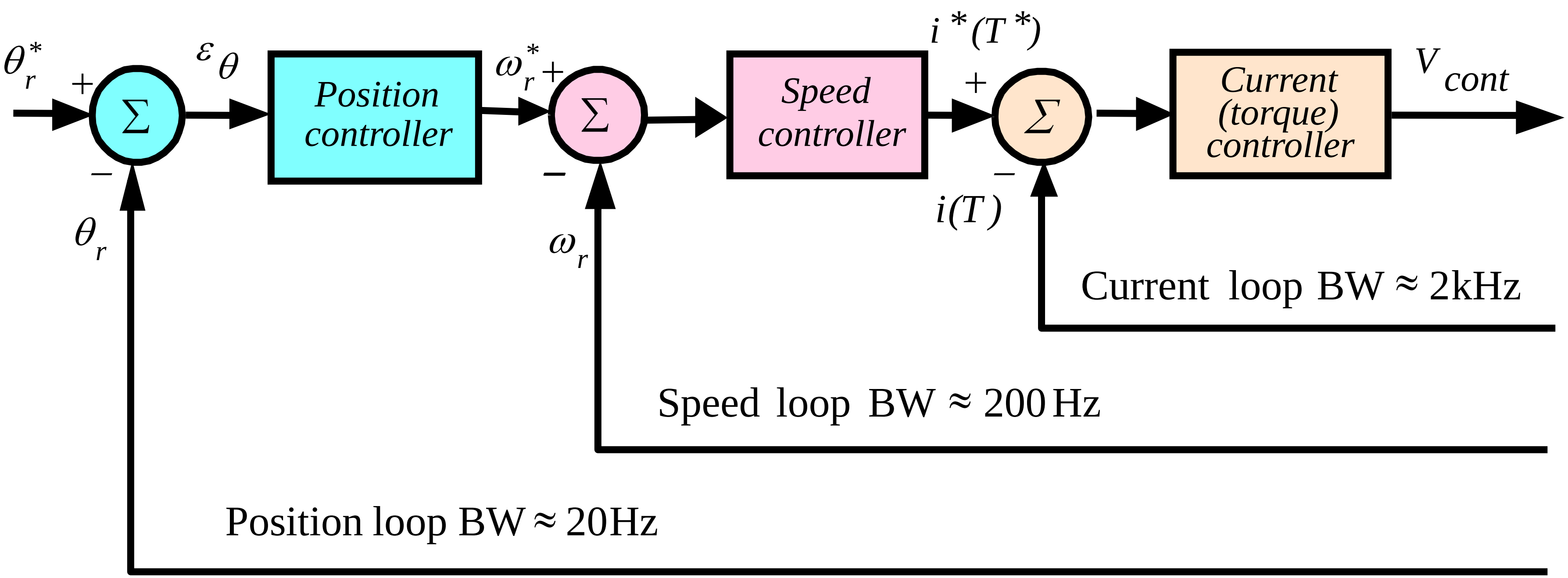
- Basic control band-width requirements (基本頻寬要求):

  Small-signal torque loop (current loop) B.W. ≈ 2kHz
  Small-signal speed loop B.W. ≈ 200Hz
  Small-signal position loop B.W. ≈ 20Hz (depending on mechanical load)

- Selection factors:

  Cost
  Power density
  Torque-to-inertia ratio
  Speed range and peak torque
  Losses and thermal capacity
  Torque-per-unit current
  Braking
  Cogging and ripple torques
  Choice of feedback devices (Absolute or incremental encoder)
  Parameter sensitivity
  Others

多迴路串級控制組態 - 頻寬規劃
(Multi-loop cascade control scheme- loop bandwidth)



Physical modeling process of static devices (Inductors and transformers)

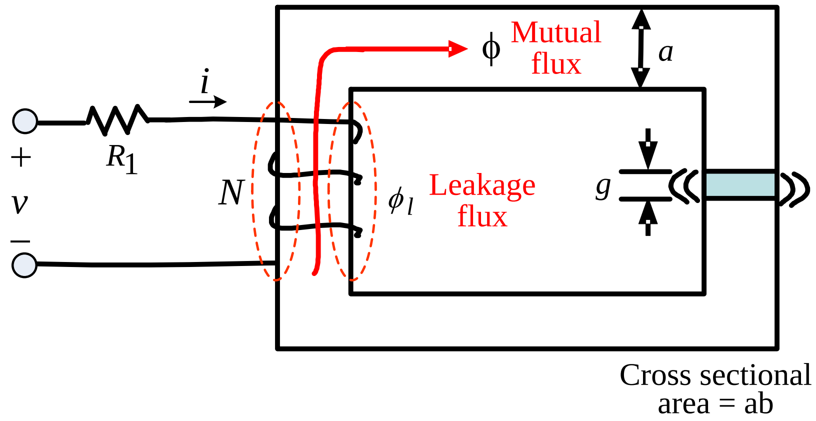
1. Energy transfer analysis and dynamic modeling:

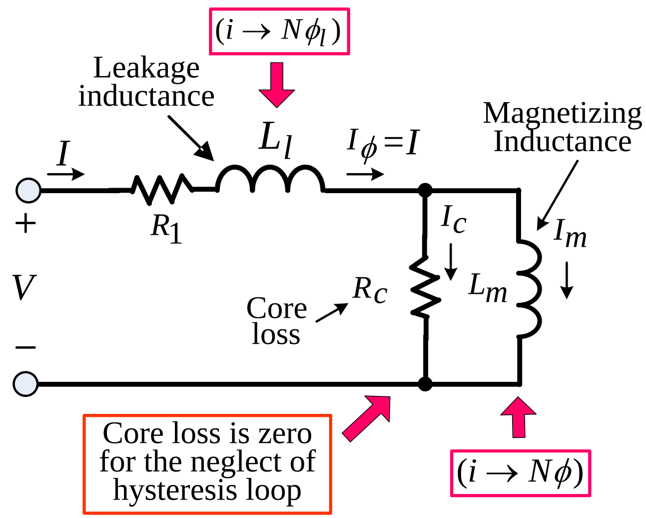
- Linear magnetic circuit assumption:
  Hysteresis loop >> Magnetization curve >> Linearized magnetization curve (Neglect saturation effect).
- Flux linkage < > exciting current: $\lambda = Li$
- List voltage equations.
- Equivalent circuit.

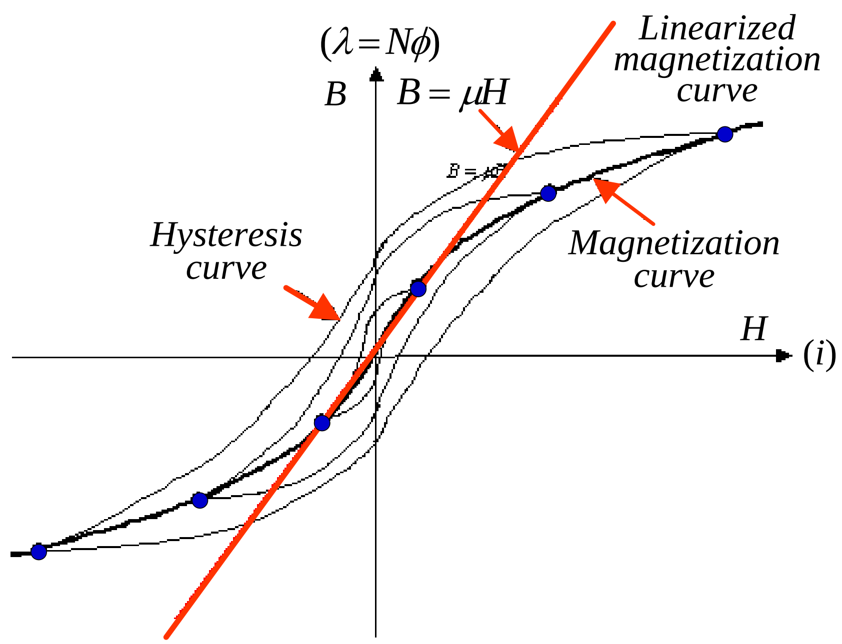
2. Performance efficiency analysis:

- The core loss is added.
- Equivalent circuit: a shunt core loss resistor is added, which can be estimated from measurements.

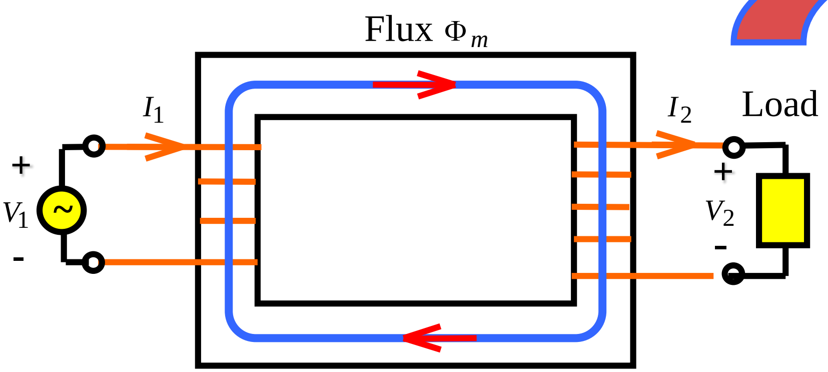
電感等效電路 (Inductor equivalent circuit)

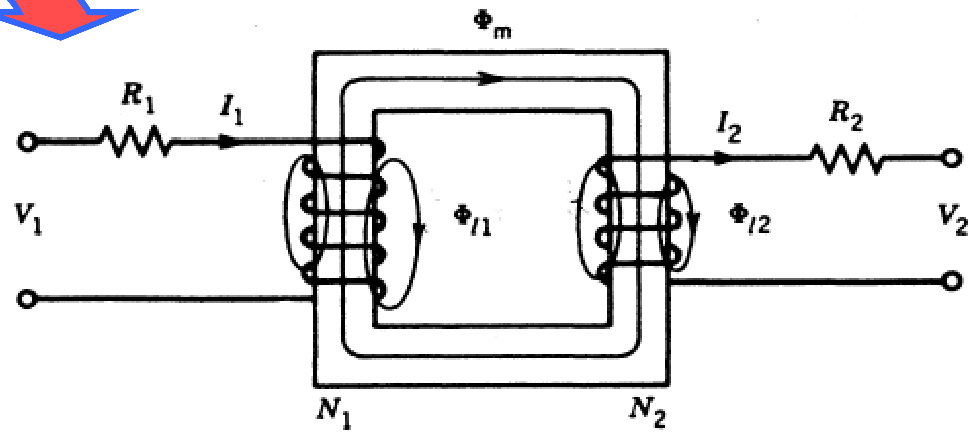


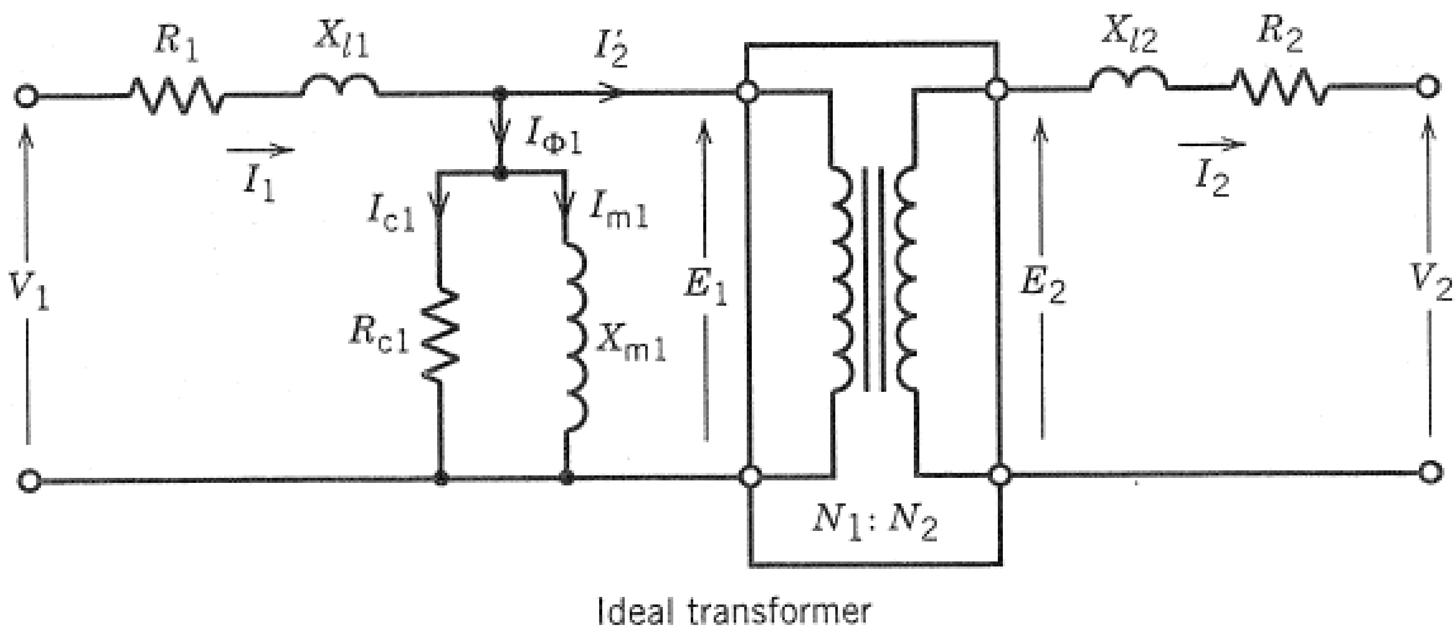


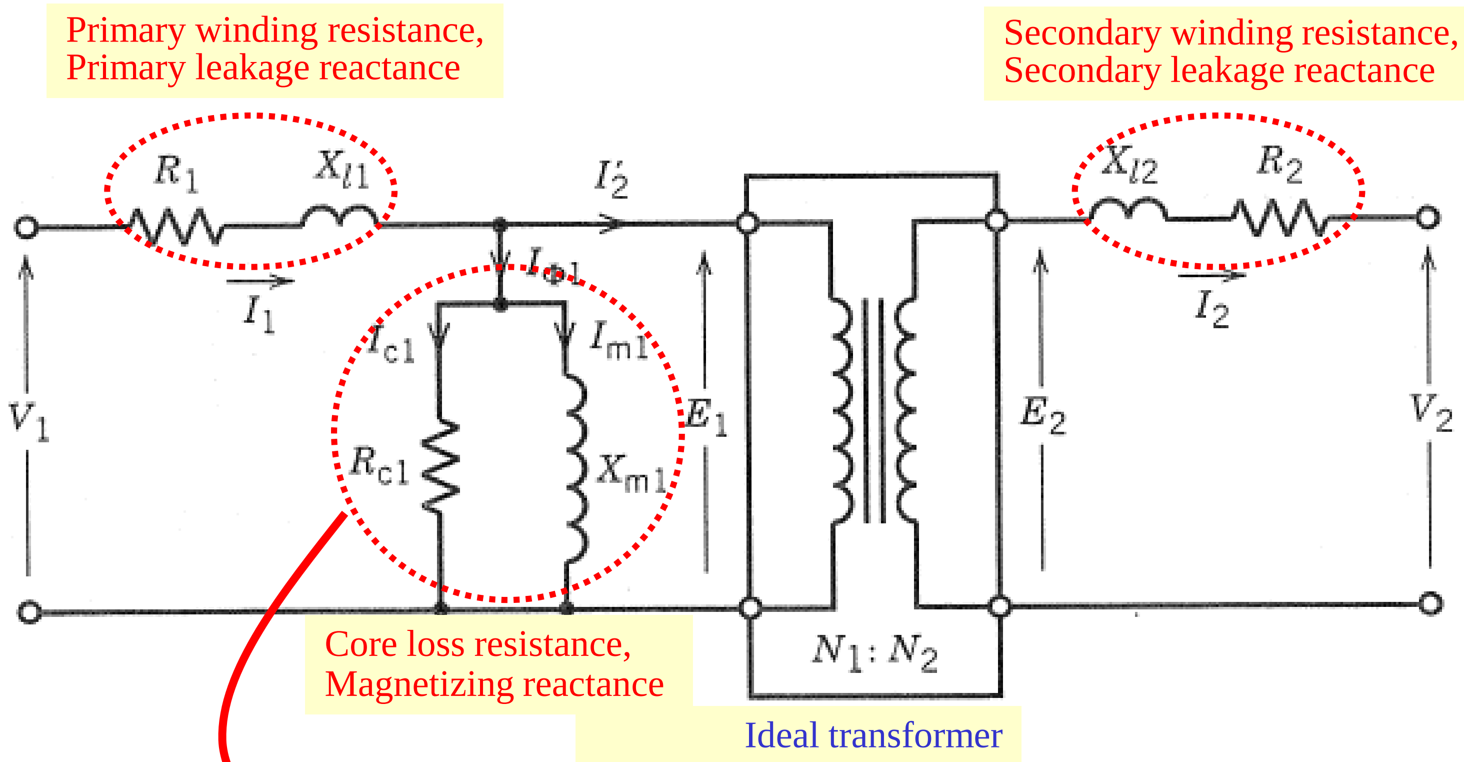


變壓器等效電路 (Transformer equivalent circuit)









Equivalent circuit parameters:

(1) Some are used in specific DC-DC converters (Flyback converter (*Lm*), LLC and CLLC converters).

(2) The effects of parasitic parameters must be considered for some DC-DC converters (Forward converter, …, etc.)

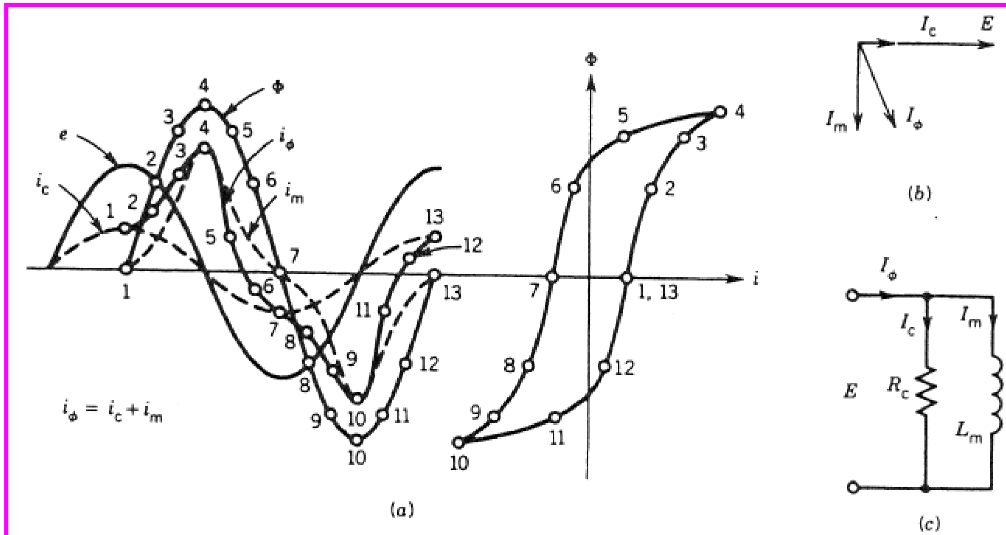


FIGURE 1.19 Exciting current with hysteresis loop. (a) Φ–i loop and exciting current. (b) Phasor diagram. (c) Equivalent circuit.

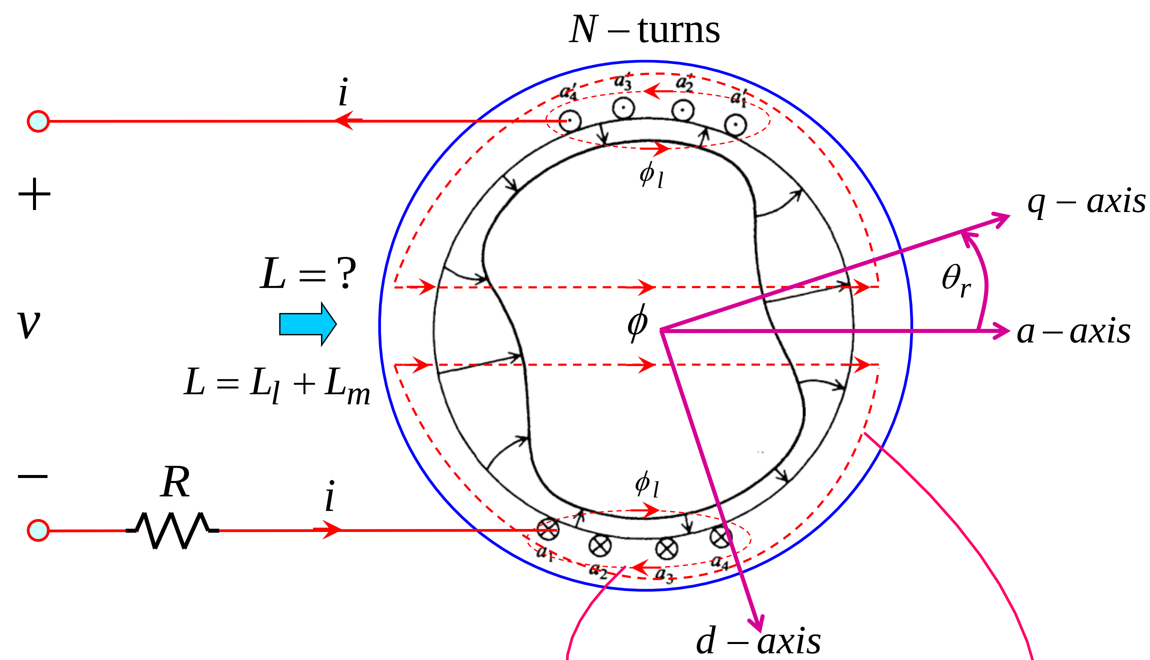
Physical modeling process of rotary electric machines

1. Energy transfer analysis and dynamic modeling:
   - Linear magnetic circuit assumption:
     Hysteresis loop >> Magnetization curve >> Linearized magnetization curve (Neglect saturation effect).
   - Flux linkage < > exciting current: $\lambda = Li$
   - Sinusoidal and symmetrical winding assumptions.
   - Sinusoidal and balanced currents assumptions.
   - The winding inductances of some machines may be function of rotor position.
   - List governing equations in abc-domain: (1) Voltage equations; (2) Torque and mechanical equations.
   - Reference frame transformations: List governing equations in dq-domain.
   - Equivalent circuit.
2. Performance efficiency analysis:
   - The core loss is added, which can be estimated from measurement.

Electric machine winding inductance

- Winding inductance may be function of rotor position for some specific machines.
- Winding inductance is decreased with the increased current and frequency.

- Core loss? It is significant for induction motor and synchronous reluctance motor (SynRM).



1. Under the assumption of conservative magnetic field, the core loss is neglected.
2. Conventionally, the IM and SynRM possess higher core losses. Hence, the core loss effects are considered in their specific controls for yielding better operation performances, including higher efficiencies.