CS1011：數位電子導論

Sensors

Outline

- Introduction
- Describing Sensor Performance
- Temperature Sensors
- Light Sensors
- Force Sensors
- Displacement Sensors
- Motion Sensors
- Sound Sensors
- Sensor Interfacing
- Future Energy Plan in Taiwan

Introduction

- Systems interact with environment via sensors and actuators

- Sensors and actuators are examples of transducers (轉換器)

  A transducer is a device that converts one physical quantity into another

  - Examples include:
    - A mercury-in-glass thermometer (converts temperature into displacement of a column of mercury)
    - A microphone (converts sound into an electrical signal)

- We will look at sensors in this lecture and at actuators in the next lecture

Wide Varieties of Sensors

- **Almost any physical property of a material that changes in response to some excitation can be used to produce a sensor**
  - **Widely used sensors include those that are:**
    - **Resistive**
    - **Capacitive**
    - **Inductive**
    - **Piezoelectric (壓電) [paɪˌizoɪˋlɛktrɪk]**
    - **Photo-resistive**
    - **Elastic**
    - **Thermal**
  - **In this lecture, we will look at several examples**

Describing Sensor Performance

Range

- Maximum and minimum values that can be measured

Resolution (解析度) or discrimination (鑑別度)

- Smallest discernible (可識別的) change in the measured value
- E.g., 0.1% percent of the full-scale value = one-thousandth ($\frac{1}{1000}$)

Error

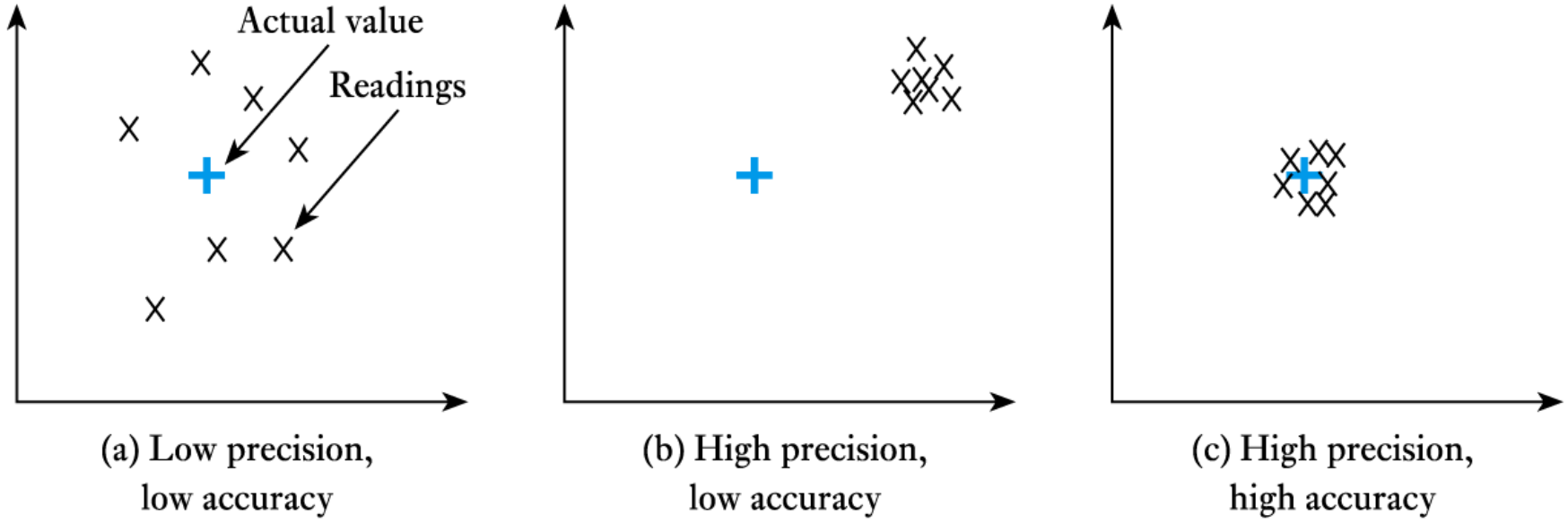
- Difference between the measured and actual values
  - Random errors
  - Systematic errors

Accuracy, inaccuracy, uncertainty

- Accuracy is a measure of the maximum expected error

Precision of a Sensor

- **Precision is very often confused with accuracy**
  - **A sensor might produce a range of readings that are very consistent but that are all very inaccurate**



(a) Low precision, low accuracy

(b) High precision, low accuracy

(c) High precision, high accuracy

Sensor Linearity and Sensitivity

Linearity

- Maximum deviation from a "straight-line" response
- Normally expressed as a percentage of the full-scale value

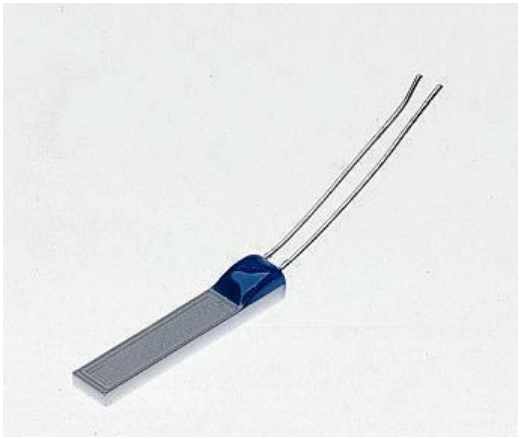
Sensitivity

- A measure of the change produced at the output for a given change in the quantity being measured
- E.g., the sensitivity of temperature sensor might be given as 10 mV/˚C, meaning that the output would change by 10 mV for every 1 ˚C change in temperature.

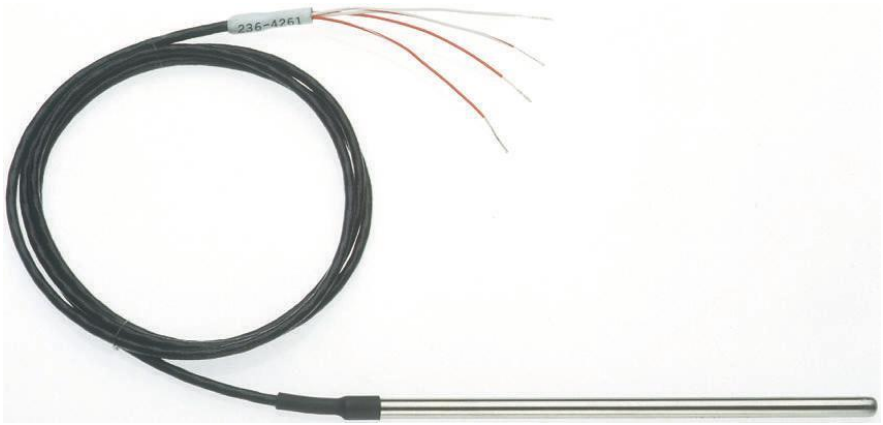
Temperature Sensors (1/3)

Resistive thermometers

- Typical devices use platinum wire (such a device is called a platinum resistance thermometers or PRT), ranges -150 °C to 1000 °C.
- *Linear* but has poor *sensitivity*
  - 100 Ω at 0 ˚C; 140 Ω at 100 ˚C



A typical PRT element



A sheathed PRT

Temperature Sensors (2/3)

▣ Thermistors (熱敏電阻)

- Use materials with a high thermal coefficient of resistance
- Negative/Positive Temperature Coefficient (NTC/PTC)
  - NTC thermistors are commonly used as a temperature sensor
  - PTC thermistors are commonly used to protect overcurrent conditions
- *Sensitive* but highly *non-linear*
  - 5 kΩ at 0 ˚C; 1.5 kΩ at 25 ˚C; 500 Ω at 50 ˚C; 200 Ω at 75 ˚C, 100 Ω at 100 ˚C

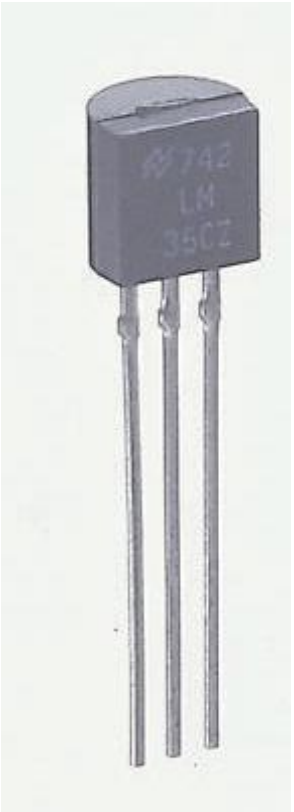
A typical disc thermistor

A threaded (螺紋) thermistor

Temperature Sensors (3/3)

pn junctions

- A semiconductor device with the properties of a diode (we will talk about semiconductors and diodes later)
- *Inexpensive*, *linear* and *easy to use*
  - *Limited temperature range* (around -50 °C to 150 °C) due to the nature of semiconductor material



pn-junction sensor

Light Sensors (1/3)

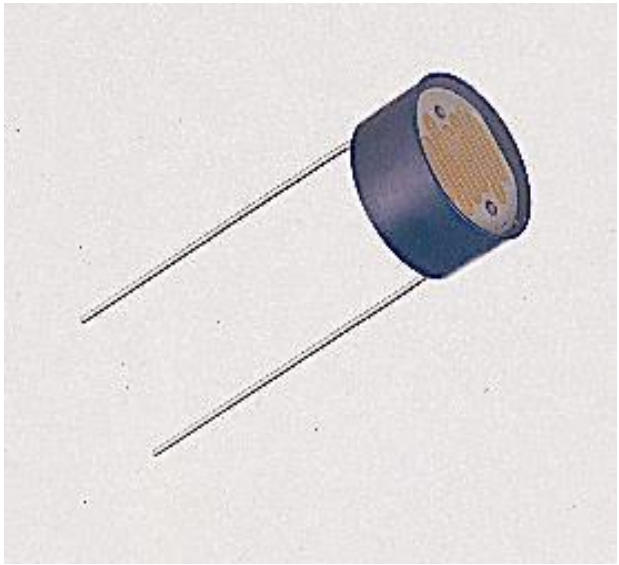
▣ Photovoltaic (光伏)

- Light falling on a *pn*-junction can be used to generate electricity from light energy (as in a solar cell)
- Small devices used as sensors are called photodiodes (光電二極體)
- Fast acting, but the voltage produced is *not* linearly related to light intensity and temperature

A typical photodiode

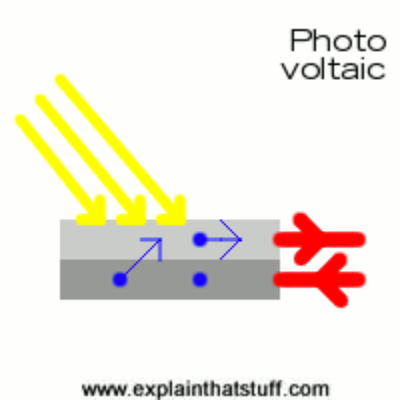
Light Sensors (2/3)

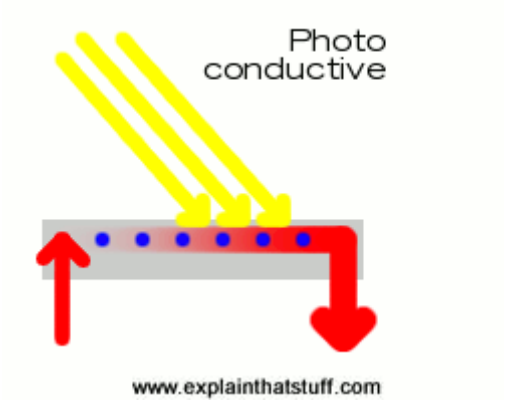
- **Photoconductive Sensors** do not produce electricity, but simply change their resistance
  - Photodiode (as described earlier) can be used in this way to produce a linear device
- Phototransistors act like photodiodes but with greater sensitivity
  - Light-dependent resistors (光敏電阻, LDR) are slow (around 100 ms), but respond like the human eye

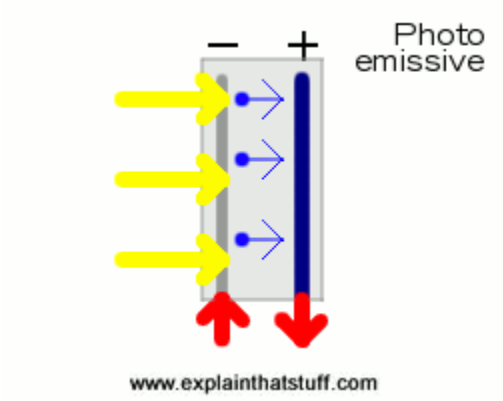


A light-dependent resistor (LDR)

Three Types of Photoelectric Cells







- **Photovoltaic — light makes electrons move between layers, producing a voltage and a current in an external circuit.**
- **Photoconductive — light increases the flow of electrons and reduces the resistance.**
- **Photoemissive (光電效應) — light knocks electrons from a cathode to an anode, making a current flow through an external circuit.**

Source: http://www.explainthatstuff.com/how-photoelectric-cells-work.html

Light Sensors (3/3)

Image sensors

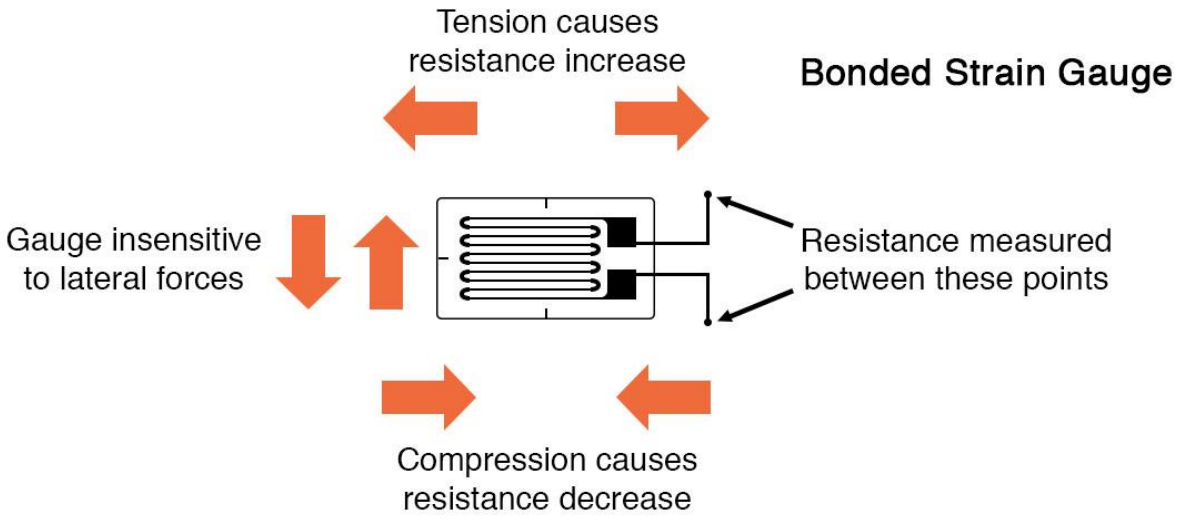
- Several technologies are available, but the most common form is CMOS
- A rectangular array of sensing elements, each element responsible for a single pixel of the image
- A typical sensor might have an aspect ratio of 4:3 or 3:2
- Resolutions vary tremendously

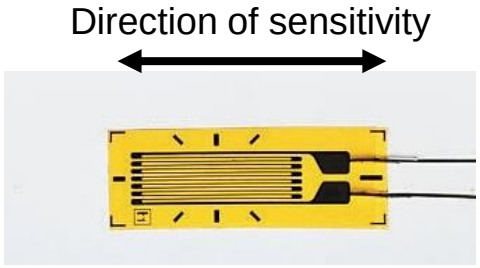
Image sensors

Force Sensors (1/2)

▣ Strain gauge

- Stretching in one direction increases the resistance of the device, while stretching in the other direction has little effect
- Can be bonded to a surface to measure strain
- Used within load cells (稱重) and pressure sensors (壓力)

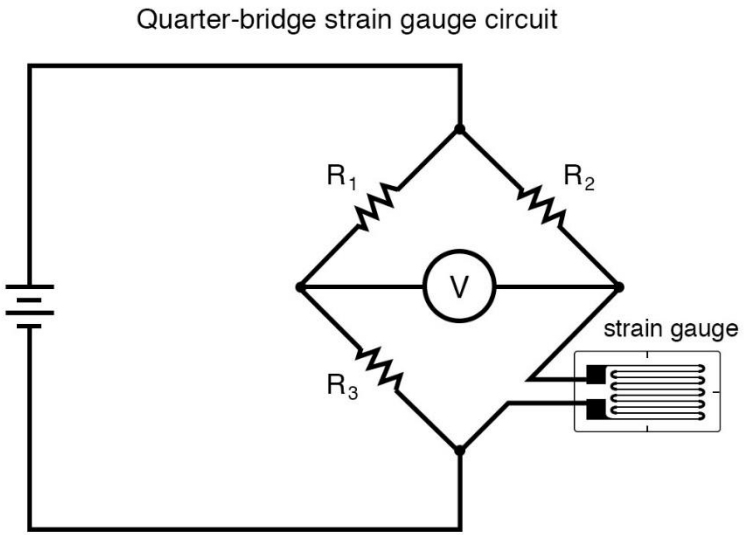




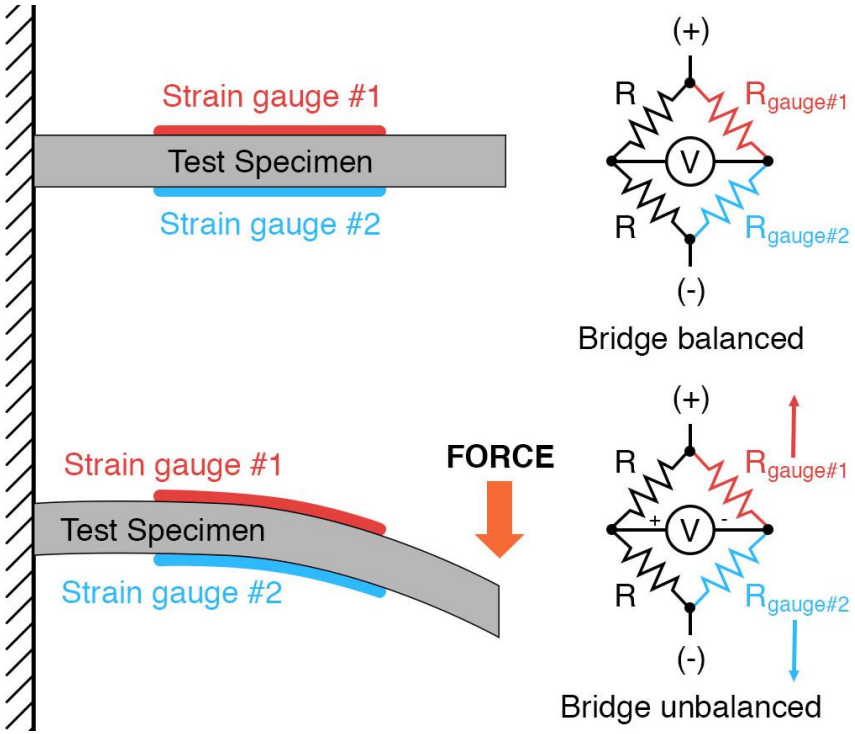
A strain gauge

Force Sensors (2/2)

- **Typical strain gauge resistances range from 30 Ω to 3 kΩ (unstressed). This resistance may change only a fraction of a percent for the full force range of the gauge, given the limitations imposed by the elastic limits of the gauge material and of the test specimen.**



Single strain gauge

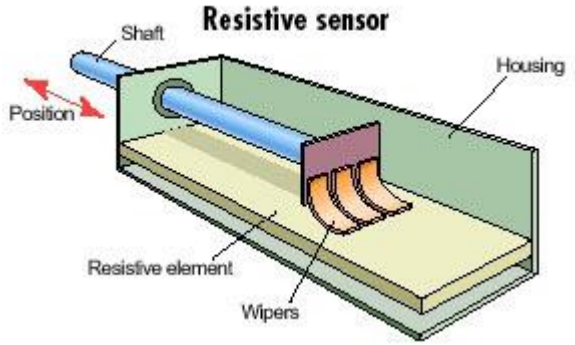


Two strain gauges

Displacement Sensors (1/7)

Potentiometers

- **Resistive potentiometers are one of the most widely used forms of position sensor for either angular or linear displacement.**
  - **Resistive potentiometers consist of a length of resistive material with a sliding contact onto the resistive track. When used as a position transducer a potential is placed across the two end terminals, the voltage on the sliding contact is then proportional to its position. It is inexpensive and easy to use.**



A potentiometer

Displacement Sensors (2/7)

Inductive proximity sensors

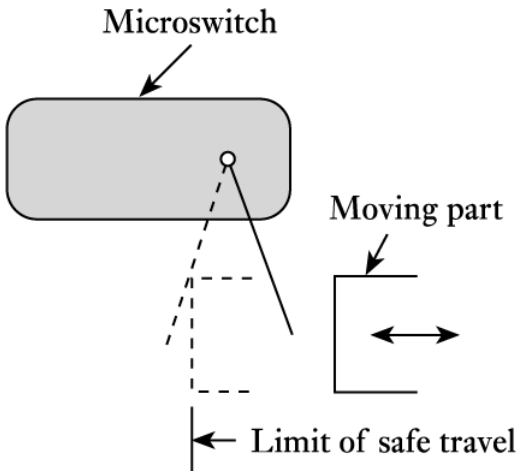
- Coil inductance is greatly affected by the presence of ferromagnetic materials (鐵磁性材料)
- The proximity of a ferromagnetic plate is determined by measuring the inductance of a coil
- We will look at inductance in later lectures

Inductive proximity sensors

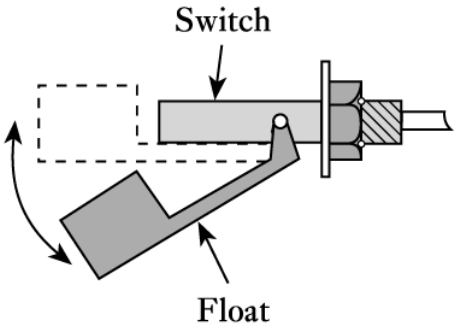
Displacement Sensors (3/7)

Switches

- **Simplest form of *digital* displacement sensor**
  - **Many forms: lever or push-rod operated micro-switches; float switches; pressure switches; etc.**



A limit switch

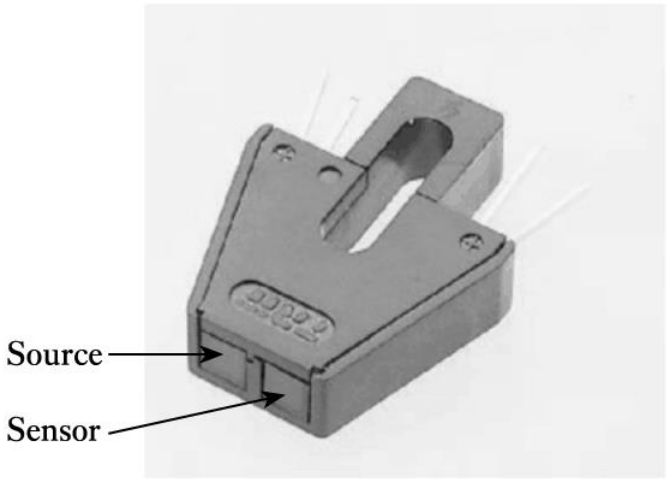


A float switch

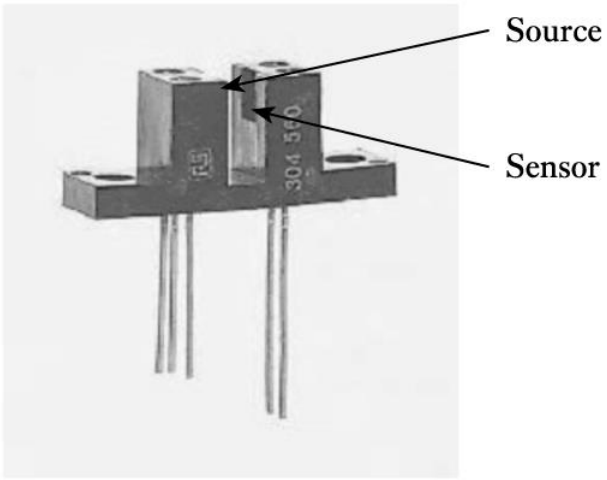
Displacement Sensors (4/7)

Opto-switches

- Consist of a light source and a light sensor within a single unit
  - 2 common forms: reflective and slotted



A reflective opto-switch

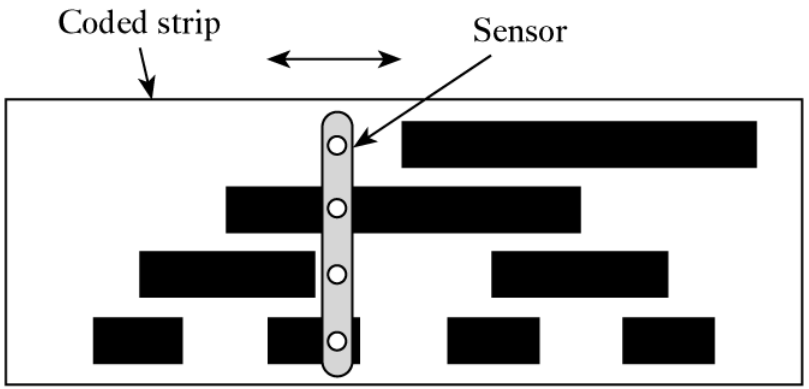


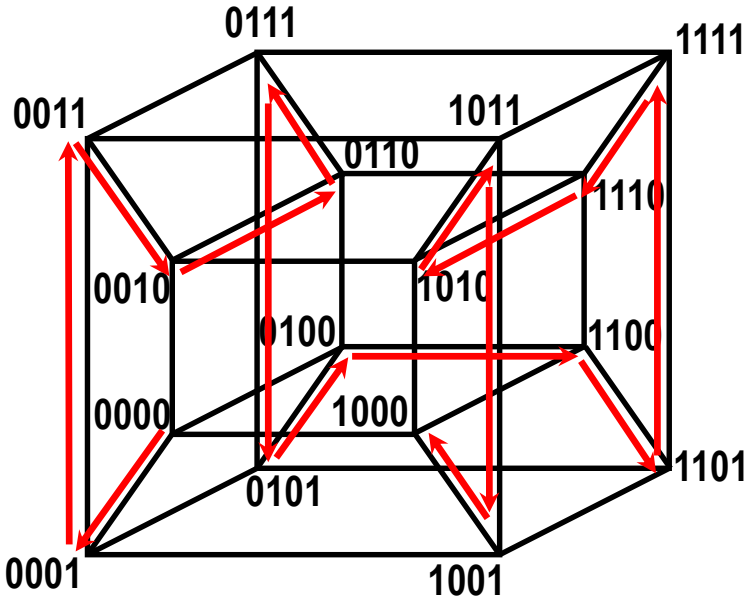
A slotted opto-switch

Displacement Sensors (5/7)

Absolute position encoders

- A pattern of light and dark strips is printed on to a strip and is detected by a sensor that moves along it
  - The pattern takes the form of a series of lines as shown below
  - It is arranged so that the combination is unique at each point
  - Sensor is an array of photodiodes



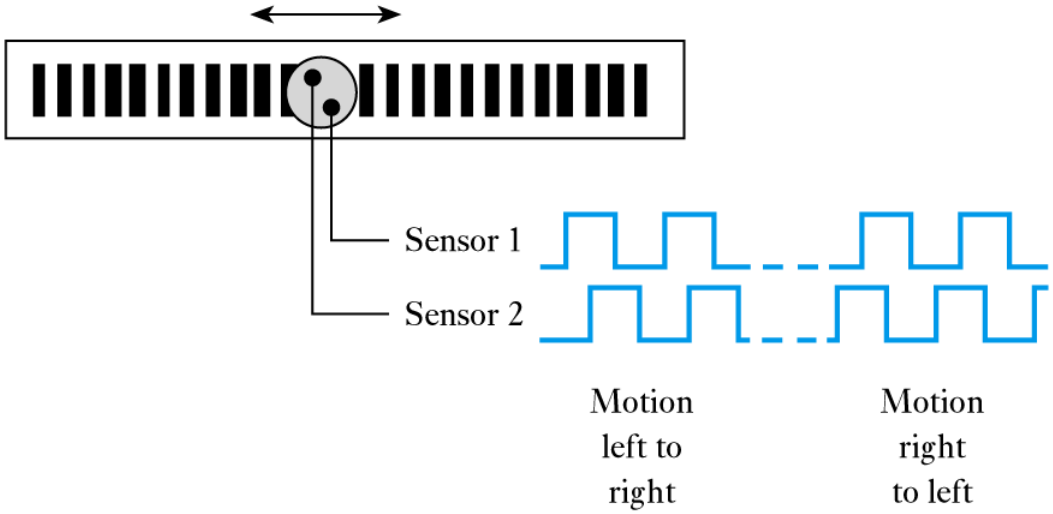


4-bit Gray Code

Displacement Sensors (6/7)

Incremental position encoder

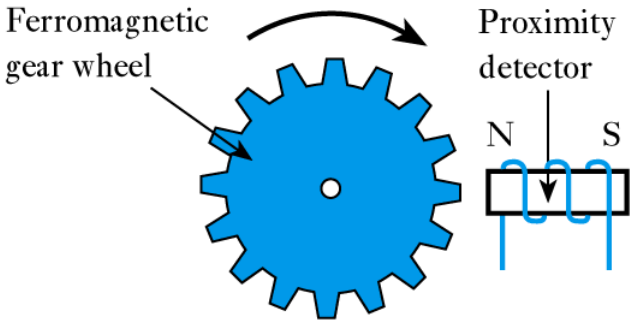
- Uses a single line that alternates black/white
  - Two slightly offset sensors could produce outputs for the detection of motions in either direction
  - Pulses are counted to determine absolute position (must be initially reset)



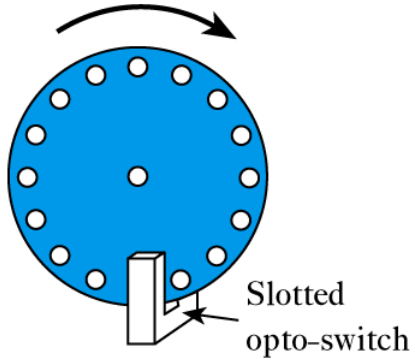
Angular position encoder

Displacement Sensors (7/7)

- **Other counting techniques**
  - **Several methods use counting to determine position**
    - » **Two examples are given below**



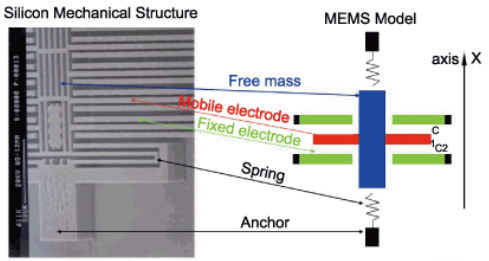
Inductive sensor



Opto-switch sensor

Motion Sensors

- **Motion sensors measure quantities such as velocity and acceleration**
  - **Can be obtained by differentiating displacement**
  - **However, differentiation tends to amplify high-frequency noise!**
- **Therefore, we measure motions directly**
  - **Some sensors give velocity directly**
    - » **E.g., measuring *frequency* of pulses in the counting techniques described earlier gives speed rather than position**
  - **Some sensors give acceleration directly**
    - » **E.g., accelerometers usually measure the force on a mass**
      - **With the Newton's Second Law: $acceleration = \frac{Force}{mass}$**
        - **By using strain gauge, displacement transducer, etc.**

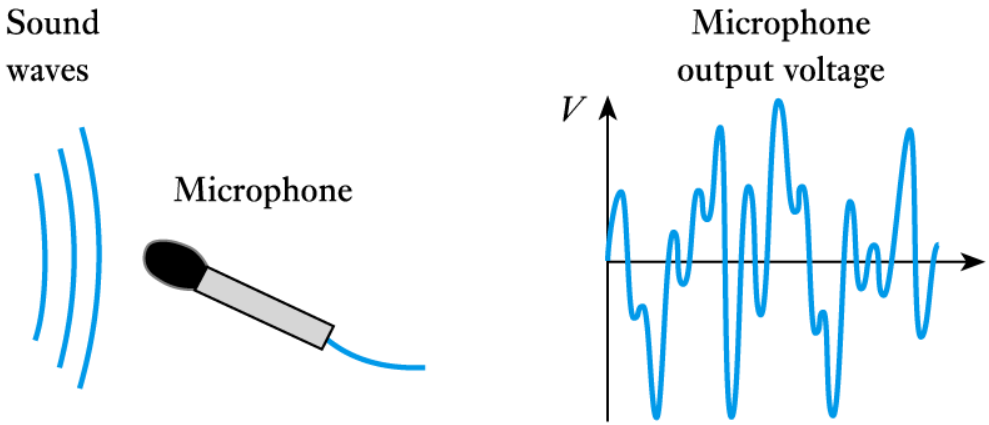


MEMS Sensor

Sound Sensors

Microphones

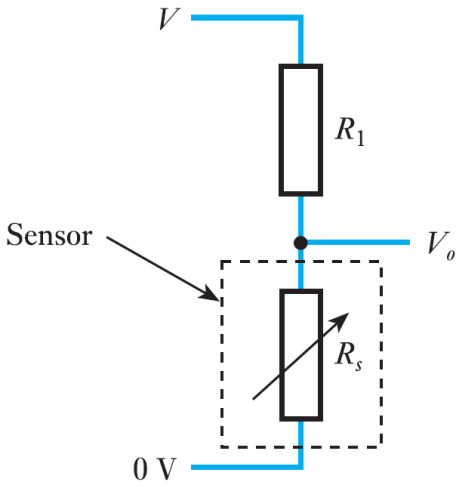
- A number of forms are available
  - E.g. carbon (resistive), capacitive, piezoelectric, and moving-coil microphones
  - Moving-coil devices use a magnet and a coil attached to a diaphragm (薄膜)
    - We will discuss electromagnetism later

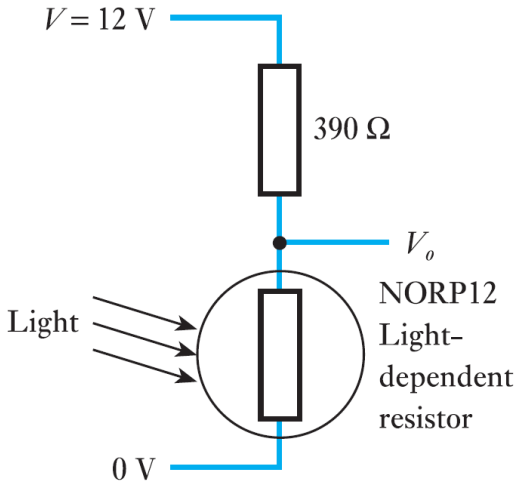


Sensor Interfacing (1/3)

Resistive devices

- Can be very simple
  - E.g., in a potentiometer, with a fixed voltage across the outer terminals, the voltage on the third is directly related to position.
- If the resistance of the sensor changes, we can converted the resistance into a voltage signal using a potential divider.
  - However, the voltage is not linearly related to the change in resistance!

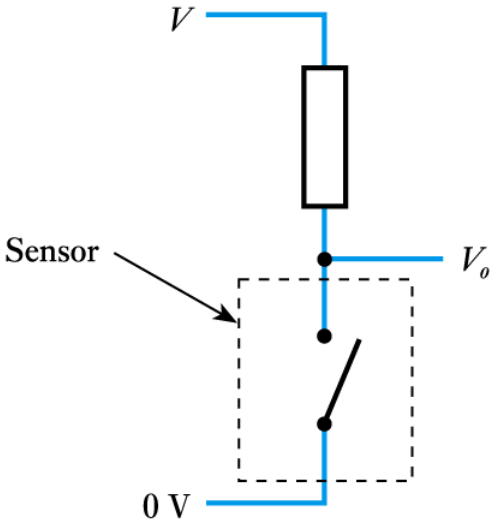


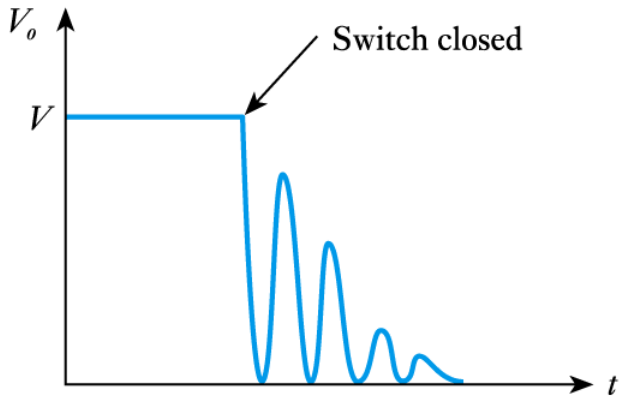


$$V_0 = V\frac{R_s}{R_1 + R_s}$$

Sensor Interfacing (2/3)

- **Switch interfacing is also simple**
  - **Can use a single resistor as below to produce a voltage output**
  - **All mechanical switches suffer from switch bounce**





Sensor Interfacing (3/3)

Capacitive and inductive sensors

- Sensors that change their capacitance or inductance in response to external influences normally require the use of alternating current (AC) circuitry
- Such circuits may not be very complicated. However, we will not cover such topics in this course.

Key Points

- A wide range of sensors is available
- Some sensors produce an output voltage related to the measured quantity and therefore supply power (very small)
- Other devices simply change their physical properties, such as resistance, capacitance, or inductance
- Some sensors produce an output that is linearly related to the quantity being measured, others do not
- Interfacing may be required to produce signals in the correct form

STUDENT

Future Energy Plan in Taiwan - 1

資料提供：經濟部

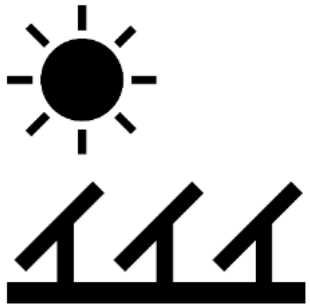
Future Energy Plan in Taiwan - 2

太陽光電產業

目標

109年	114年
6.5GW	20GW

推動現況說明



現有總裝置容量

980.5MW

(占114年政策目標量4.9%)

105年8月底止

太陽光電2年推動計畫 9/8行政院准予備查

1520MW

屋頂型910MW

地面型610MW

105/7~107/6

二大類型

屋頂型

中央公有屋頂、工廠屋頂、農業設施及其它屋頂

地面型

鹽業用地、嚴重地層下陷區域、水域

空間(水庫、滯洪池、埤塘、魚塭)及掩埋場

6

Future Energy Plan in Taiwan - 3

風力發電產業

以台灣風場為產業鏈本土化練兵場域，搶攻亞太離岸風場

推動規劃與現況說明

陸域現況

總計 **682MW** / **346 架**

國營 **294MW** **169 架**

民營 **388MW** **177 架**

(占 114年政策目標 56.8 %)

(統計至 105 年 8 月底)

目標

短程	中程	長程	
671	745	1,200	陸域
			單位 (MW)
16	520	3,000	離岸

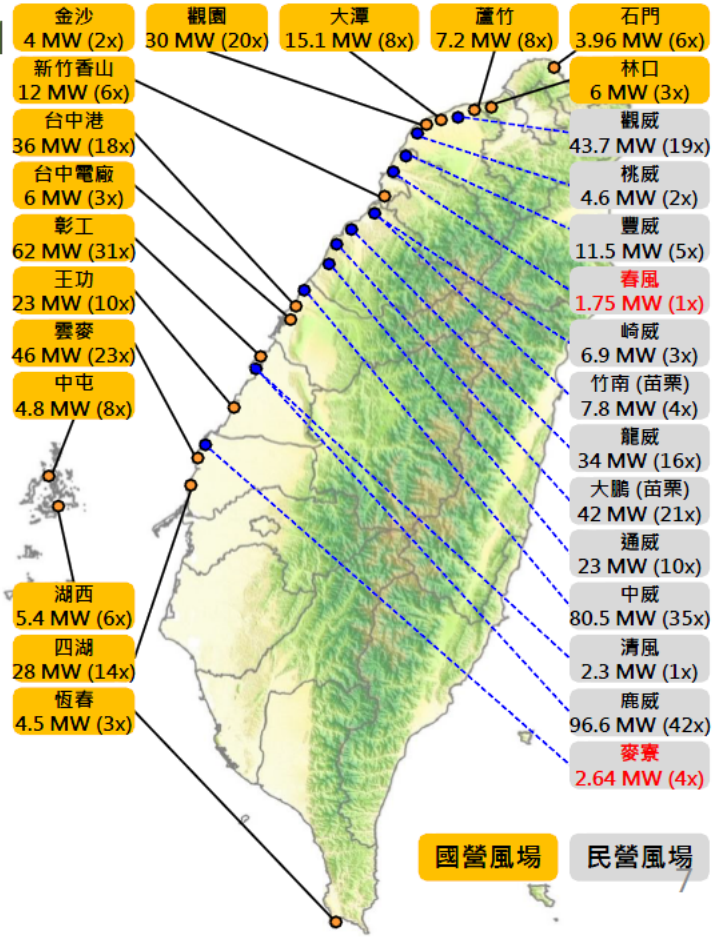
離岸現況

累計裝置容量

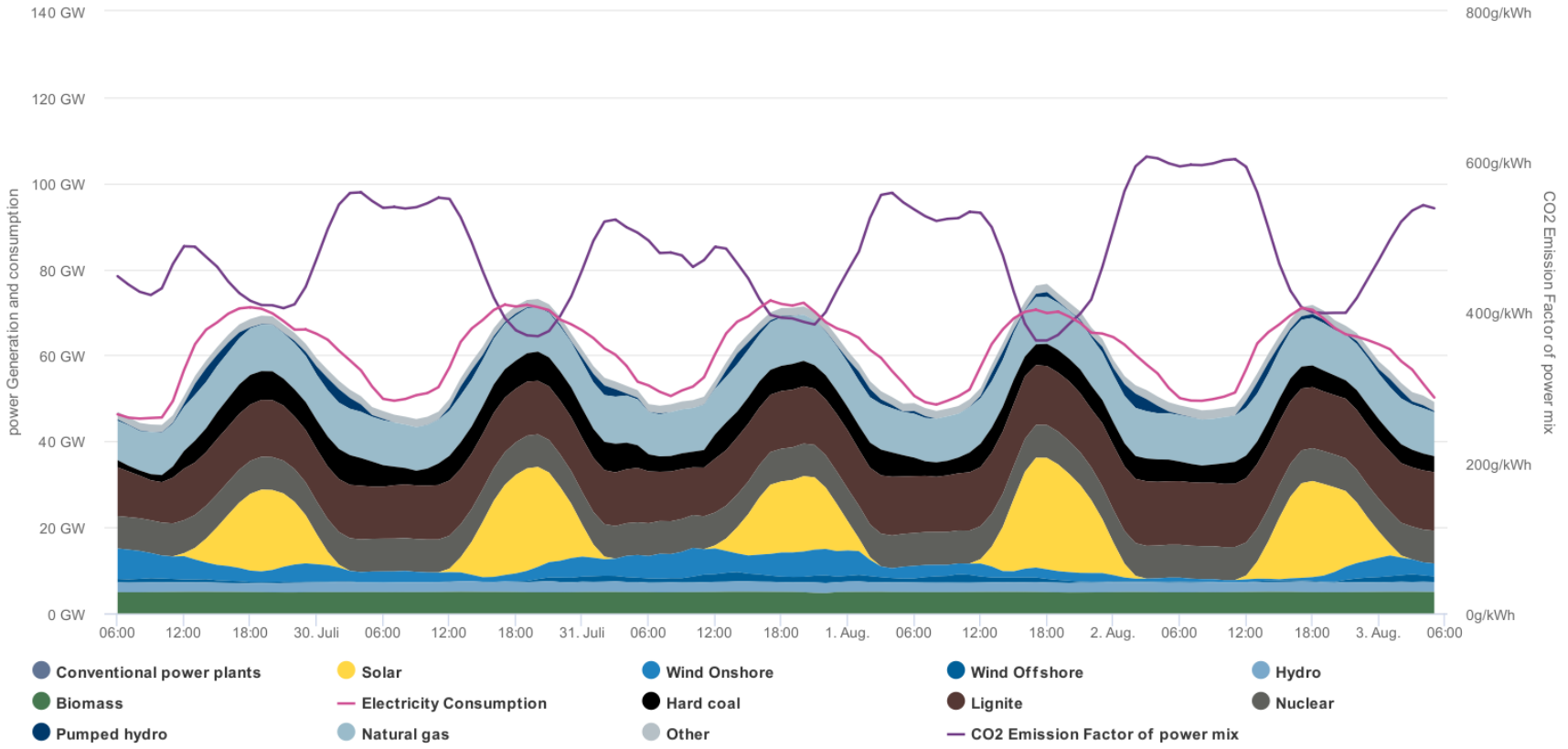
目前尚無設立離岸風力機 (0 MW)。

預計105年底完成4架示範機組 (16 MW)。

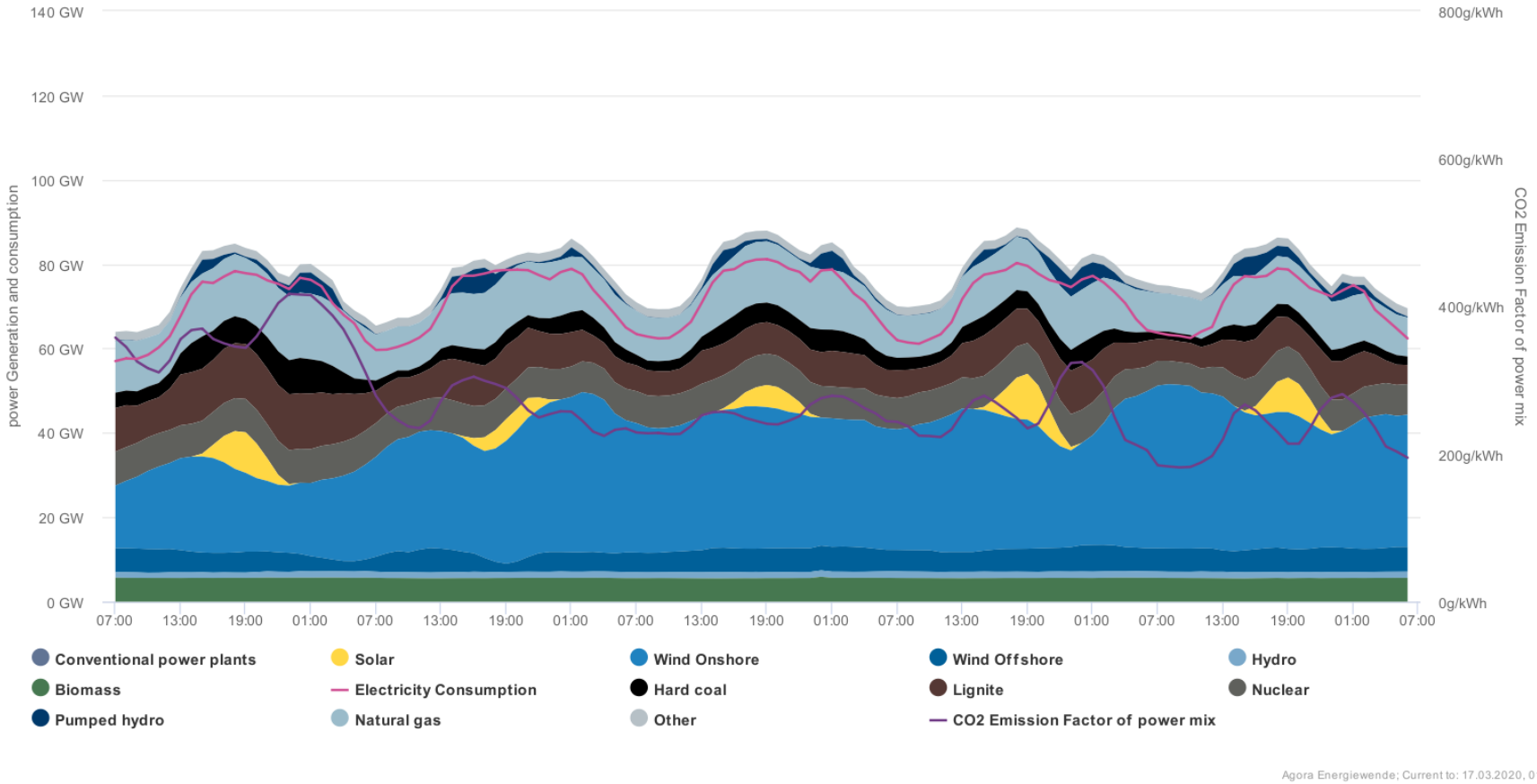
(占 114年政策目標 0.5 %)



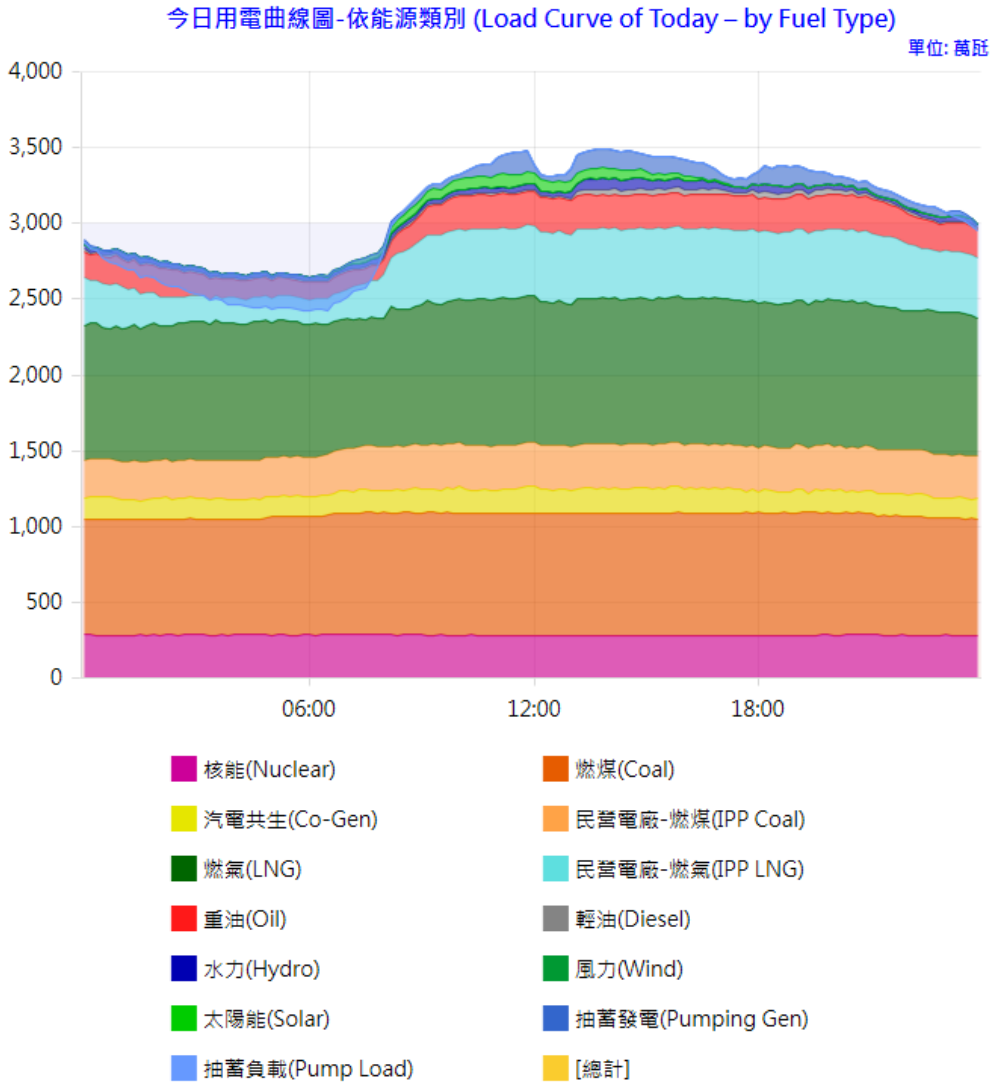
Power Generation in Germany (2019/07/29-08/02)



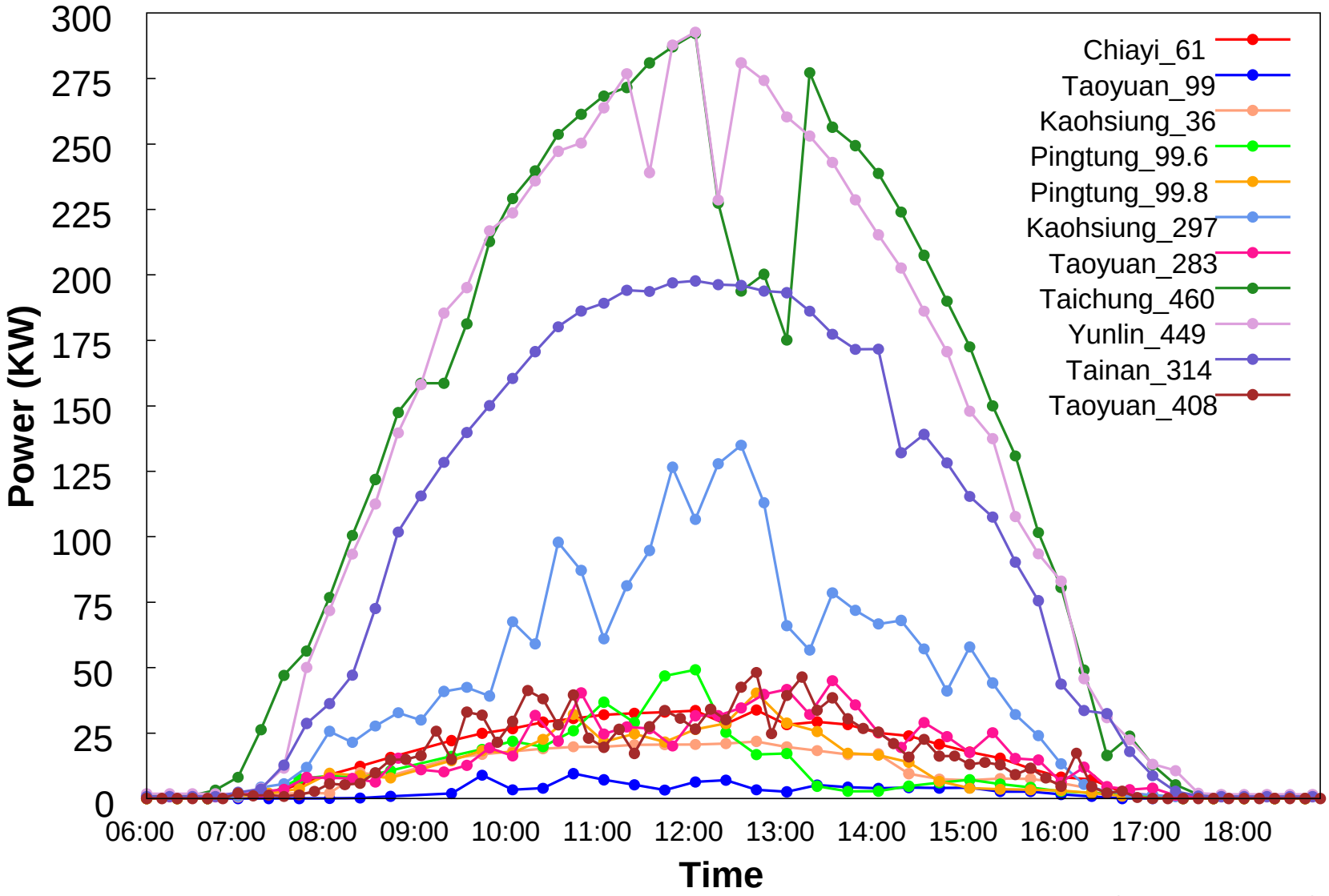
Power Generation in Germany (2020/01/27-01/31)



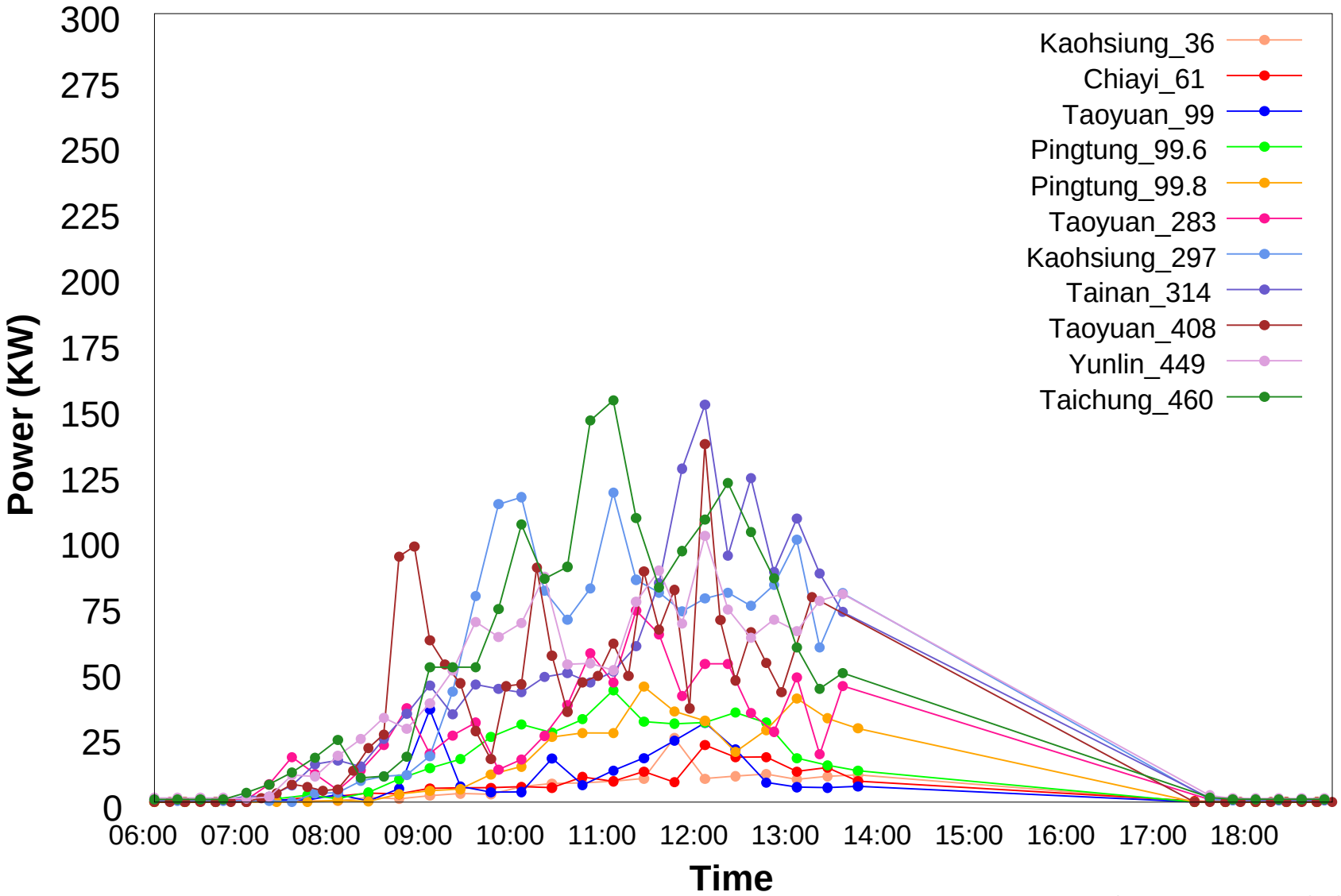
Current Energy Source in Taiwan (2018/09/21)



NTUST PV Data Collection (2018/12/27)



NTUST PV Data Collection (2019/01/16)



PV Sites for Data Collections

案場代號	裝置容量	案場地點	案場所有單位	資通訊方式
NTUST_NEP2 (計畫實驗案場)	6 KWp	台北	台科大	Online Modbus
NTUST_NEP2_04736133904	408.87 KWp	桃園	旭鑫能源	Database Query
NTUST_NEP2_03514797039	22.2 KWp	宜蘭	綠點能創	Socket API
NTUST_NEP2_04211256885	99.71 KWp	桃園	綠點能創	Socket API
NTUST_NEP2_09683773001	61.8 KWp	嘉義	綠點能創	Socket API
NTUST_NEP2_11562902959	36 KWp	高雄	綠點能創	Socket API
NTUST_NEP2_12747203979	99.825 KWp	屏東	綠點能創	Socket API
NTUST_NEP2_12621273864	99.6 KWp	屏東	綠點能創	Socket API
NTUST_NEP2_04762770886	283.20 KWp	桃園	大同公司	Socket API
NTUST_NEP2_07924388970	460.80 KWp	台中	大同公司	Socket API
NTUST_NEP2_19920095028	449.28 KWp	雲林	大同公司	Socket API
NTUST_NEP2_10140017995	314.08 KWp	台南	大同公司	Socket API
NTUST_NEP2_18387450015	297.36 KWp	高雄	大同公司	Socket API
NTUST_NEP2_22820546128	93.60 KWp	金門	大同公司	Socket API
NTUST_NEP2_22750296980	499.20 KWp	金門	大同公司	Socket API
NTUST_NEP2_22660007319	424.32 KWp	金門	大同公司	Socket API
NTUST_NEP2_22580004305	249.60 KWp	金門	大同公司	Socket API

Taiwan Energy Transition (2022/02)

天下雜誌

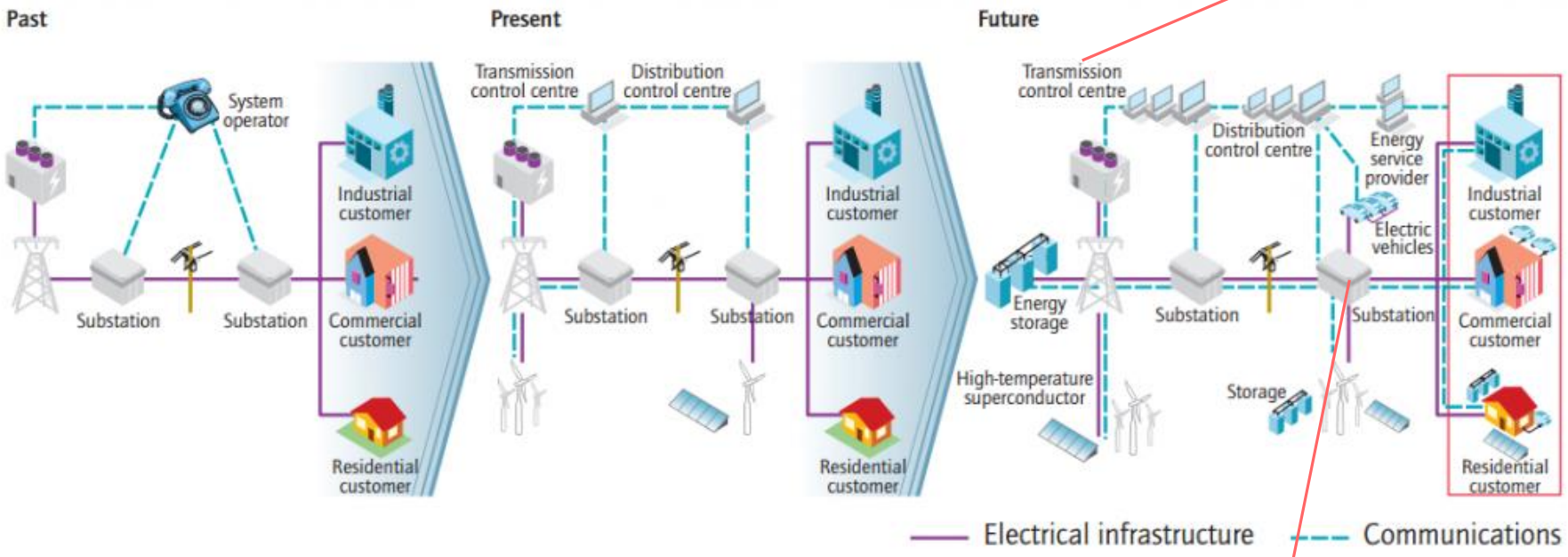
他們在「風光」之外，搶進穩綠電商機

新能源戰隊與重點領域

	公司名	穩綠電實績
地熱	結元能源	宜蘭清水地熱電廠（已商轉）
	李長榮化工	台東金崙地熱電廠計劃
	台泥綠能	台東延平地熱園區計劃
	倍速羅得	花蓮萬榮地熱電廠計劃
	中油	宜蘭仁澤、土場地熱電廠計劃
	台電	宜蘭仁澤地熱電廠計劃
	工研院	全台地熱探勘
	漢力能源科技	國產地熱發電設備
生質能源	東糖能源	屏東內埔東糖沼氣中心
	台糖	東海豐畜殖場循環園區
	永豐餘	木質素發電、沼氣發電、SRF 汽電共生
	正隆	沼氣發電、SRF 汽電共生
	山林水環工	外埔綠能園區、沼氣發電設備
	漢能綠電	速生草種植與生質能發電設備
水力	台電	11 座水力發電廠、10 個進行中小水力計劃
	水利署	盤點全國小水力潛力場址，已完成牡丹水庫小水力
	農田水利會	烏山頭水力發電廠
	大同	4MW 儲能系統通過台電測試，為首家加入台電電力交易平台的廠商。另有 1MW 儲能系統獲得台電 AFC 標案
儲能	台達電	5MW 儲能系統 11 月加入台電電力交易平台，投入電力輔助服務市場
	大亞電線電纜	1MW 儲能系統興建中，未來儲能系統將搭配光電場
	台泥綠能	5MW 儲能系統獲得台電 AFC 標案。另將投資 55 億元，在蘇澳、和平建置 87.5MW 及 250MW 的大型儲能系統
	台普威能源	2MW 儲能系統獲得台電 AFC 標案
	翰可國際	5MW 儲能系統獲得台電 AFC 標案
	聚恆科技	2MW 儲能系統獲得台電 AFC 標案
穩定供電	亞力電機	不斷電系統
	台達電	不斷電系統
	伊頓	不斷電系統
	雅瑞科技	不斷電系統
綠能售電	富威電力	隸屬正崴集團，主要客戶包括群聯等
	陽光伏特家	以群眾集資概念打造再生能源售電平台，管理全台超過 350 個光電場
	瓦特先生	將台中的綠電賣給台灣萊雅，完成台灣商辦首筆綠電交易
	台汽電綠能	國內轉供量最大的再生能源售電業者，主要客戶包括台達電、台灣大哥大
智慧能源管理	聯齊科技	虛擬電廠與智慧能源管理系統已打進日本發電量前五大的中部電力公司
	優必閣	取得 10 億元的台電智慧電表布建專案
	斯其大科技	智慧電表、智慧水表與智慧能源管理相關產品

Renewable Energy and Smart Grid

軟硬體資通訊
電力系統整合



Source: Unless otherwise indicated, all material derives from IEA data and analysis.

人工智慧
供需平衡技術