Distributed Generation

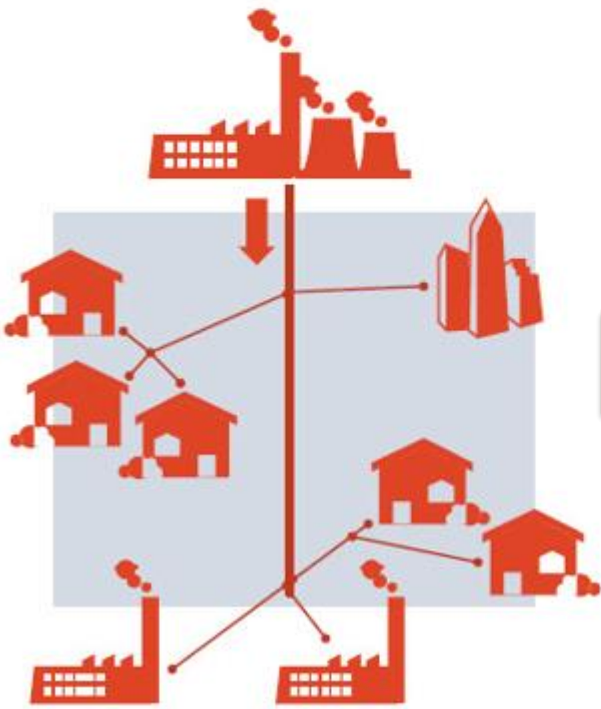
Dr Yan Xu
Associate Professor | School of EEE
Nanyang Technological University
Singapore

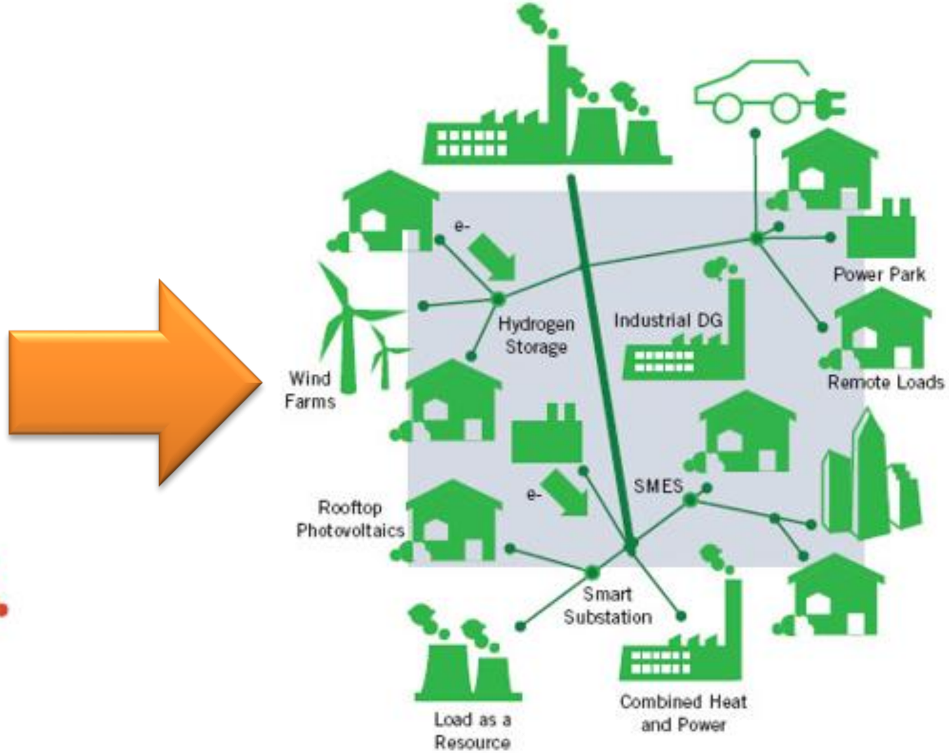
EE6509 – “Renewable Energy Systems in Smart Grids”

Lecture Objectives

1. **Review mainstream distributed generation techniques**
2. Introduce the roles of different stakeholders and electricity market in Singapore
3. Discuss the challenges of distributed generation integration to the power system

Centralized v.s. Distributed

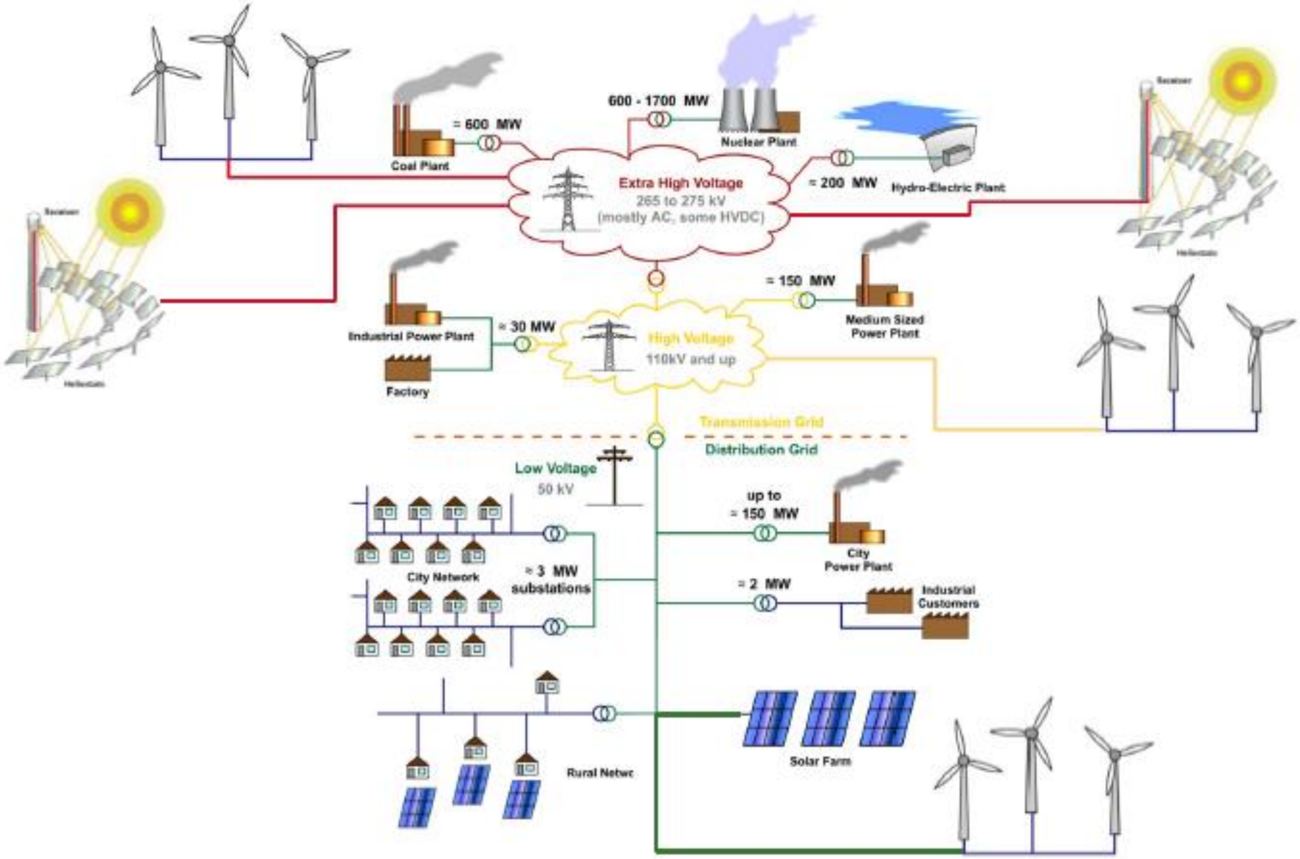




• Conventional power generation are based on coal, gas and nuclear, as well as hydroelectric and large-scale solar power stations, are **centralized, large capacity,** and often require electricity to be **transmitted over long distances**.

• By contrast, distributed generation systems are decentralized, modular and using more flexible technologies, that are **located close to the loads** they serve, generally having capacities of less than 10 megawatts (MW).

Typical Characteristics of DG



- **Small** in size (normally up to 1MW)
- **Clean** energy oriented (solar, wind, biogas)
- Located **nearer** the loads, connected at distribution levels (low voltage)
- Can be owned by **customers**

Why DG?

- **Promote** clean energy integration
- **Improves** power supply reliability and availability
- **Independent** of distribution network failures
- **Alleviate** the impact of individual generator(s) failure
- **Onsite** trigeneration of heat, electricity and cooling (**multi-energy supply**)
- Reduces transmission and distribution **losses**

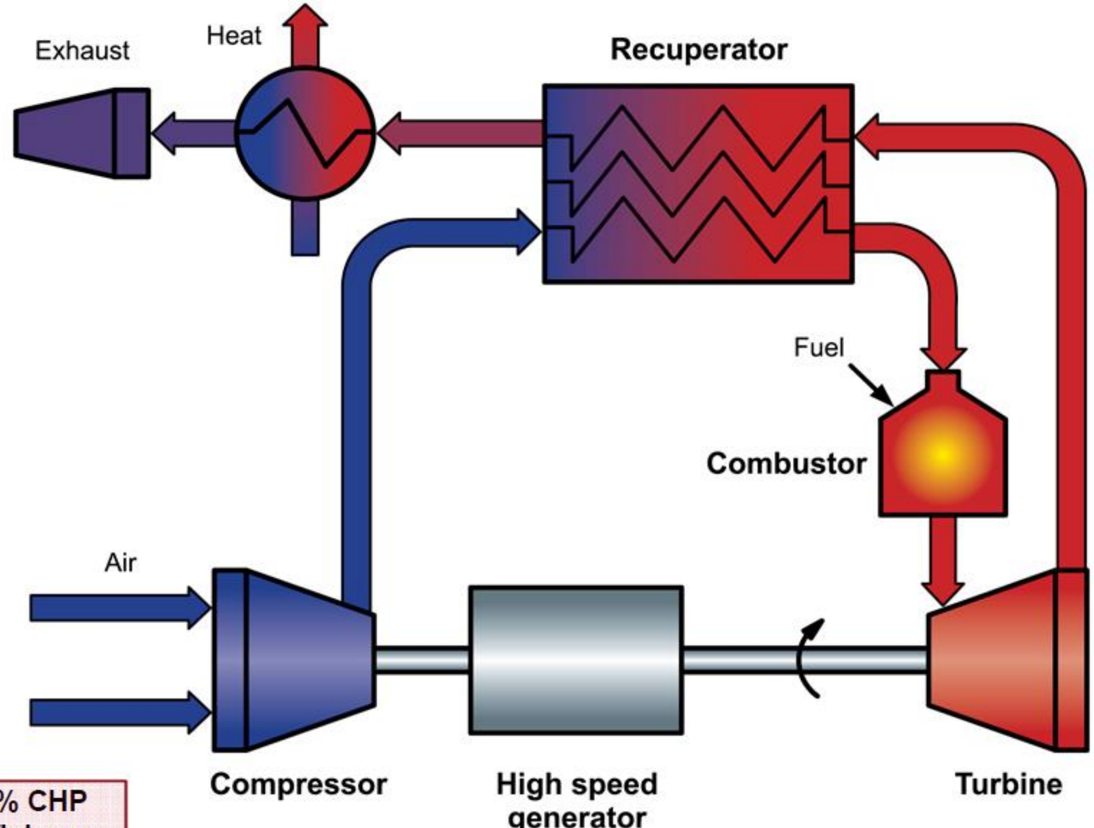
Mainstream DG units

1. Micro-turbines
2. Biogas
3. Small hydro
4. Photovoltaic systems (rooftop solar PV)
5. Small wind power systems
6. Fuel cells

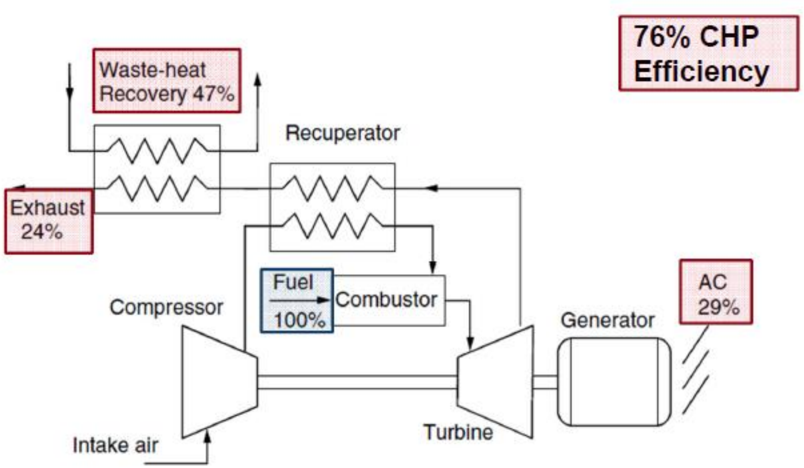
controllable V.S. non-controllable

utility-owned V.S. customer-owned

Micro Turbines

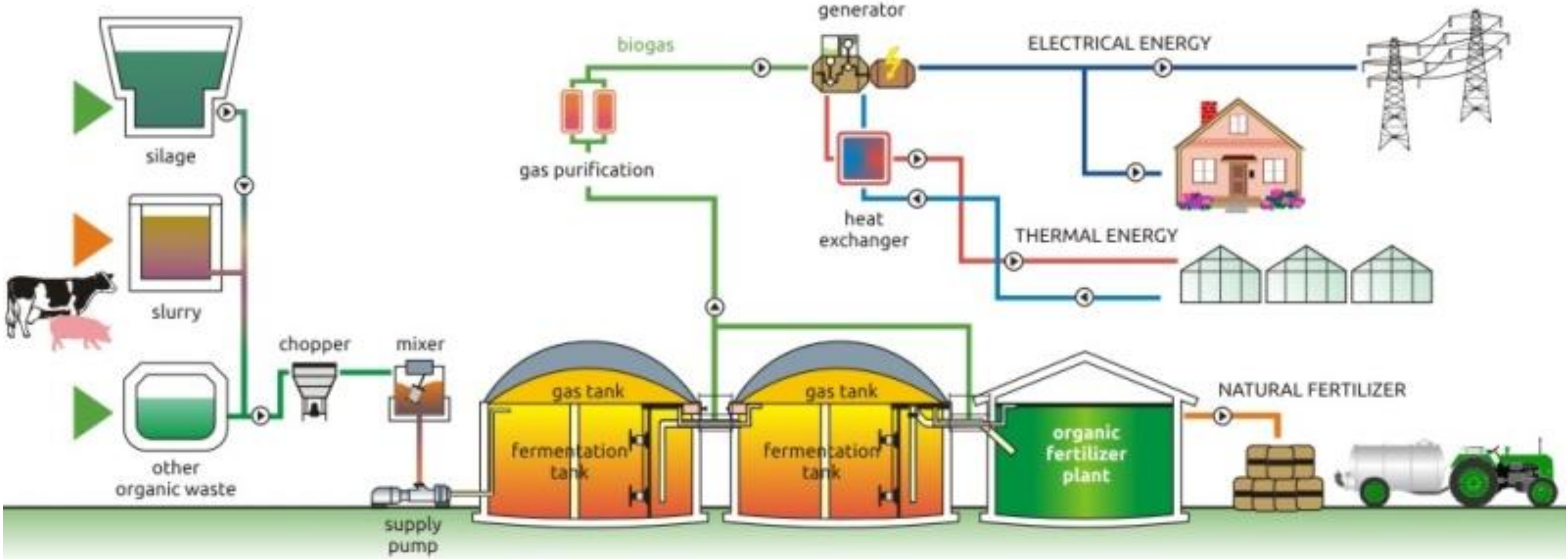


http://www.enertwin.com/enertwin-en/the-micro-turbine-technology



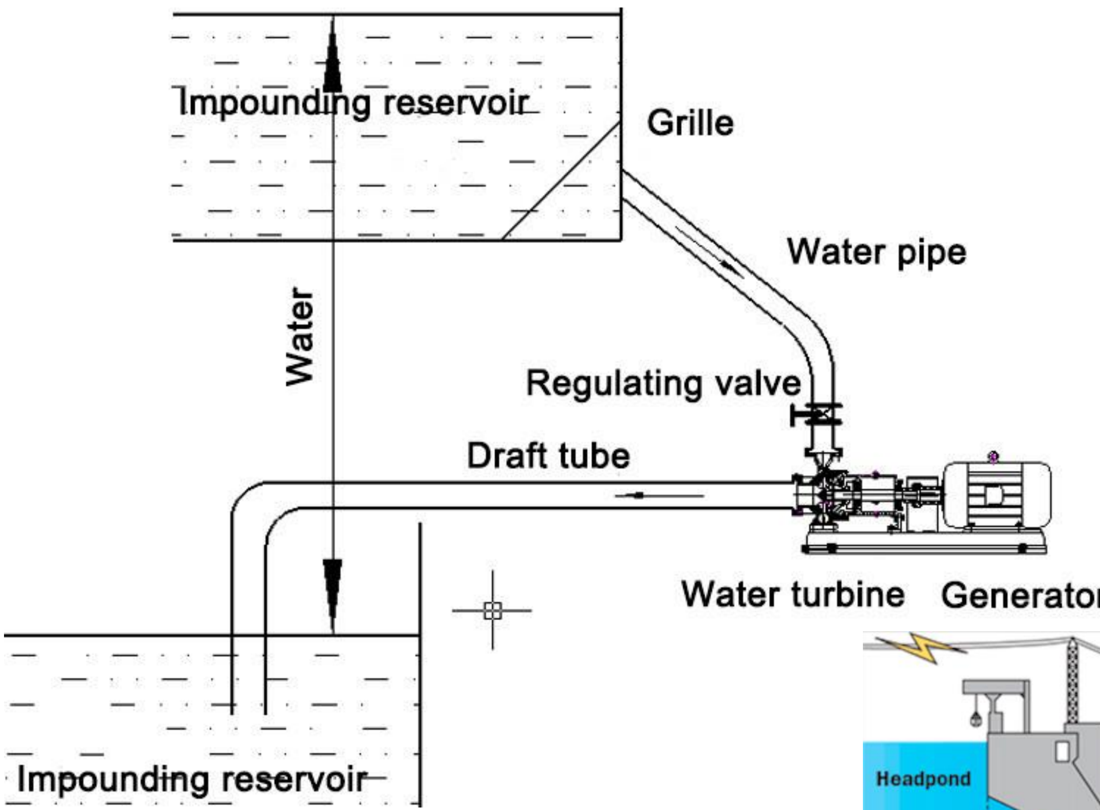
Combined cooling and heating generation

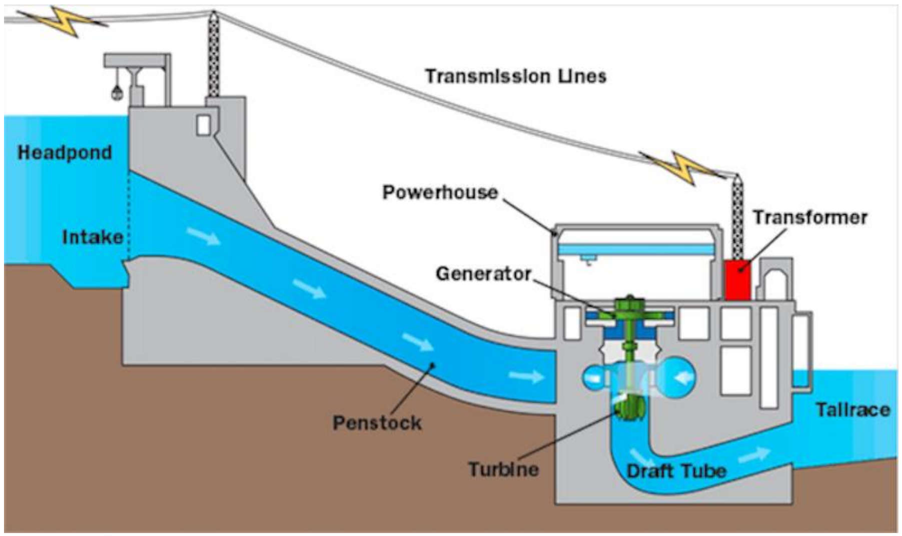
Bio gas



http://sunfadgroup.com/Biogas%20Plant.html

Small Hydro

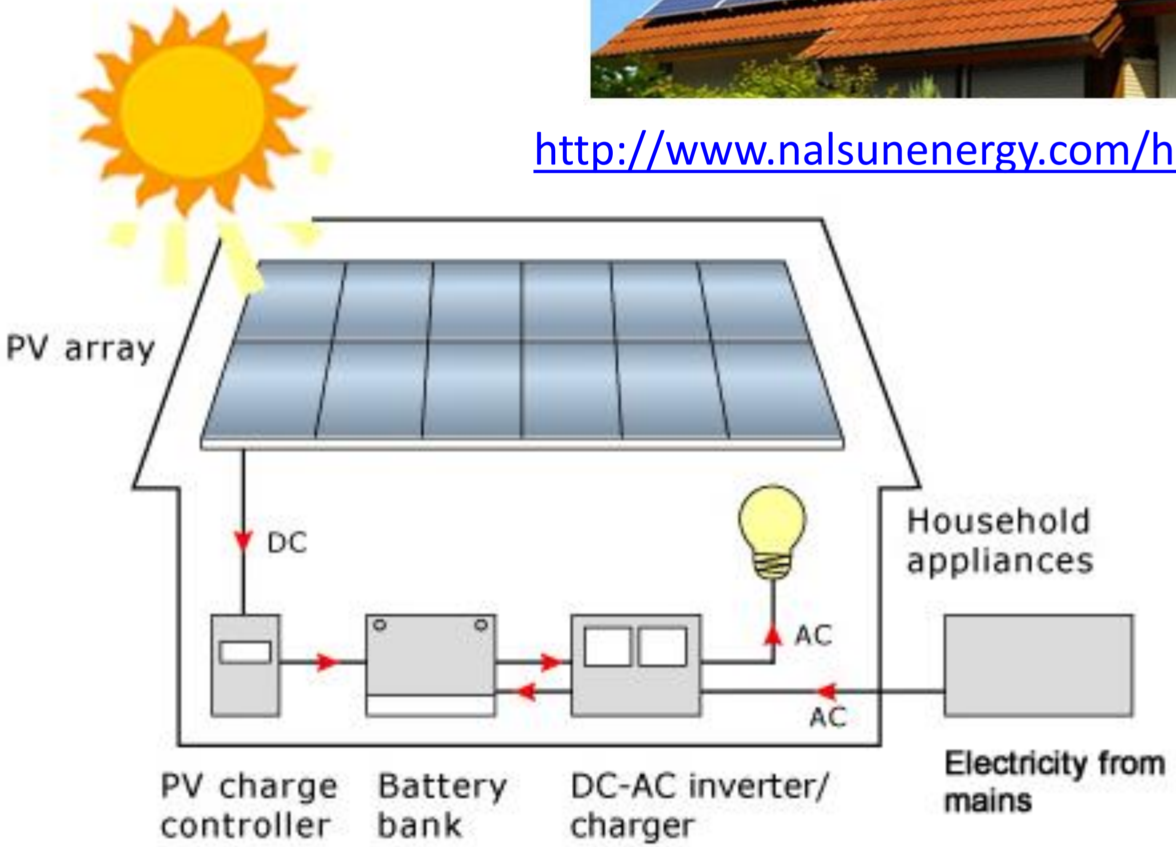




http://suntcgroup.com/small-hydropower/

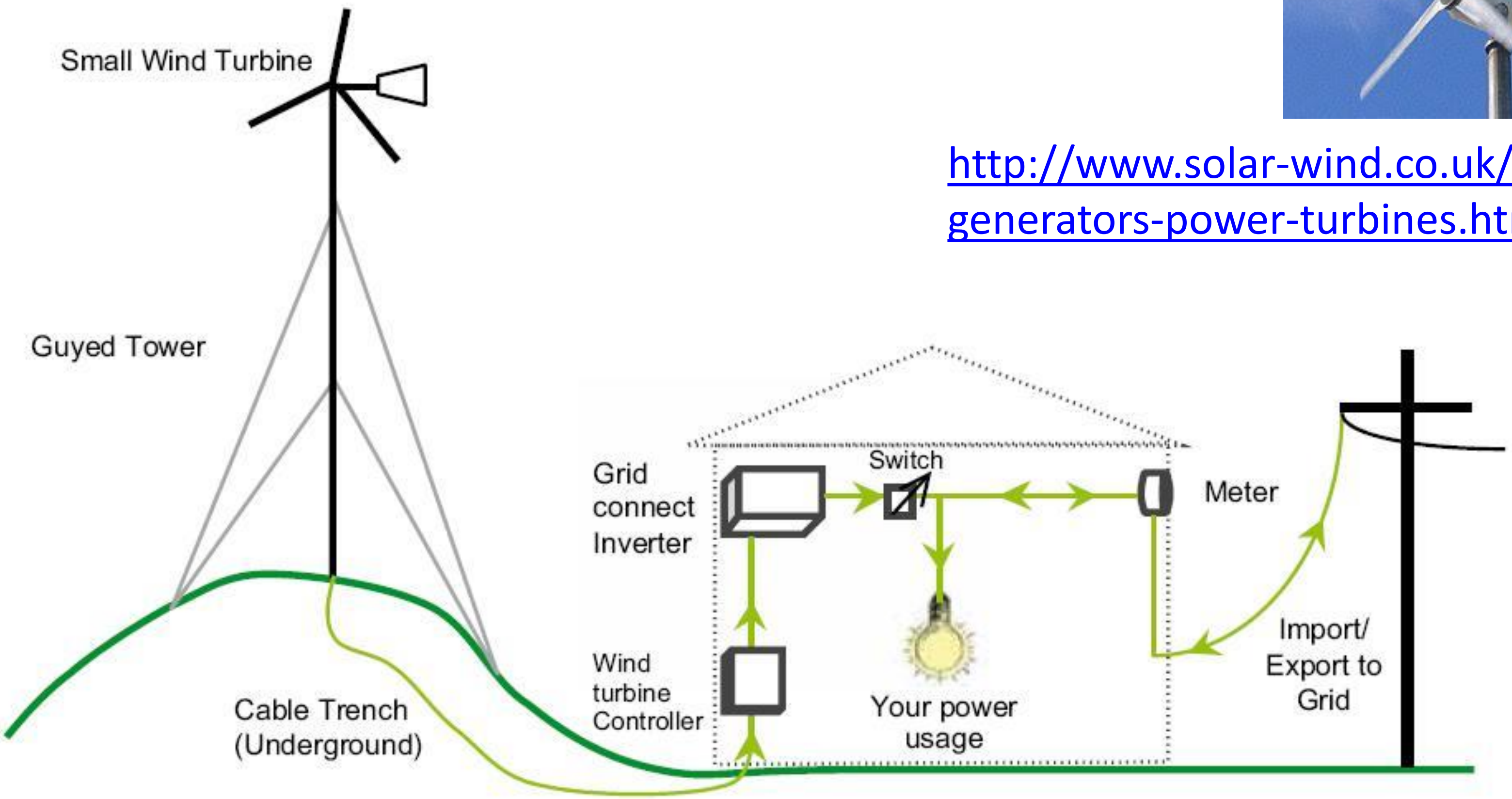
Rooftop PV

http://www.nalsunenergy.com/how-is-solar-energy-stored/



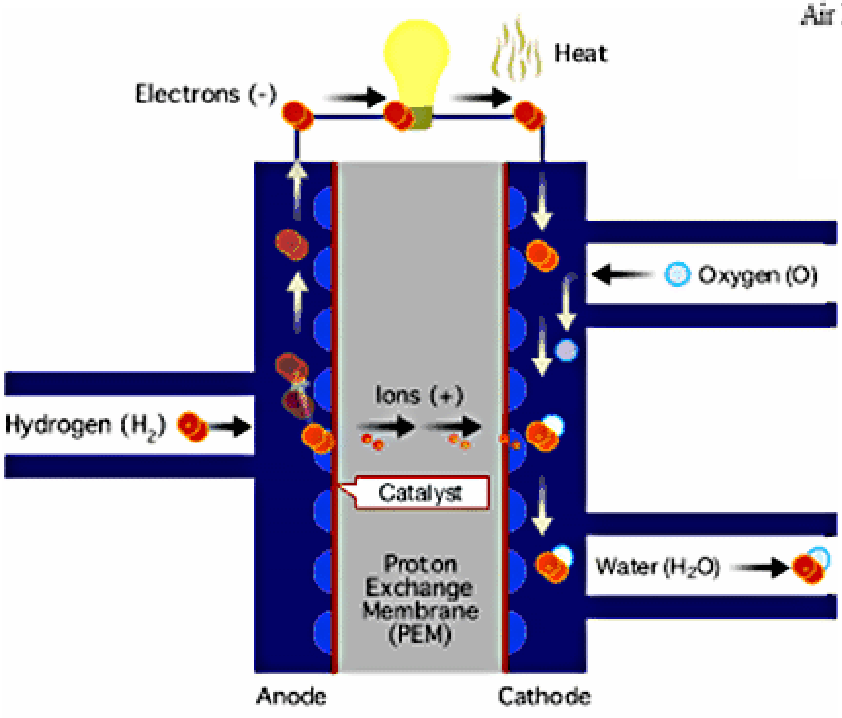
Small Wind Power Systems

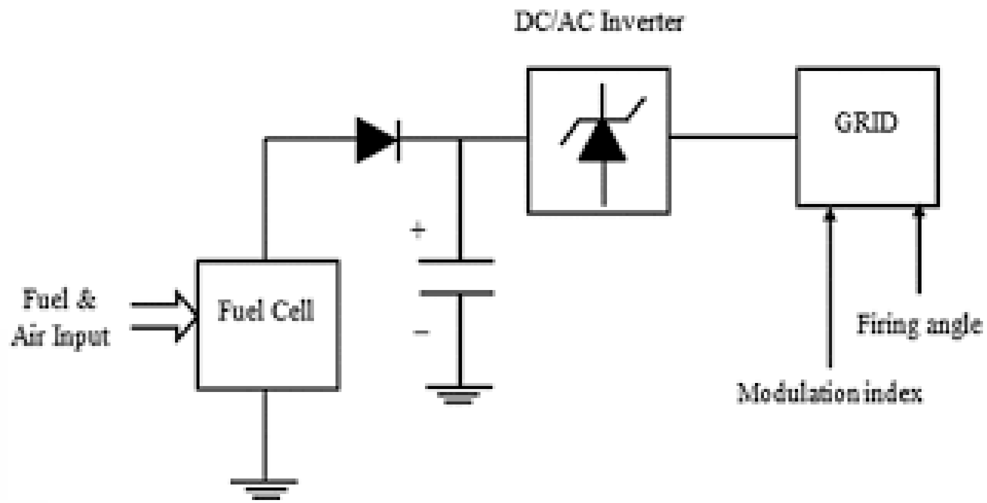
http://www.solar-wind.co.uk/wind-generators-power-turbines.html



http://www.enhar.com.au/renewable-energy/wind-energy/consumer-guide/

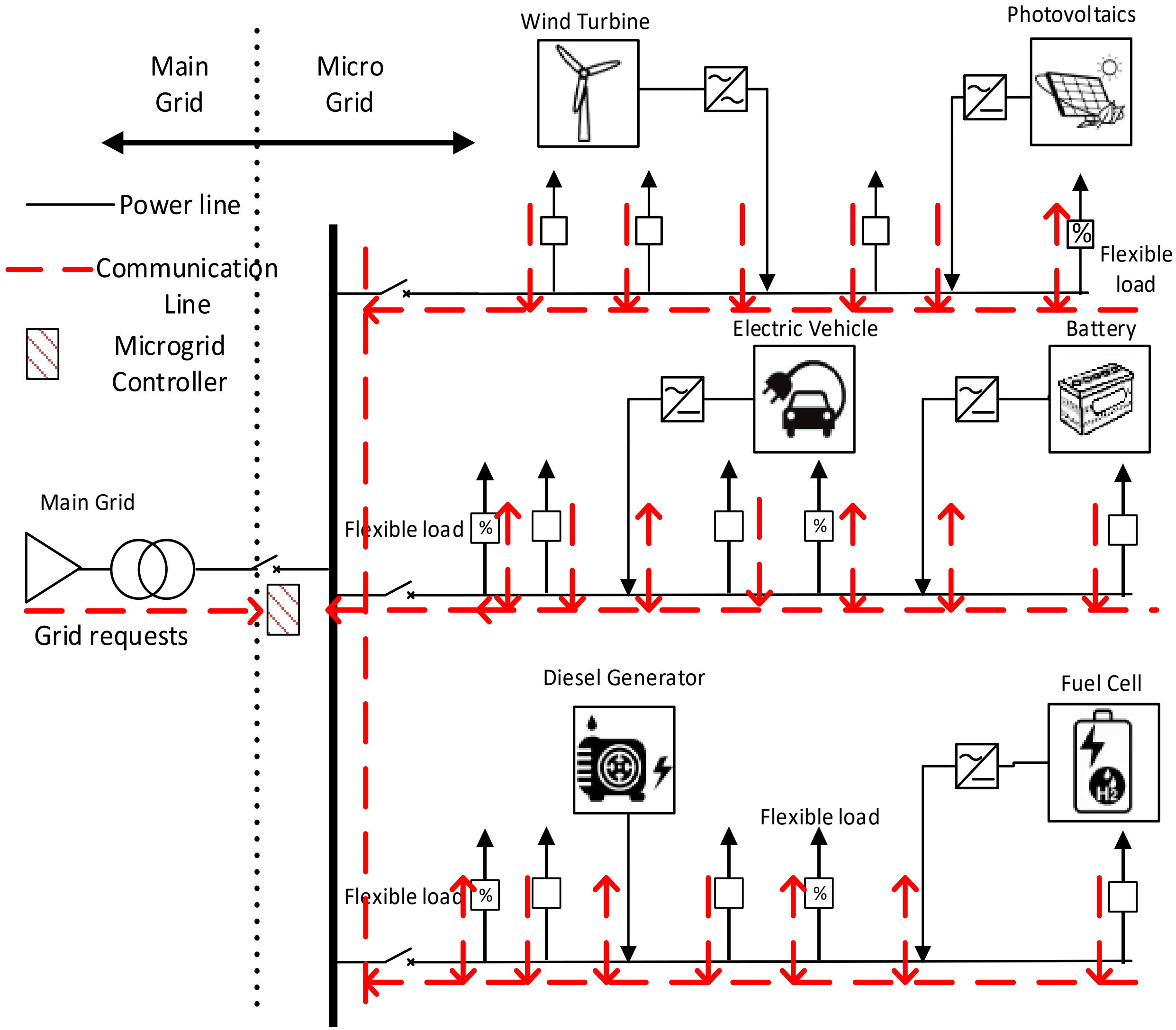
Fuel Cell





http://www.apep.uci.edu/der/buildingintegration/2/Technologies/FuelCells.aspx

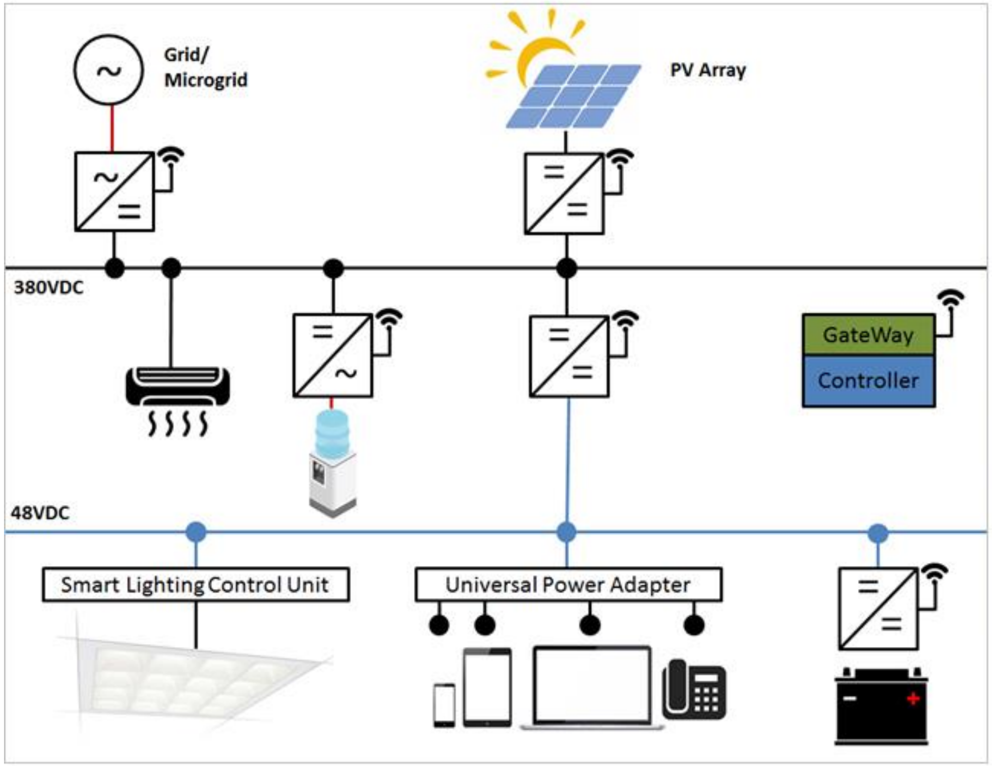
DG in Microgrids



Planning:
Sizing and locating

Operation:
Dispatch and control

DG in Nanogrids (Smart Buildings)



Experimental set up

CleanTech One Roof top with solar panels

http://ecocampus.ntu.edu.sg/Current-Projects/Pages/DC-Renewable-Connected-Building-Grid-Wireless-Intelligent-LED-Lighting-System.aspx

Benefits of Distributed Generation

		Benefit Categories							
		Energy Cost Savings	Savings in T&D Losses and Congestion Costs	Deferred Generation Capacity	Deferred T&D Capacity	System Reliability Benefits	Power Quality Benefits	Land Use Effects	Reduced Vulnerability to Terrorism
DG Services	Reduction in Peak Power Requirements	✓	✓	✓	✓	✓	✓	✓	✓
	Provision of Ancillary Services –Operating Reserves – Regulation – Blackstart –Reactive Power	✓	✓	✓	✓	✓	✓	✓	✓
	Emergency Power Supply	✓	✓			✓	✓		

T&D= transmission and distribution.

Lecture Objectives

1. Review mainstream distributed generation techniques
2. **Introduce the roles of different stakeholders and electricity market in Singapore**
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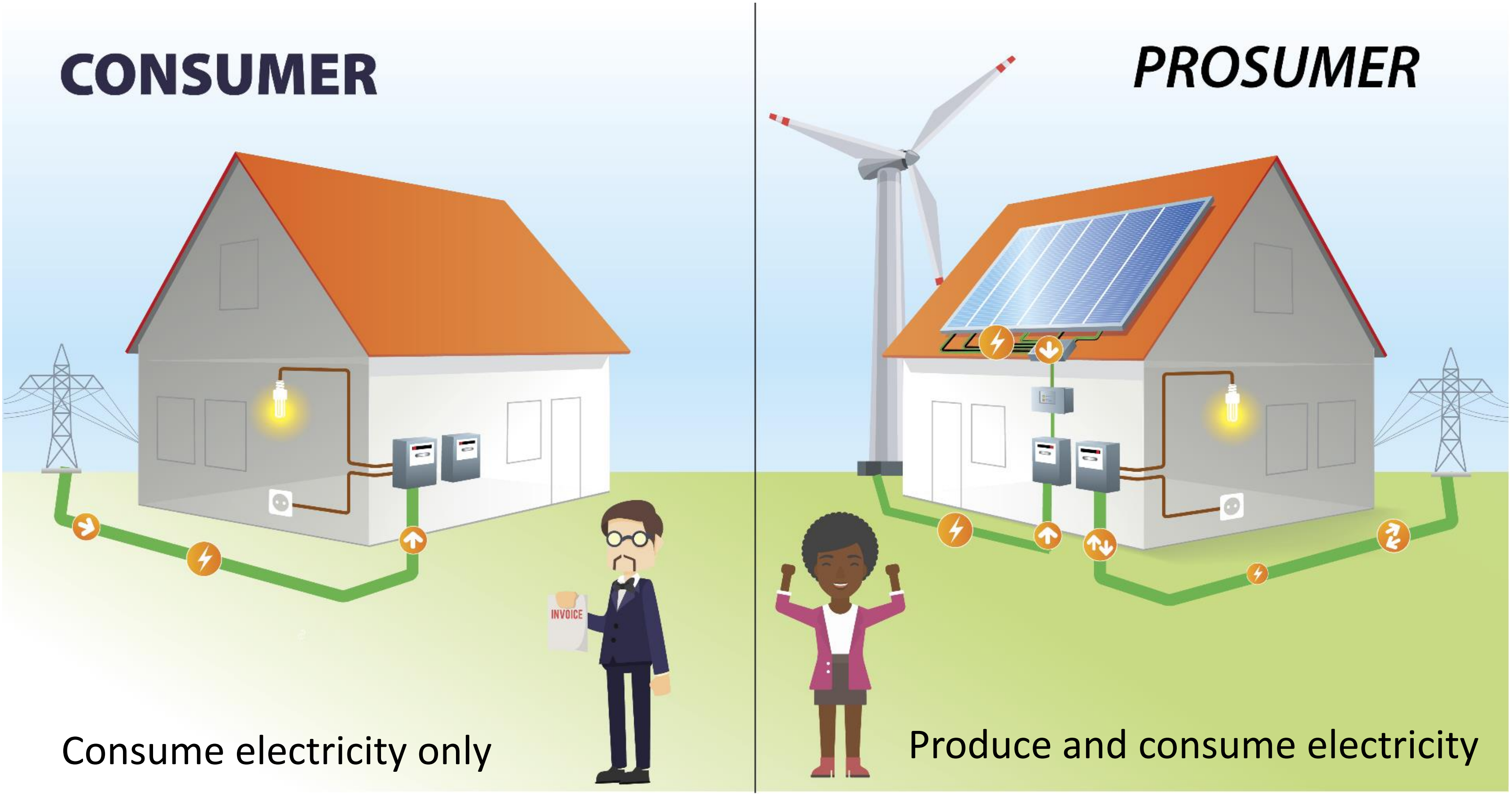
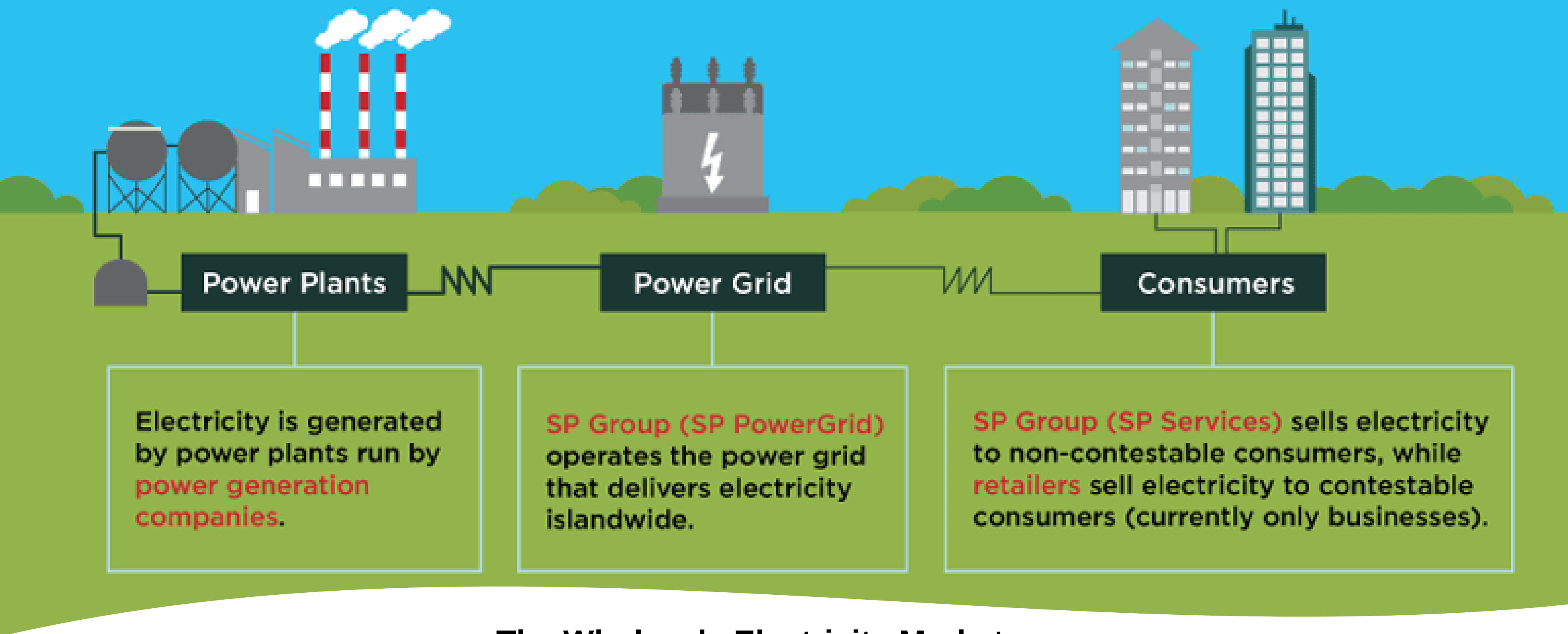
Stakeholder

- The term “**stakeholder**” refers to a person, group or organization that has interest or concern in an organization.
- Stakeholders can affect or be affected by the organization's actions, objectives and policies.

Stakeholders – Prosumer



https://energy.gov/eere/articles/consumer-vs-prosumer-whats-difference



Singapore's Electricity Market

- **The Wholesale Electricity Market**
  - ✓ Power generation companies have to bid to sell electricity in the wholesale electricity market every half-hour. Depending on electricity demand and supply, the price of electricity in the wholesale electricity market changes every half-hour.
  - ✓ Electricity retailers buy electricity in bulk from the wholesale electricity market and compete to sell electricity to consumers.
- **The Retail Electricity Market**
  - ✓ Since 2001, the Energy Market Authority (EMA) has progressively opened up the retail electricity market to competition. This is to allow consumers to enjoy more choices and flexibility when buying electricity. Consumers will also benefit from competitive pricing and innovative offers while enjoying the same electricity supply.

https://www.openelectricitymarket.sg/about/market-overview

Stakeholders in the Electricity Market

- **Energy Market Authority (EMA)**

The Energy Market Authority is the government agency that oversees Singapore's electricity and gas sectors. EMA's main goals are to ensure a reliable and secure energy supply, promote effective competition in the energy market and develop a dynamic energy sector in Singapore.

- **Power Generation Companies**

Power generation companies compete to generate and sell electricity in the wholesale electricity market every half-hour.

- **Energy Market Company (EMC)**

The Energy Market Company operates and administers the wholesale electricity market.

- **Electricity Retailers**

Electricity retailers buy electricity in bulk from the wholesale electricity market and compete to sell electricity to consumers.

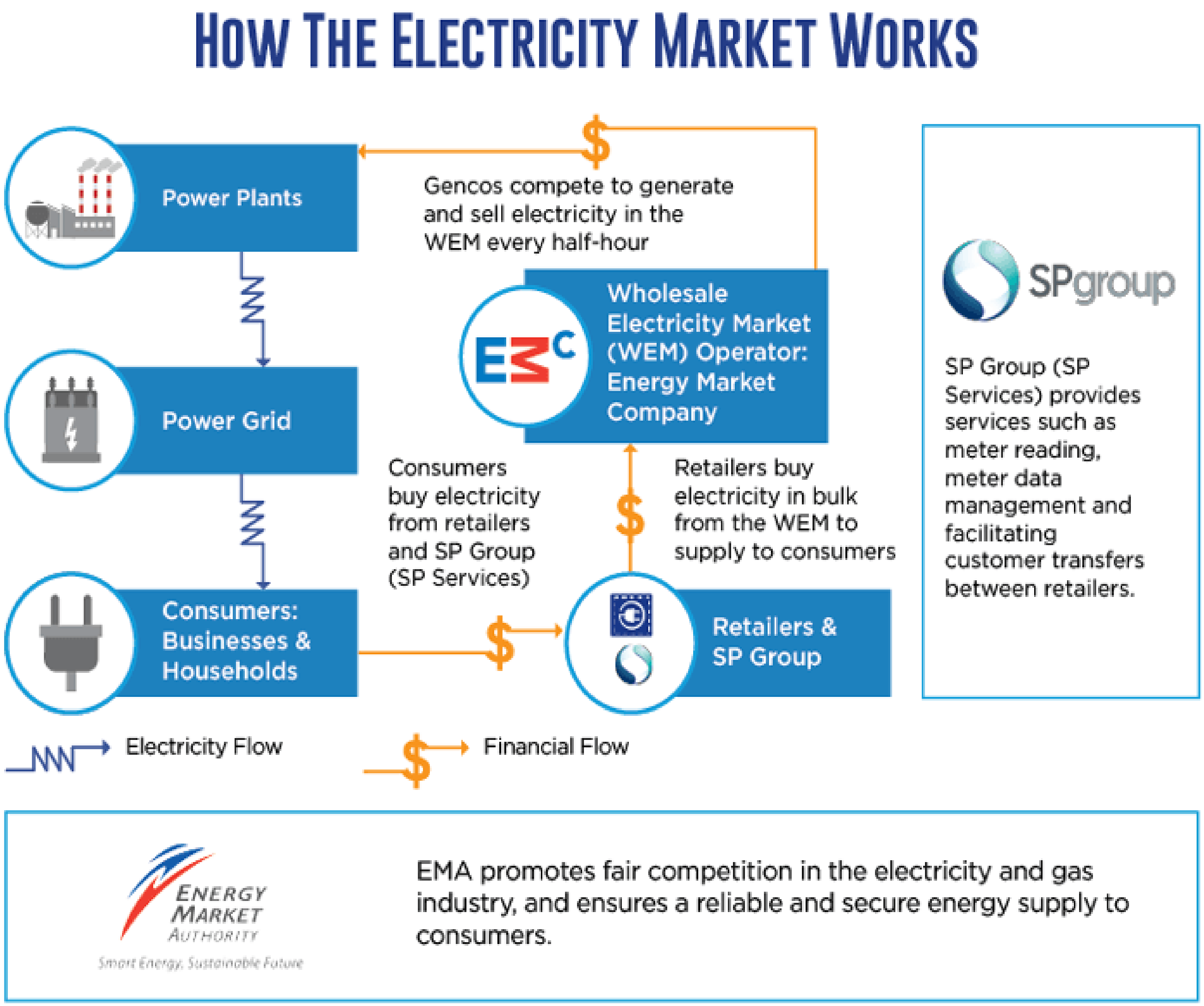
- **SP Services (SPS)**

SP Services, a member of SP Group, is the Market Support Services Licensee (MSSL). It provides services such as the reading of electricity meters, management of meter data and facilitation of access to the wholesale electricity market.

- **SP PowerAssets (SPPA) and SP PowerGrid (SPPG)**

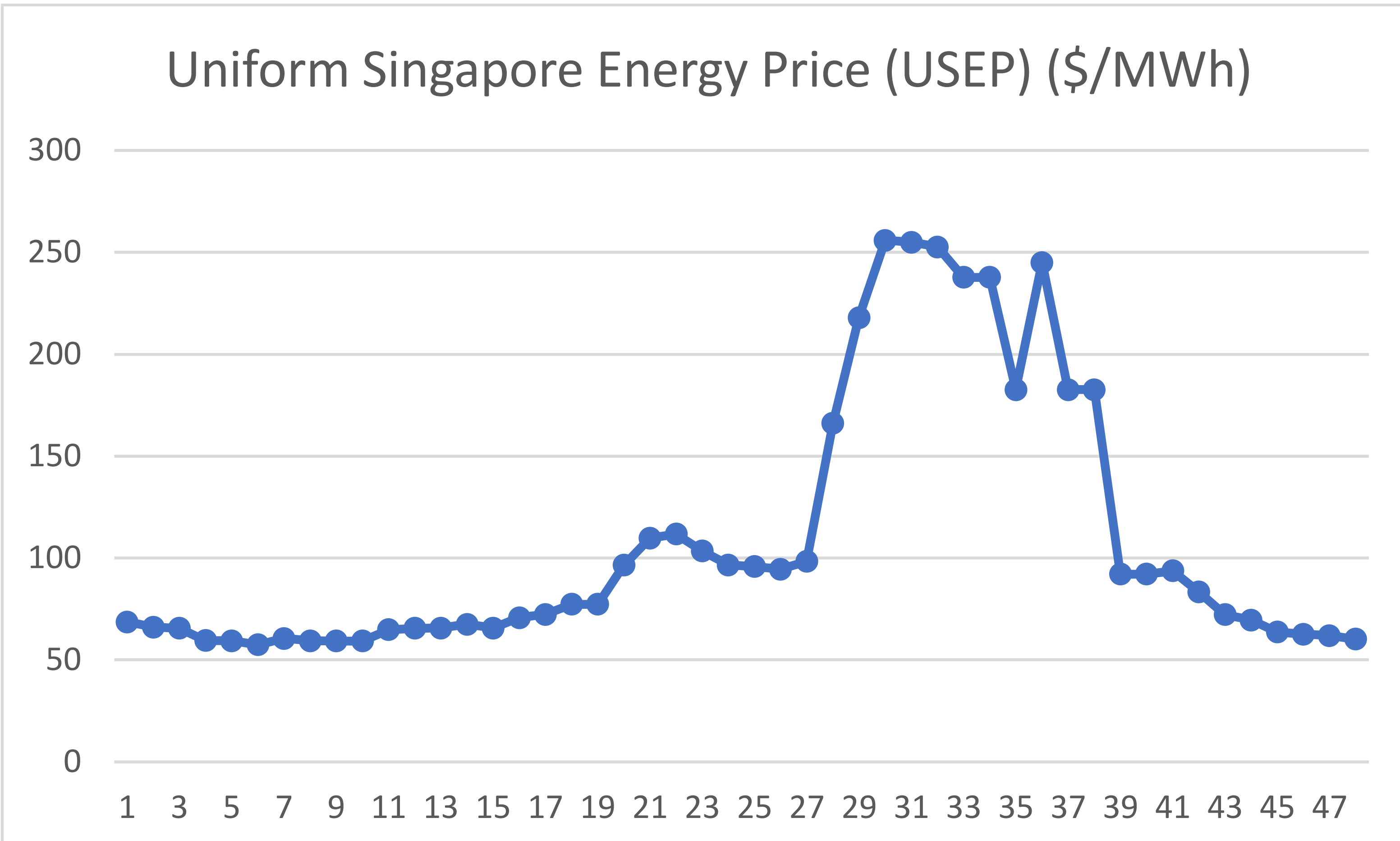
SP PowerAssets is the Transmission Licensee. It owns the power grid which delivers electricity island-wide. SP PowerGrid is the agent appointed by SP PowerAssets to build and maintain the power grid. Both SPPA and SPPG are members of SP Group.

Singapore's Electricity Market



https://www.openelectricitymarket.sg/home

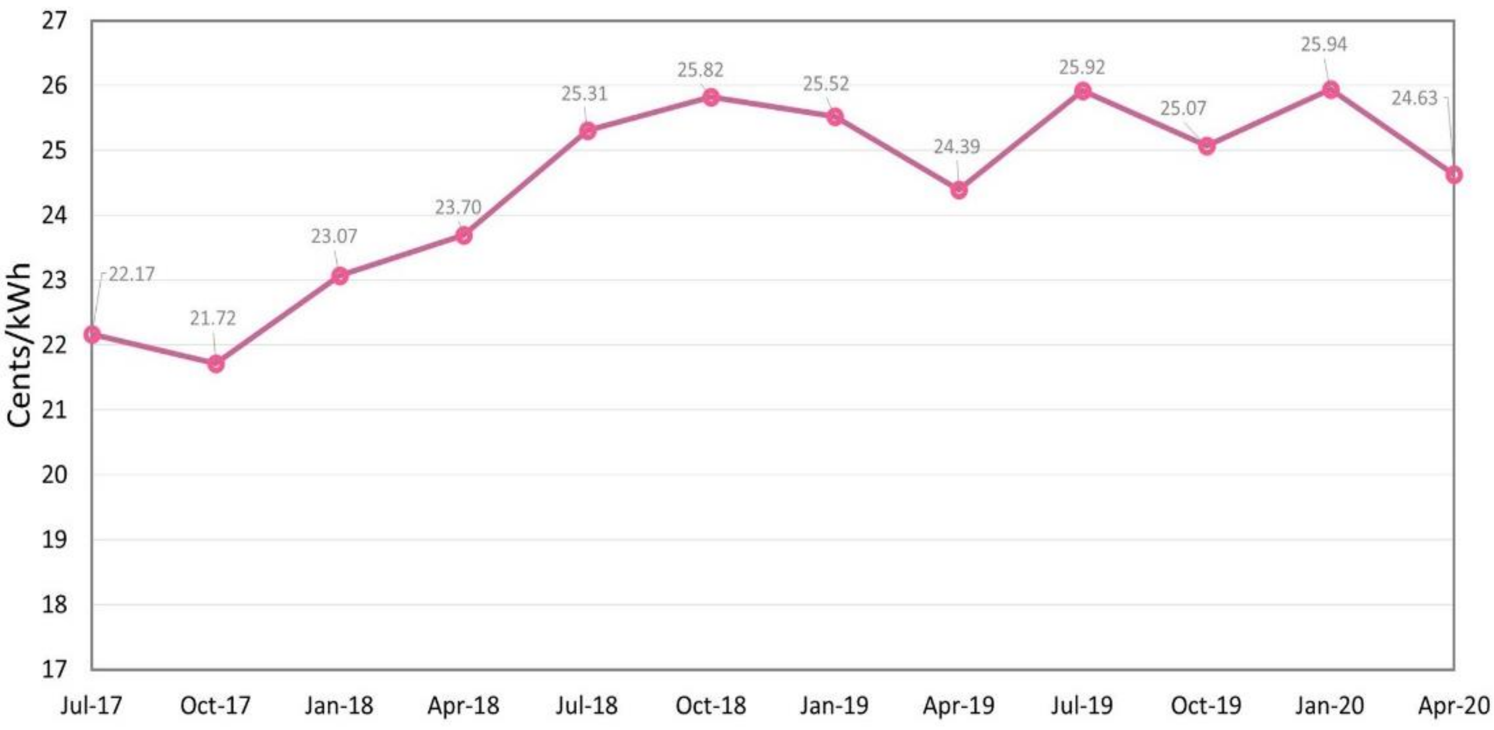
Market clearance price



2020/9/1 from period 1 to 48 (30mins a point)

Regulated Tariff

The electricity price in the retail market is set by the SP Group, supervised and approved by the EMA, and updated every quarter to reflect changes in the actual cost of electricity production and transmission in a timely manner. This electricity price is called the **regulated electricity price** (supervised electricity price). The chart above shows the changes in Singapore's regulatory electricity prices in the past three years, with the largest change being as high as 19%.



Source: SP Group website; rates inclusive of GST

Open Electricity Market

- Since 1 May 2019, **the Open Electricity Market (OEM)** is fully launched by the Energy Market Authority (EMA) that allows customers to enjoy more choices and flexibility when buying electricity. Customers can benefit from competitive pricing and innovative offers from retailers.
- With the Open Electricity Market, **you have the choice of buying electricity from**:

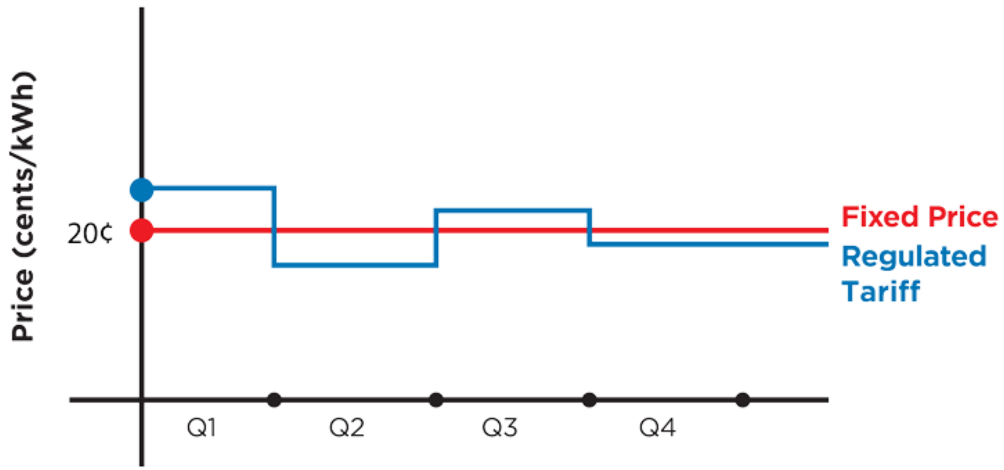
(a) SP Group at the regulated tariff (as usual);

(b) An electricity retailer at a price plan that best meets your needs; or

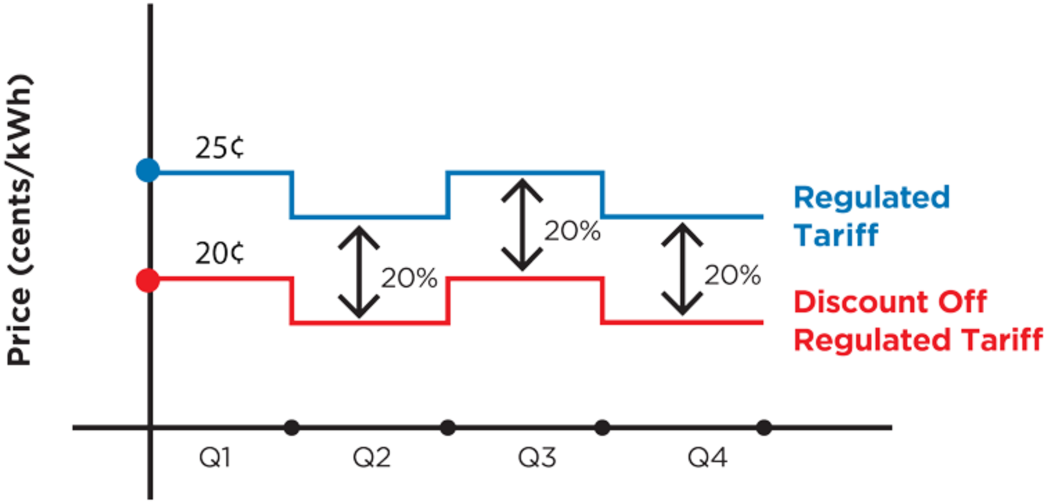
(c) The wholesale electricity market at half-hourly wholesale electricity prices through SP Group.

A short introduction to Singapore's OEM (in Chinese only):
http://www.csg.cn/xwzx/nygc/202007/t20200703_312078.html

Price plan



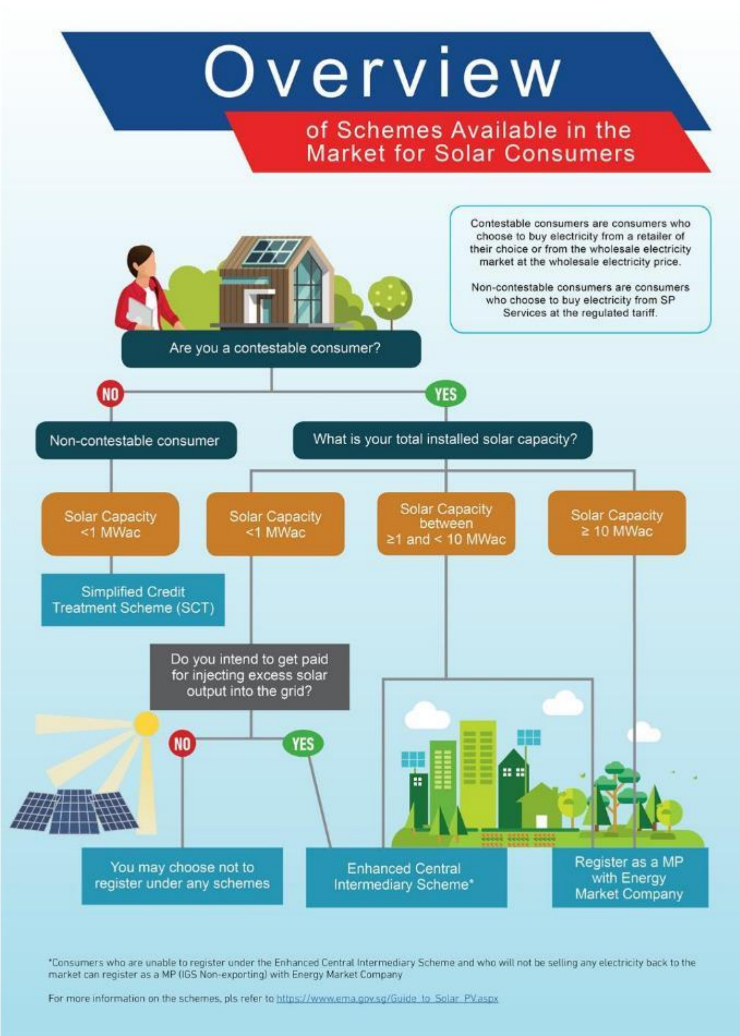
a. Fixed Price Plan
Pay a constant rate (e.g. 20 cents/kWh) for electricity throughout your contract duration. However, the rate may be higher or lower than the regulated tariff during the contract duration as the regulated tariff is reviewed every quarter. This plan is suitable for consumers who prefer certainty over price and bill size.



b. Discount Off the Regulated Tariff Plan
Enjoy a fixed discount off the prevailing regulated tariff (e.g. 20%) throughout your contract duration. This is suitable for consumers who do not mind that their electricity rate changes every quarter so long as it is lower than the regulated tariff. The regulated tariff is reviewed by SP Group quarterly, and approved by EMA.

More info: https://www.ema.gov.sg/openelectricitymarket.aspx

Schemes Available in the Market for Solar Consumer



Based on "PROPOSED ENHANCEMENT TO THE CENTRAL INTERMEDIARY SCHEME FOR EMBEDDED GENERATION" released by EMA and "Solar PV – User Guide for Residential Consumers" by SPGroup

Price Plan	Able to Sell Back? (Y/N)	User Type	Sell Back Rate
Fixed Price	N	Non-contestable Consumer	-
Regulated Tariff	Y	Non-contestable Consumer	Regulated tariff less grid charge
Wholesale Electricity Price	Y	Contestable Consumer	Weighted average nodal price

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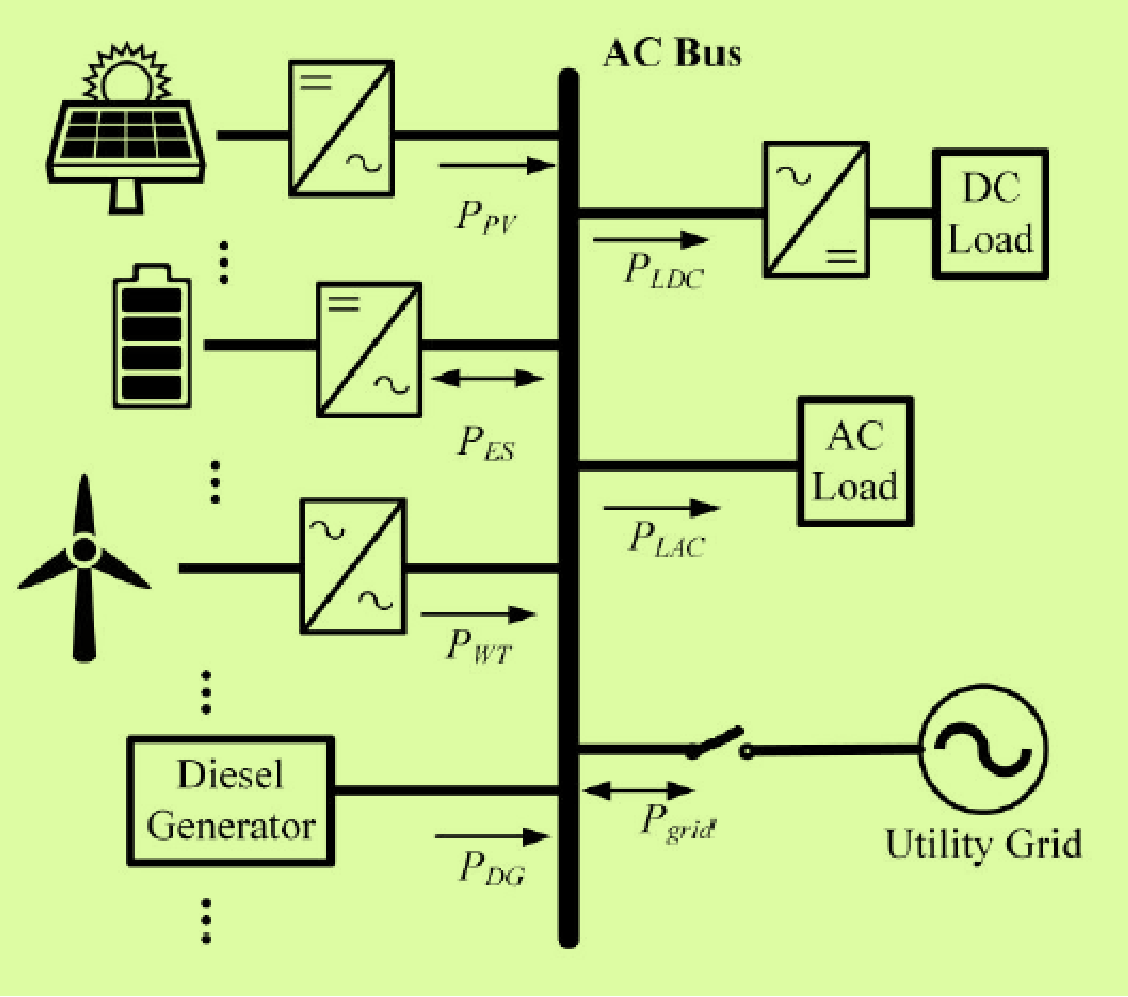
Main Challenges of DG Integration

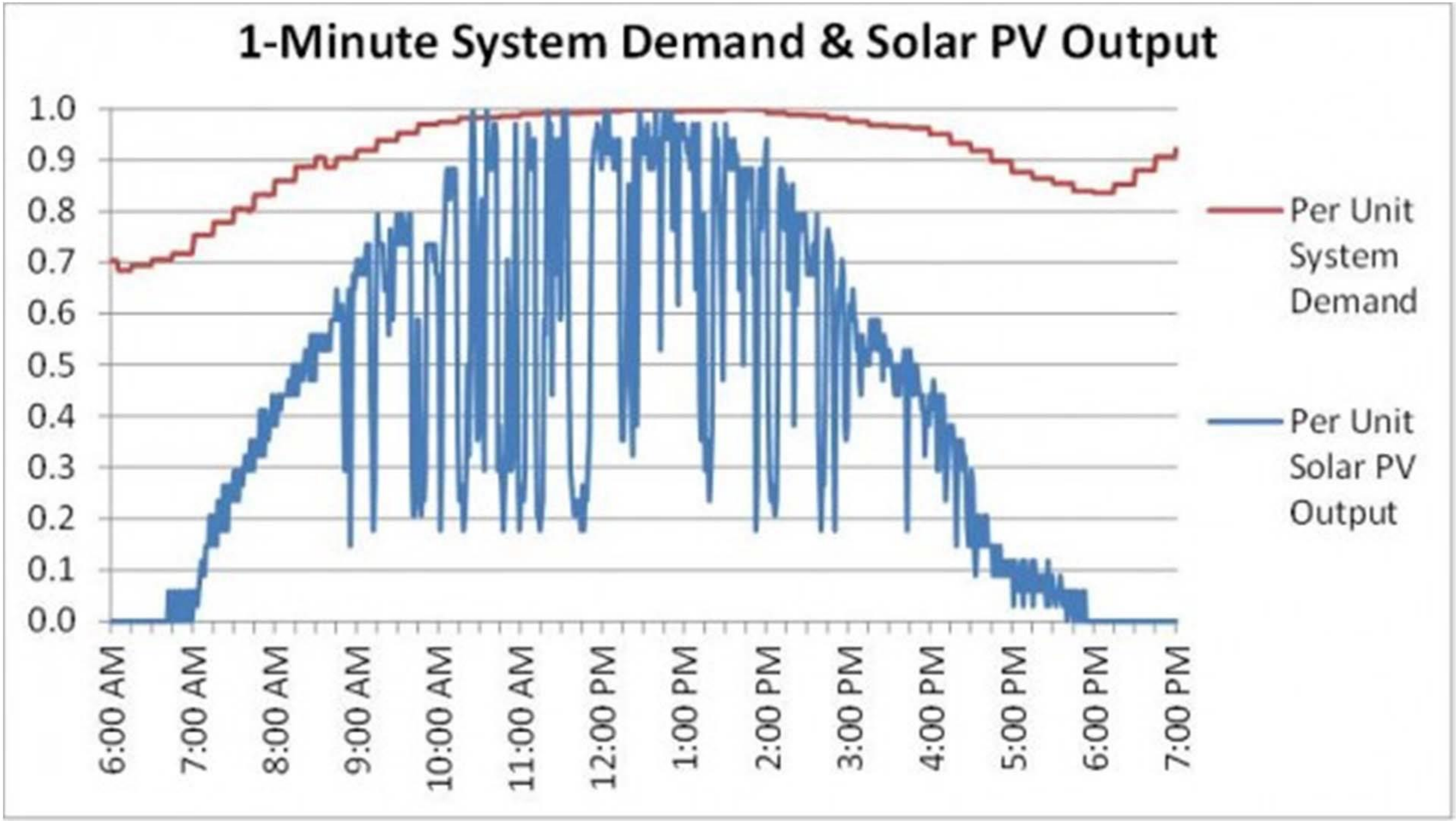
- Technical challenge
  - Maintain acceptable levels of voltage quality and continuity of power supply
  - Ensure that transport capacity is able to cope with peaks in power transport.
- Excessive DG integration can endanger the reliability and quality of the grid supply, exceeding the "**hosting capacity**" of the grid.
- Liberalization of electricity market may form challenges if not understood properly.

Interfacing of DG



synchronous and asynchronous units

Intermittency of DG Integration



The intermittency nature of renewable electricity

Challenge to Voltage

- The original design of the distribution network does not consider the distributed generation units.
- Above a certain production, the system performance deteriorates and may result in an overvoltage phenomenon.

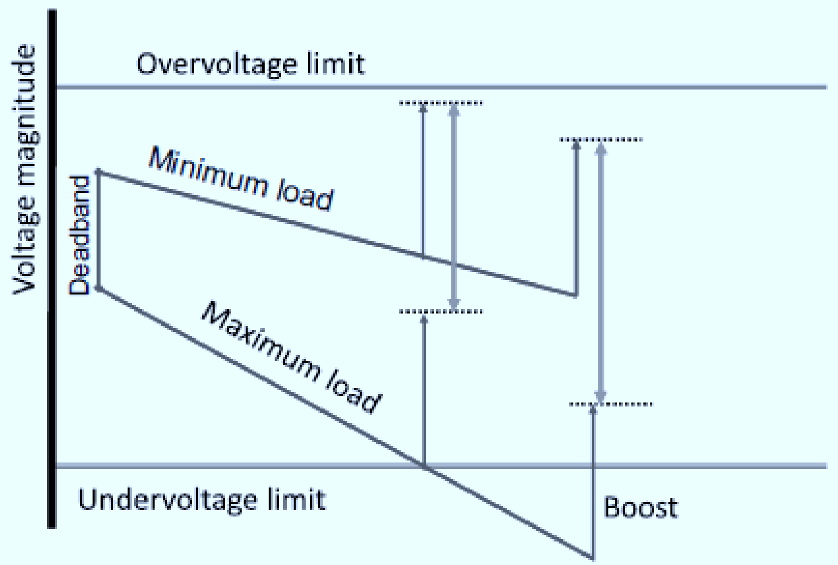


Figure 5.3 Voltage coordination along a distribution feeder: worst case for overvoltage.

Challenge to Protection

- Reduction in voltage drop or cause system overvoltage
- Protection coordination can be endangered. This may either result in an incorrect trip or in a fail-to-trip situation.

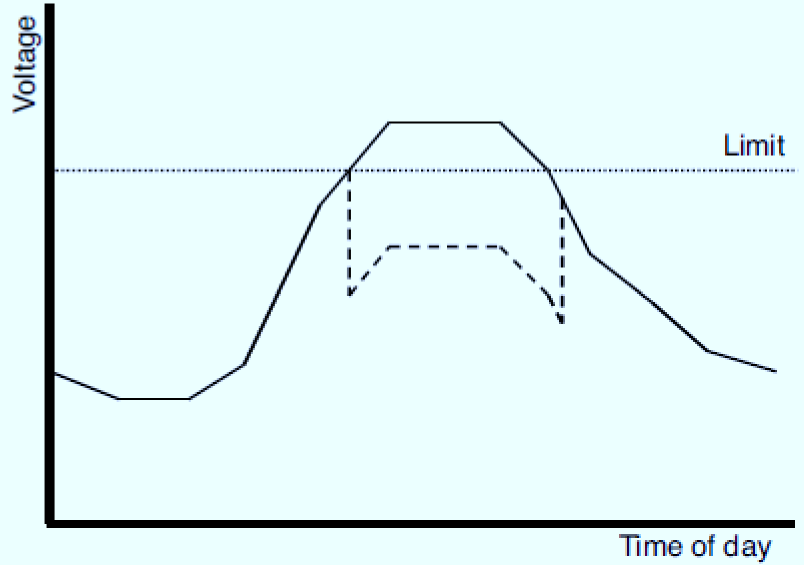
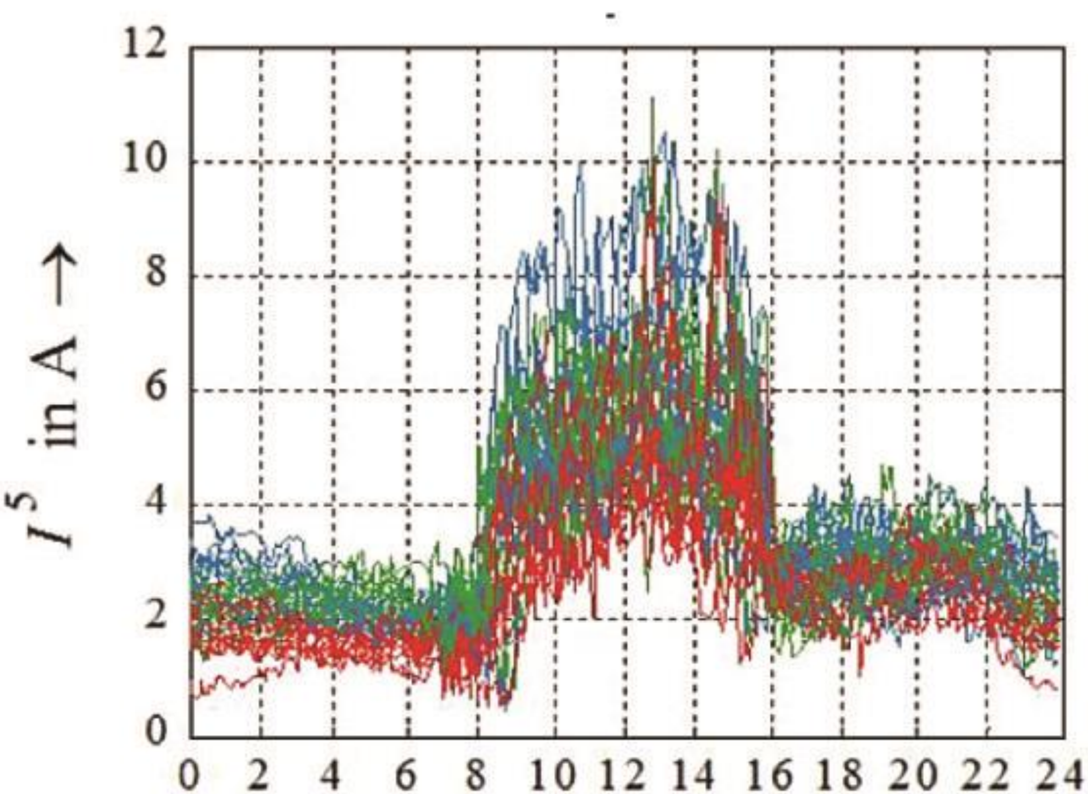


Figure 5.40 Impact of overvoltage tripping on the voltage variations: voltage magnitude versus time without tripping (solid curve) and with tripping (dashed curve). The dotted line indicates the overvoltage margin.

Challenge to Power Quality

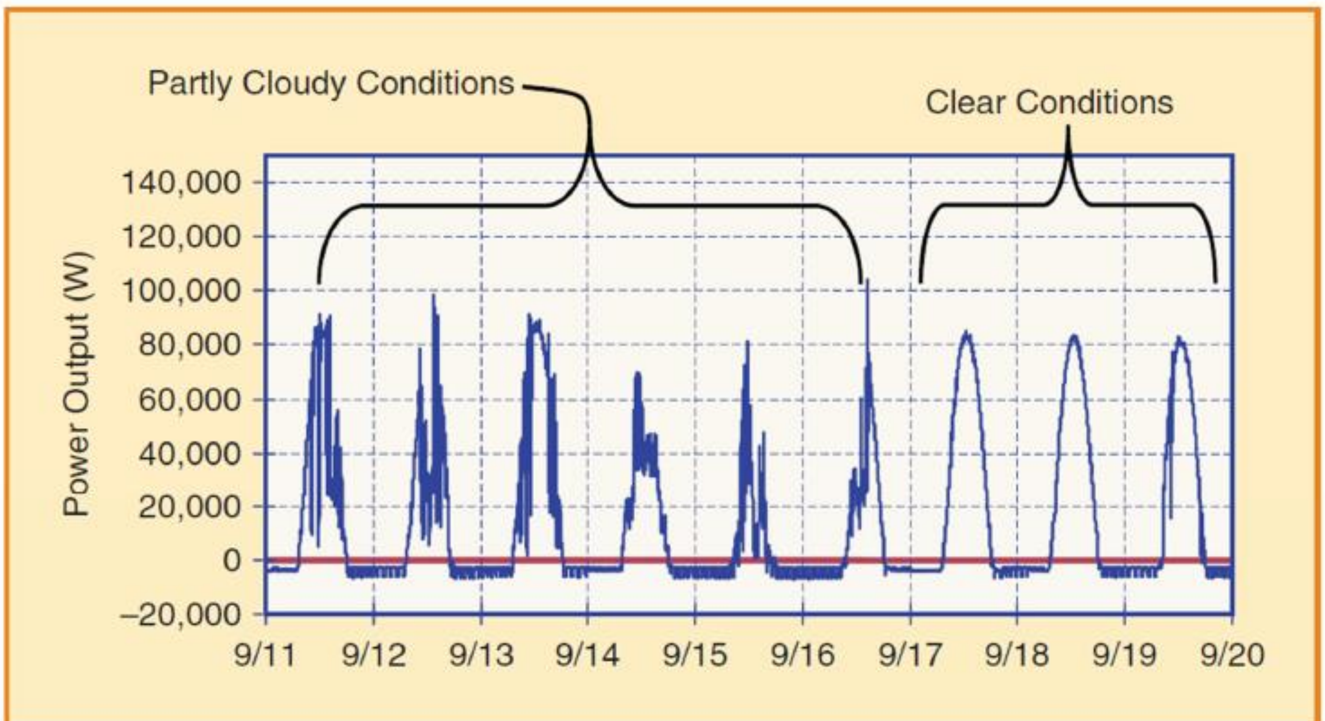
- Increase the harmonic levels of distribution network



Total fifth harmonic current as a function of the time of day measured at the busbar of a public LV grid with installed PV power of 332 kW.

Challenge to Transmission Network

- May result in system overload or insufficient operating reserves due to uncertainty and intermittency in the distributed generation.

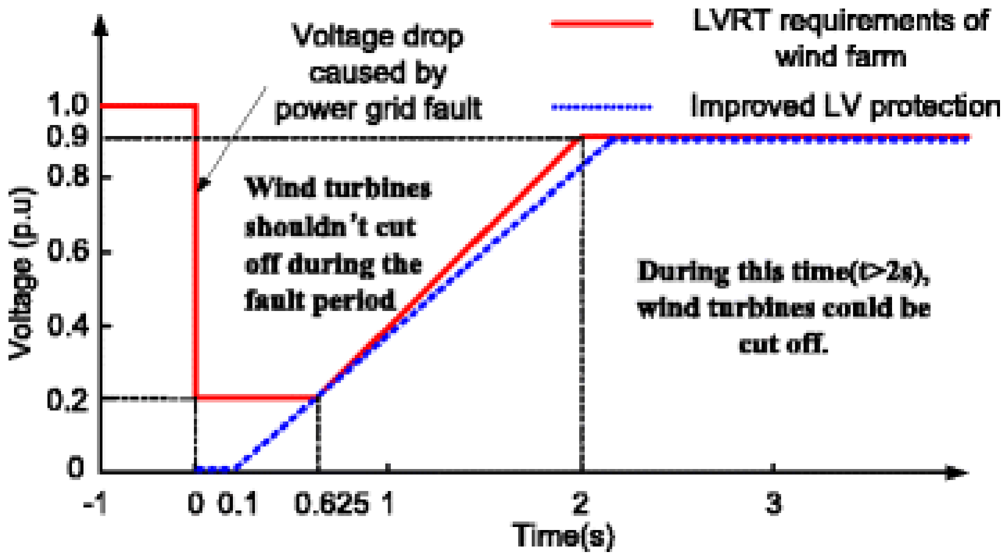


Key, T.; , "Finding a bright spot," *Power and Energy Magazine, IEEE* , vol.7, no.3, pp.34-44, May-June 2009

Challenge to Transmission Network

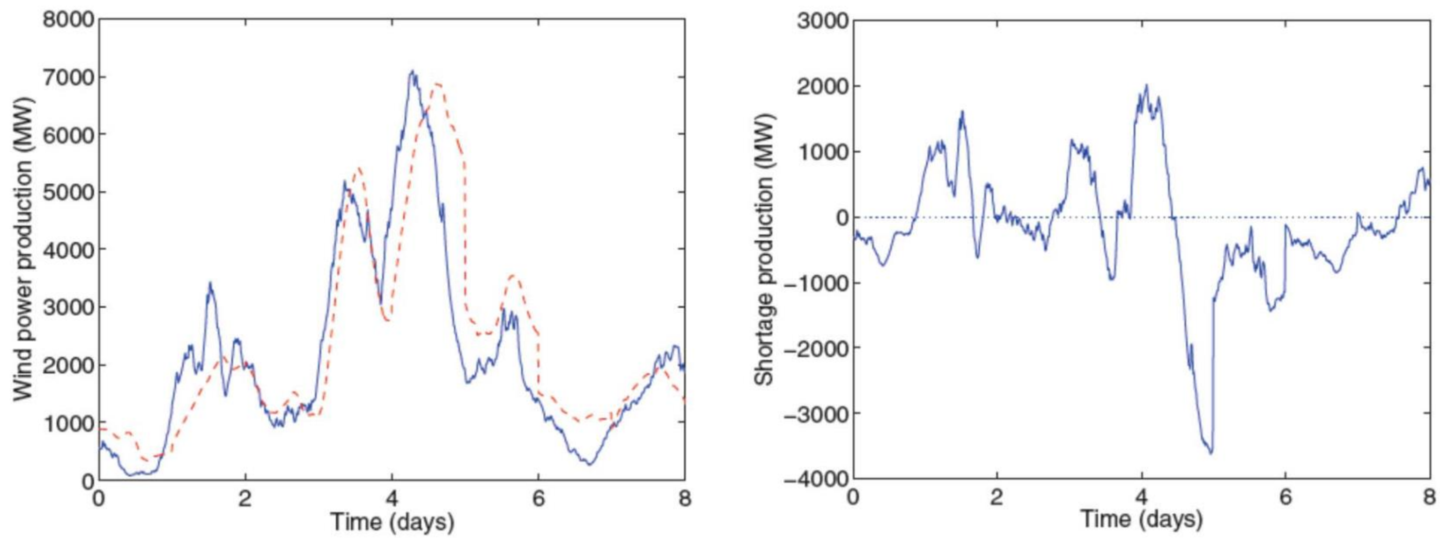
- The "**fault-ride-through**": the ability to remain connected (and support the grid) during large disturbances associated with serious drops in voltage or to disconnect when voltage and/or frequency deviate too much from their nominal values.

A voltage profile of a fault ride through event



Challenge to Renewables Energy Forecasting

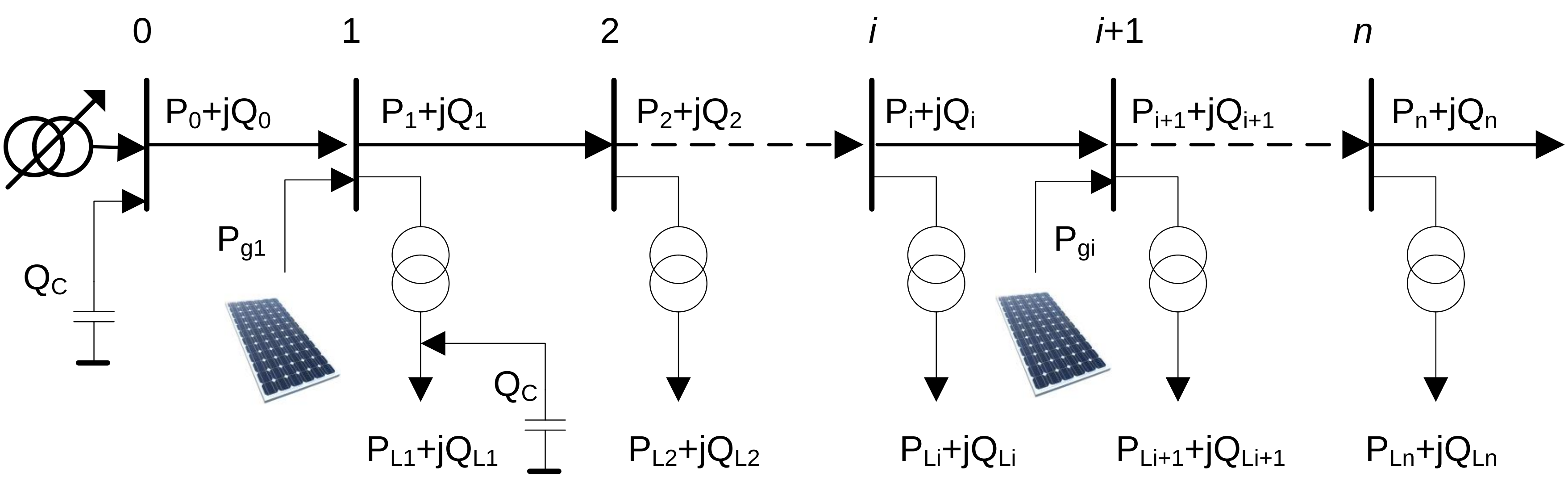
- Predicting intermittent renewable energy is a key task.
- Further complicated by prediction errors in consumption (net load).
- Additional reserves are needed due to large prediction errors and also for the worst case scenario



Actual (left; blue solid line) and predicted (left; red dashed line) wind-power production and prediction error (right).

Challenge to Network Transport Capacity at Distribution Level

- The "**worst-case-design**" of the grid transmission capacity has to be able to cope with the following to maintain the highest continuity of power supply
  - The highest consumption (Max Supply – Min Demand)
  - The expected growth in consumption during coming years (Future expansion)
  - An amount of reserve to cover loss of an important component. (such as faulted lines/generation unit)
- This is to maintain the highest continuity of supply



Summary

Any new technologies can bring both benefits and challenges

1) Accurate **forecasting** techniques to predict DG generation (or net load)
2) Advanced **control** techniques to utilize DG inverter for voltage regulation
3) Advanced **optimization** techniques for system operation and planning under DG uncertainty
4) New design of electricity **market**