ENGG1300
Introduction to Electrical Systems
Week 11

Power Systems 2:
The Queensland Electricity Network

The week ahead

- Quiz 10: Due 4pm Monday 17th May, (Week 12).
- Quiz 11 (final one): Due 4pmMonday 24th May, (Week 13)
- Prac 11A: Power Factor Correction
- Prac 11B: Transformers and Transmission line impedance
- Audio Filter Design Report: Due 2pm this Thursday, 13th of May. No further lab access is available to work on this task; and lab equipment will not be available in Session 11A or Session 11B.

Teaching/Course evaluations

- Your opportunity to provide constructive feedback on the course!
- Details/Links on blackboard ('Course, teaching & tutor evaluations' from left hand menu)
- You will evaluate:
  - The lecturer/course coordinator (online: Opens Monday 17 May and Closes 11:59pm Friday 04 June)
  - The course as a whole (online: Open Monday 15th October until 1st ovember)
  - Each of the tutor's scheduled on your lab sessions. (online: Information posted shortly, and open till 11:59pm Sunday 23 May)
- All completed at: https://eval.uq.edu.au/
- 10 minutes allocated at the start of session 12B
- These help us to:
  - Make improvements to future offerings of the course to make them better
  - Help individual teachers improve their teaching methods
  - Reward teaching staff that are doing a fantastic job!
- I recognise that this will be several evaluations for the course, but please take the time to fill these in thoughtfully – we really are keen to continue to keep improving the course

Audio Filter Design Activity/Report Reminder

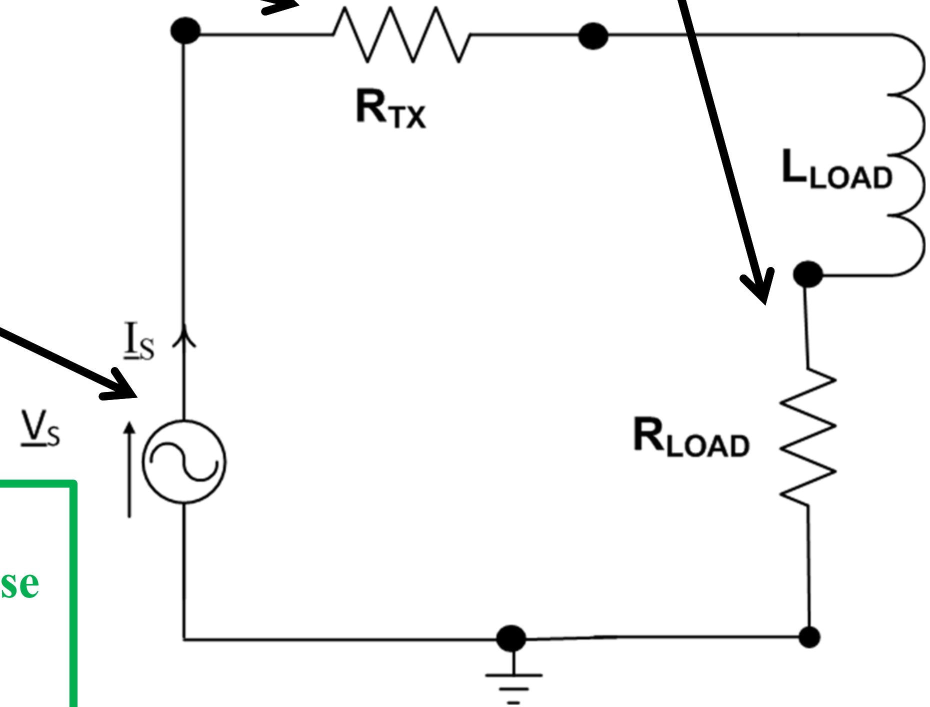
- Full details and documents on blackboard: “Assessment” -> “Audio Filter Design Report (10%)”
- Assessment (10% to total grade):
  - Due 2pm Thursday 13th of May (week 11)
  - Report must be completed using the template provided.
  - Strictly title/cover page + 2*A4 Pages maximum; 2cm margins; 11-point Times New Roman Font; Single Line spaceing. **If a longer report is submitted only the first two pages will be marked! No appendices beyond this permitted.**
- Marking criteria available by "My Grades" from the left hand menu, and then clicking "view rubric" for:
  - the "Audio Filter Design Report (Flexible)" item, or
  - the "Audio Filter Design Report (External)" item
- Submitted electronically via blackboard as a single pdf
  - Automatically screened for plagiarism)
  - Submission link is in “Assessment” -> “Audio Filter Design Report (10%)”
  - Resubmit as many times as you like up till the due date

Week 10: Efficient Delivery of Power

Power is delivered by cables (i.e. wires) which have their own resistance

Many of the highest power consuming loads in industry (motors, pumps), and in the home (fridges, washing machines) are modelled by a combined inductive and resistive load

Primary power delivery in Australia (and most parts of the world) is AC.

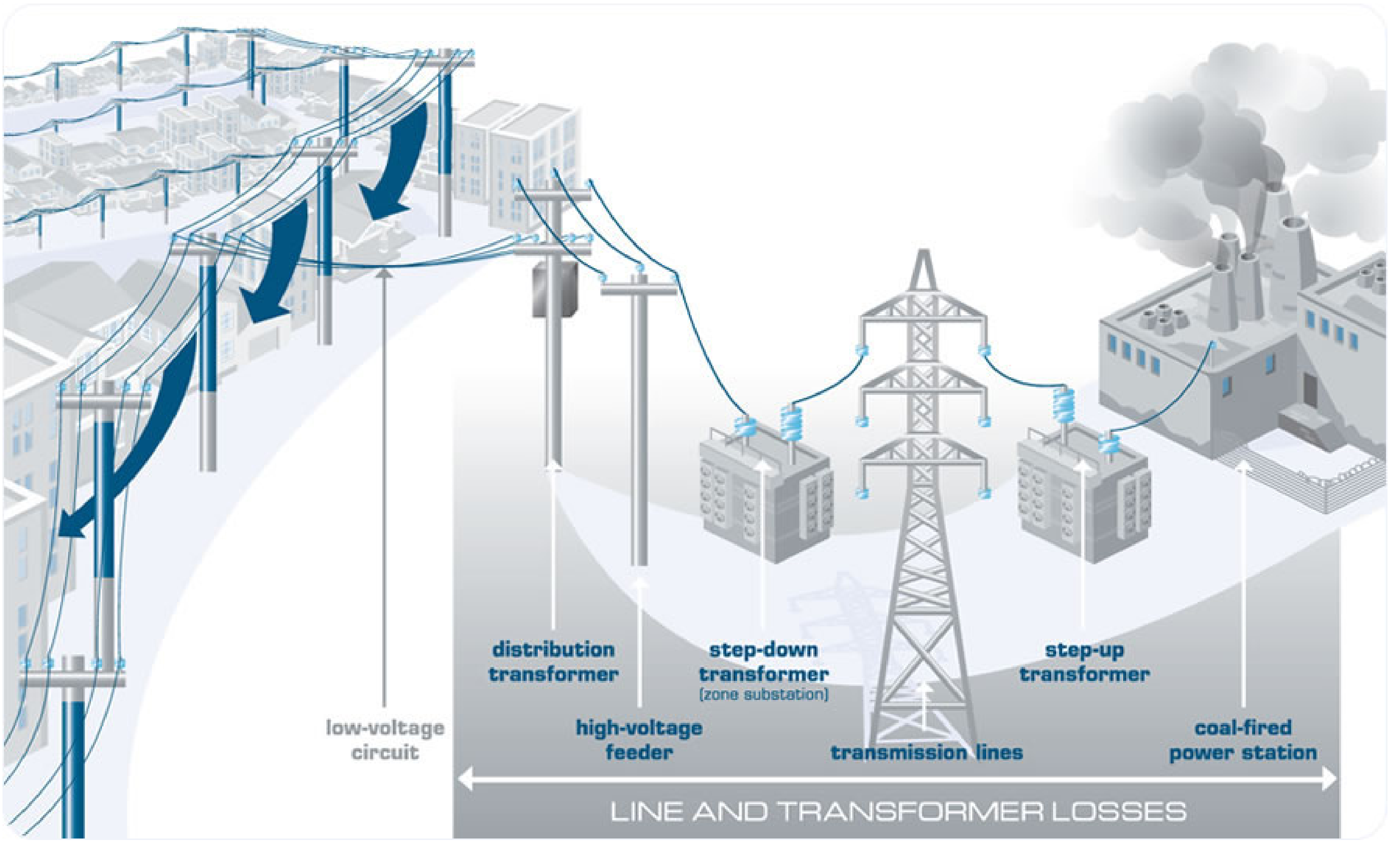


- Power factor correction
- Design transmission lines to minimise resistance
- Transmit power at high voltages

How do we implement in practice?

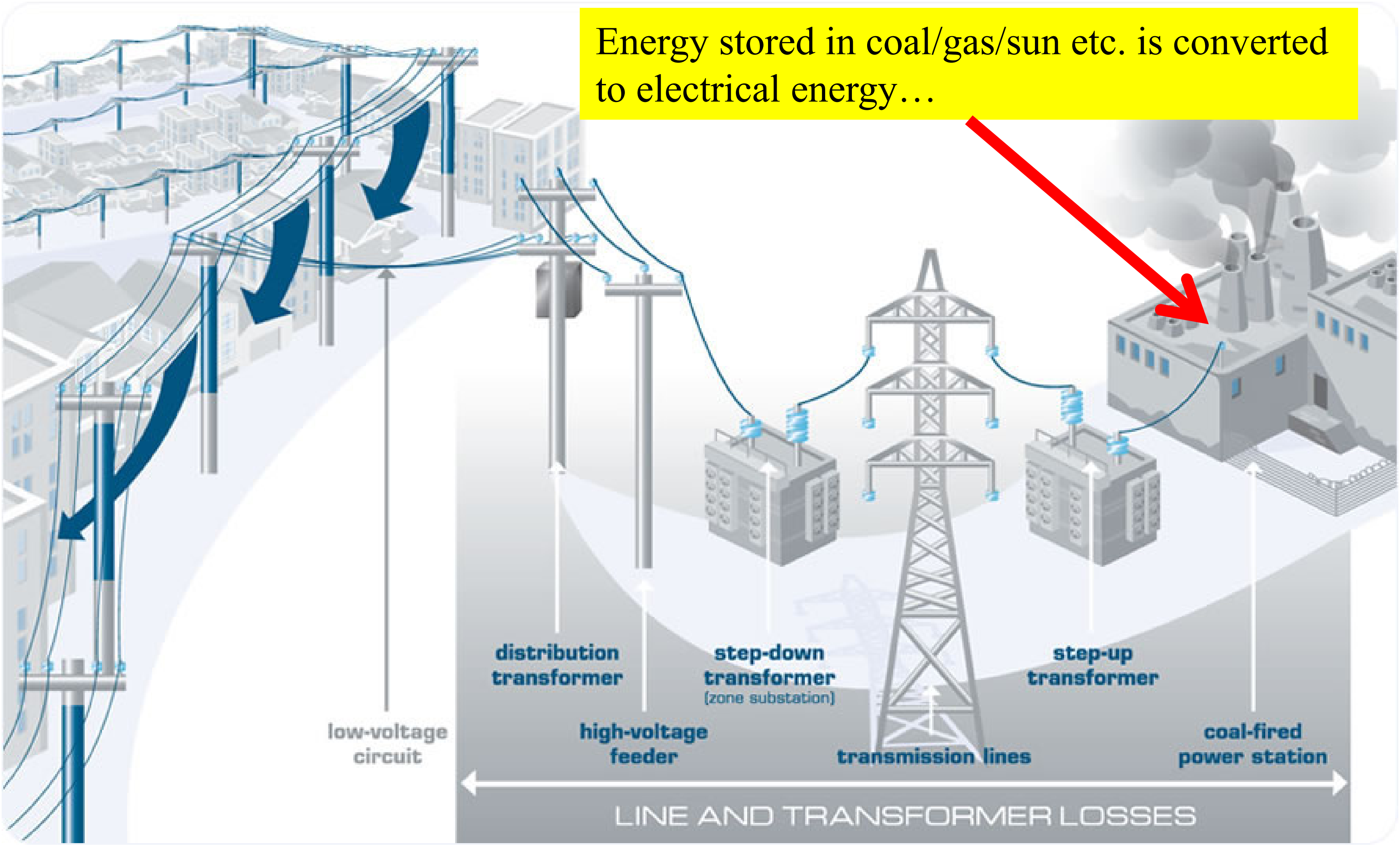
Week 11: Electricity Network in Practice

- Generation of power
- Transmission and distribution in Queensland



Electricity Network - Generation

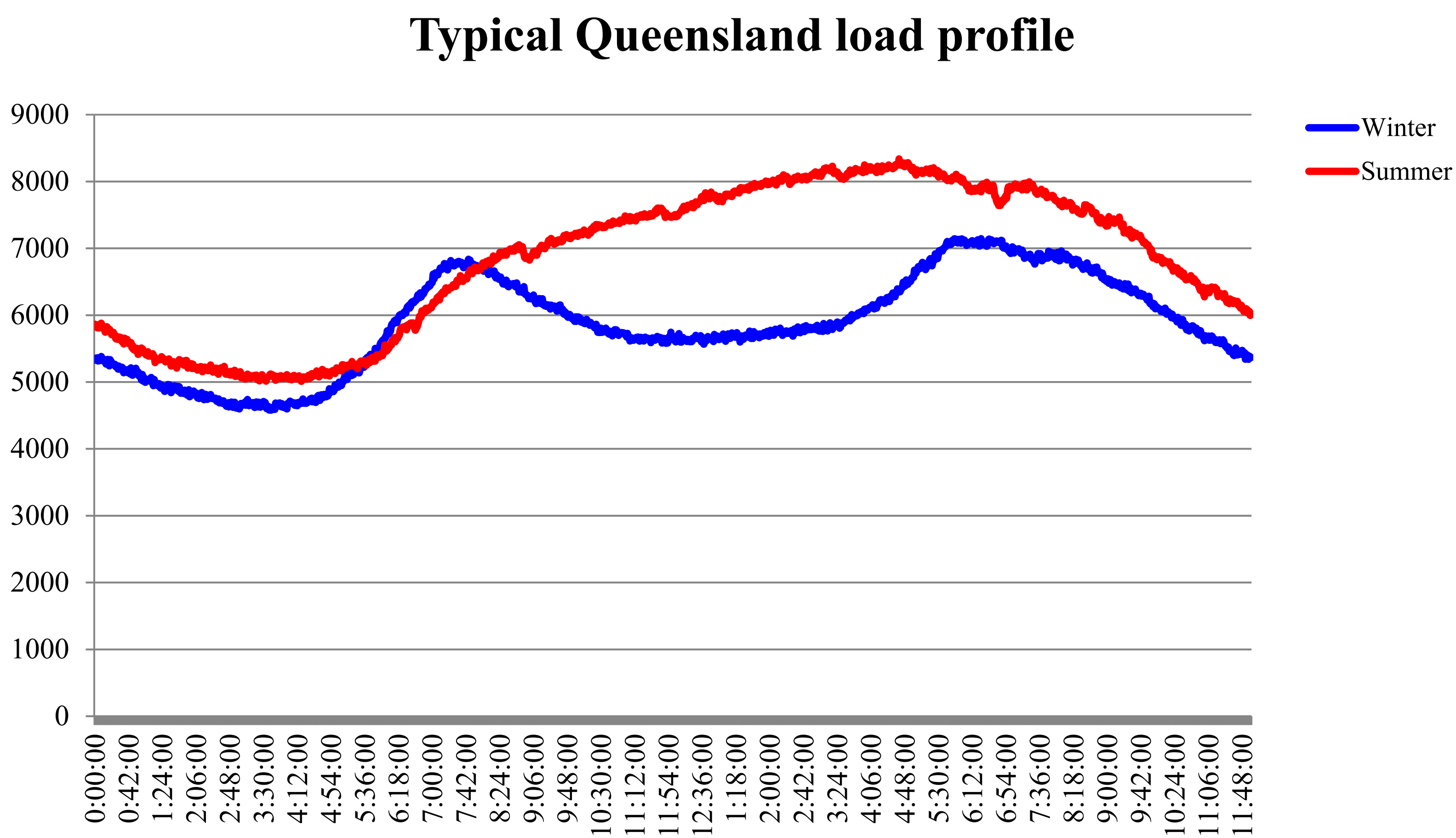
Energy stored in coal/gas/sun etc. is converted to electrical energy…



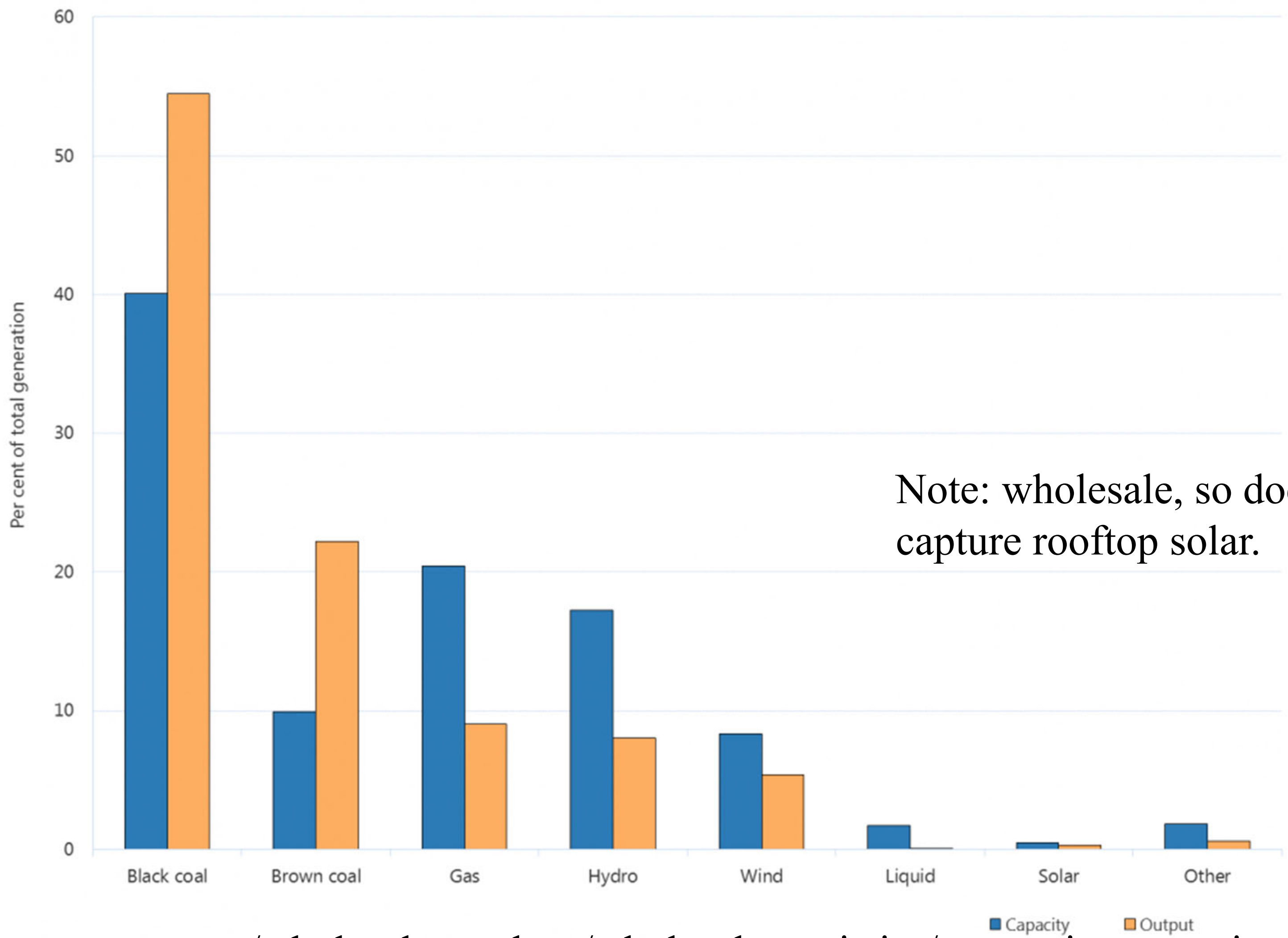
Generation

- There is no substantial storage in the grid. Thus:

  Generation(t) = Load(t) + Losses(t)



Generation In Australia (2016-17)



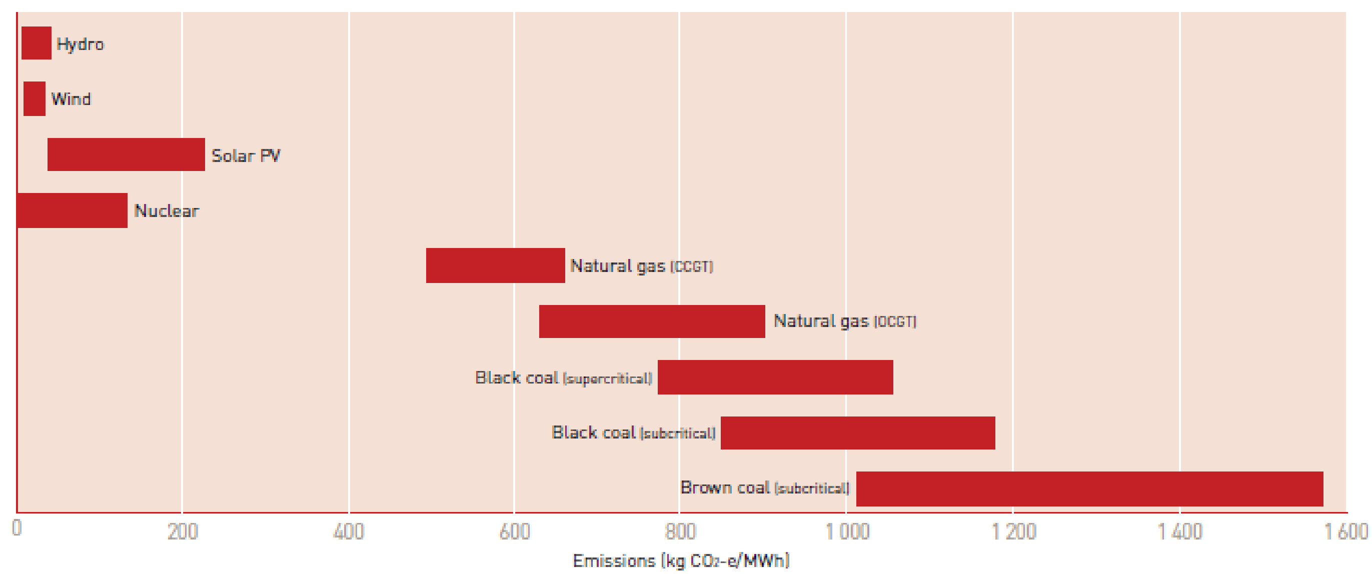
Note: wholesale, so doesn't capture rooftop solar.

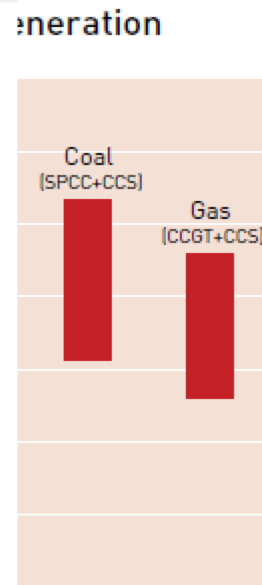
https://www.aer.gov.au/wholesale-markets/wholesale-statistics/generation-capacity-and-output-by-fuel-source

Generation

- In Australia most large generators are either Coal or Gas Fired Synchronous Generators.

Lifecycle greenhouse gas emissions from electricity generation





CCGT, combined cycle gas turbine; OCGT, open cycle gas turbine; PV, photovoltaic.

Notes:

The figure shows the estimated range of emissions for each technology and highlights the most likely emissions value. It includes emissions from power station construction and the extraction of fuel sources.

kg CO_2-e/MWh refers to the quantity of greenhouse gas emissions (in kilograms, converted to a carbon dioxide equivalent) that are produced for every megawatt hour of electricity produced.

Source: Commonwealth of Australia, *Uranium mining, processing and nuclear energy—opportunities for Australia?*, Report to the Prime Minister by the Uranium Mining, Processing and Nuclear Energy Review Taskforce, Canberra, December 2006.

Canberra, December 2006.

ınd storage (costs
pulverised coal
tures and pressures).
ıcessing and
rime Minister
eview Taskforce,

Queensland Generation over the years

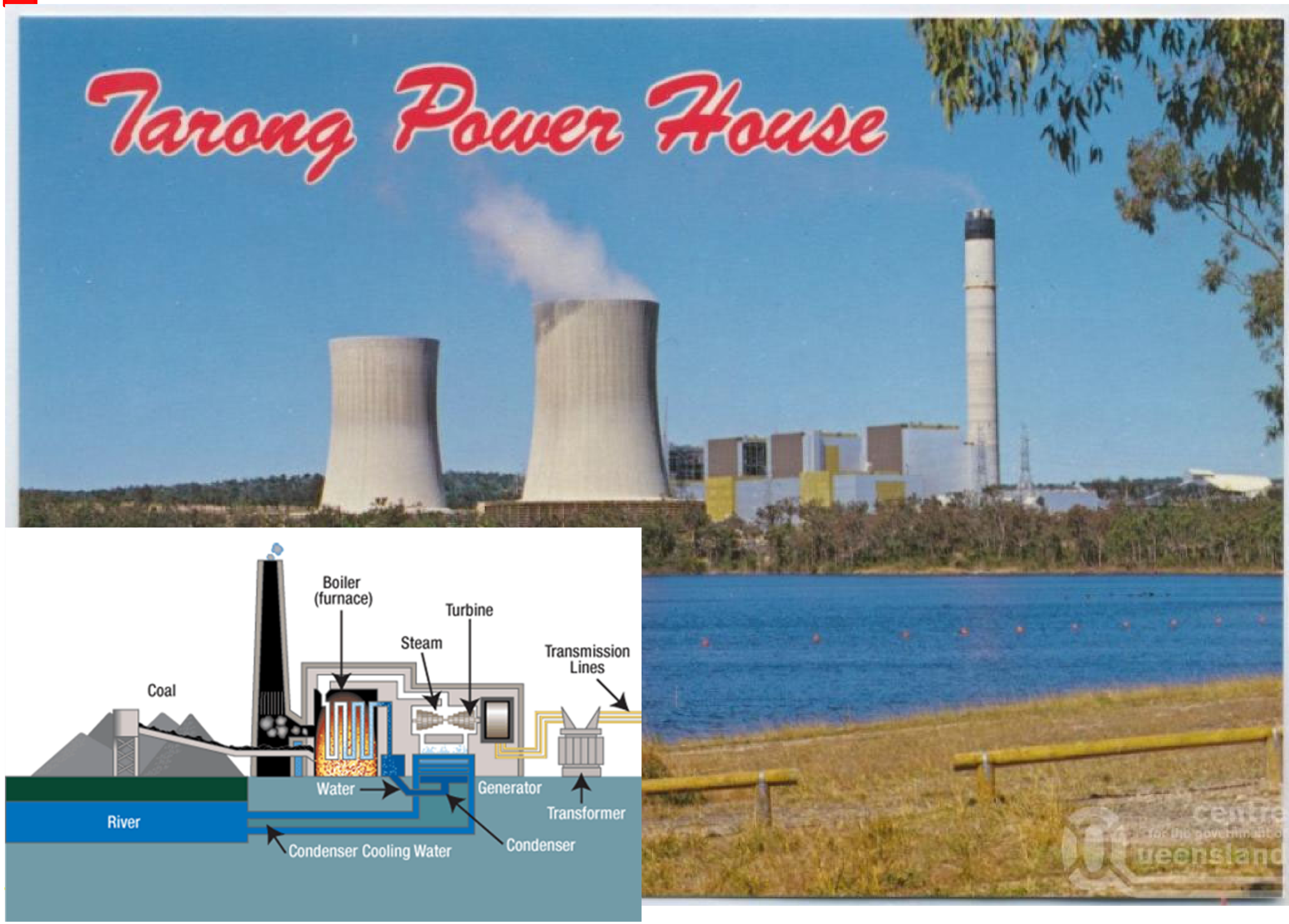
Table O4
Electricity generation in Queensland, by fuel type, physical units

	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18(e)
	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Non-renewable fuels										
Black coal	50,882.2	49,713.7	45,864.3	45,417.3	44,415.6	40,260.7	44,553.8	48,015.8	51,042.7	53,480.2
Brown coal										
Natural gas	9,257.2	12,020.6	14,595.3	15,303.4	13,909.5	15,454.3	18,248.5	13,816.9	12,236.6	11,112.1
Oil products	711.4	370.7	373.7	306.0	1,042.6	959.5	1,197.2	1,199.1	1,215.9	1,001.9
Other a	691.8	1,025.9	1,038.7	15.7	54.2					
Total non-renewable	**61,542.6**	**63,130.9**	**61,872.0**	**61,042.4**	**59,421.9**	**56,674.5**	**63,999.5**	**63,031.9**	**64,495.2**	**65,594.2**
Renewable fuels										
Biomass	1,588.5	1,548.0	920.7	1,124.8	1,239.2	1,485.8	1,641.4	1,771.8	1,410.0	1,434.1
Wind	27.3	30.9	27.3	27.7	30.7	33.7	32.5	28.4	29.0	28.5
Hydro	820.2	572.8	965.6	723.2	684.1	820.9	649.1	491.7	672.2	657.3
Large-scale solar PV						4.0	5.9	7.3	34.1	171.5
Small-scale solar PV	50.8	121.3	400.6	760.3	1,310.2	1,460.6	1,788.0	2,055.9	2,335.9	2,760.9
Geothermal	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.2	0.5	
Total renewable	**2,487.3**	**2,273.5**	**2,314.7**	**2,636.5**	**3,264.7**	**3,805.5**	**4,117.5**	**4,355.3**	**4,481.7**	**5,052.1**
Total	**64,029.9**	**65,404.4**	**64,186.7**	**63,678.9**	**62,686.6**	**60,480.0**	**68,117.0**	**67,387.1**	**68,976.8**	**70,646.3**

https://www.energy.gov.au/publications/australian-energy-statistics-table-o-electricity-generation-fuel-type-2017-18-and-2018

Generation

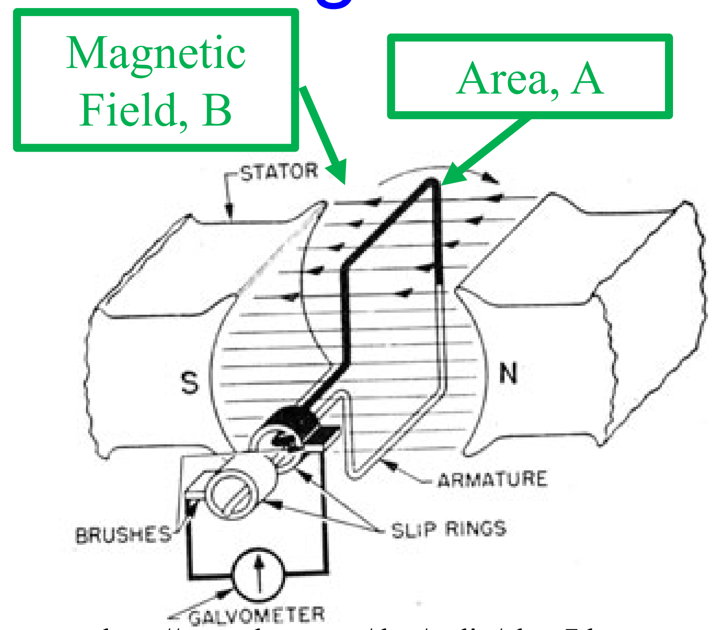
- In Queensland most large generators are either Coal or gas Fired Synchronous Generators.
- Tarong Power Station 4 x 350MW (20kV) generators totalling 1400MW capacity.
- Renewable Power Generation in Queensland:
  - Roof top solar
  - Hydroelectric
  - Bagasse (sugar cane trash)


Tarong Power House
Boiler
(furnace)
Turbine
Steam
Transmission
Lines
Coal
Water
Generator
Transformer
River
Condenser Cooling Water
Condenser

Generating Electricity: Electromagnetic Induction

- If we have a loop of wire we can quantify the magnetic flux Φ which is enclosed by that loop: $\Phi = B.A$
- If we have N loops then: $\Phi = N.B.A$
- Faraday's Law says that if the magnetic flux inside the loop changes, then we generate a voltage

$$\boxed{v(t) = \frac{d\Phi}{dt}}$$



http://www.hnsa.org/doc/radio/chap7.htm

Generated voltage, V, depends on

- **N** (number of turns in the coil),
- **B** (magnetic flux density),
- **A** (area of coil),
- **ω** (the speed that the coil is turned).

$$\boxed{\begin{aligned} v(t) = \frac{d\Phi}{dt} &= \frac{d(\mathrm{N.B.A.}\cos\omega t)}{dt} \\ &= \mathrm{N.B.A}\frac{d(\cos\omega t)}{dt} \\ &= -\mathrm{N.B.A}\omega\sin\omega t \end{aligned}}$$

Coal Fired Generators typically supply low 10's of kV (i.e. 24kV).

Electricity Network – Transmission

240V

$$I = \frac{1GW}{240} = 4.2\text{MA}$$

200km Transmission line, 1Ω

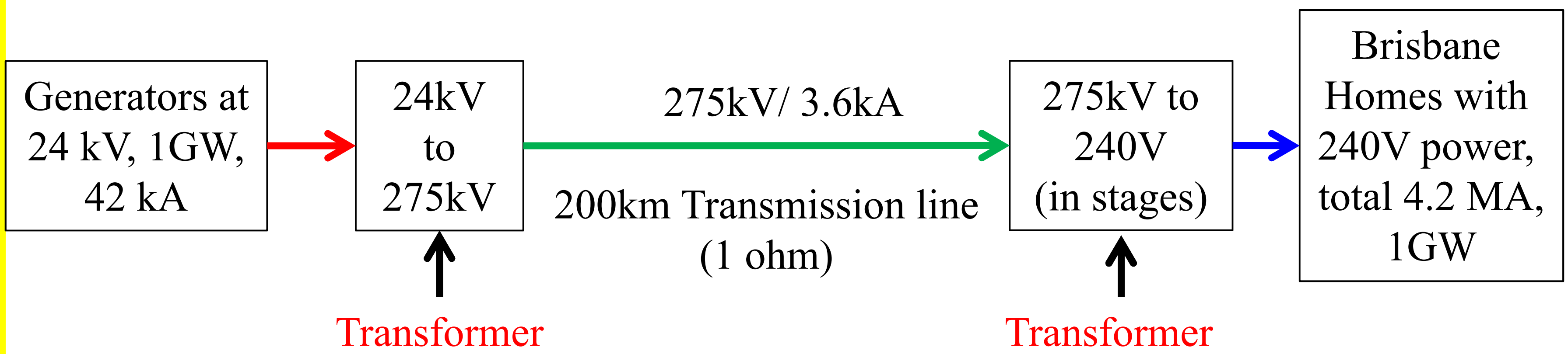
The "load" of Brisbane
Requiring 1GW
(240V)

Resistive losses in transmission wires for 4.2 MA: I^2R = 17,640 GW

It is only by transmitting at very high voltages that large scale power transmission becomes efficient

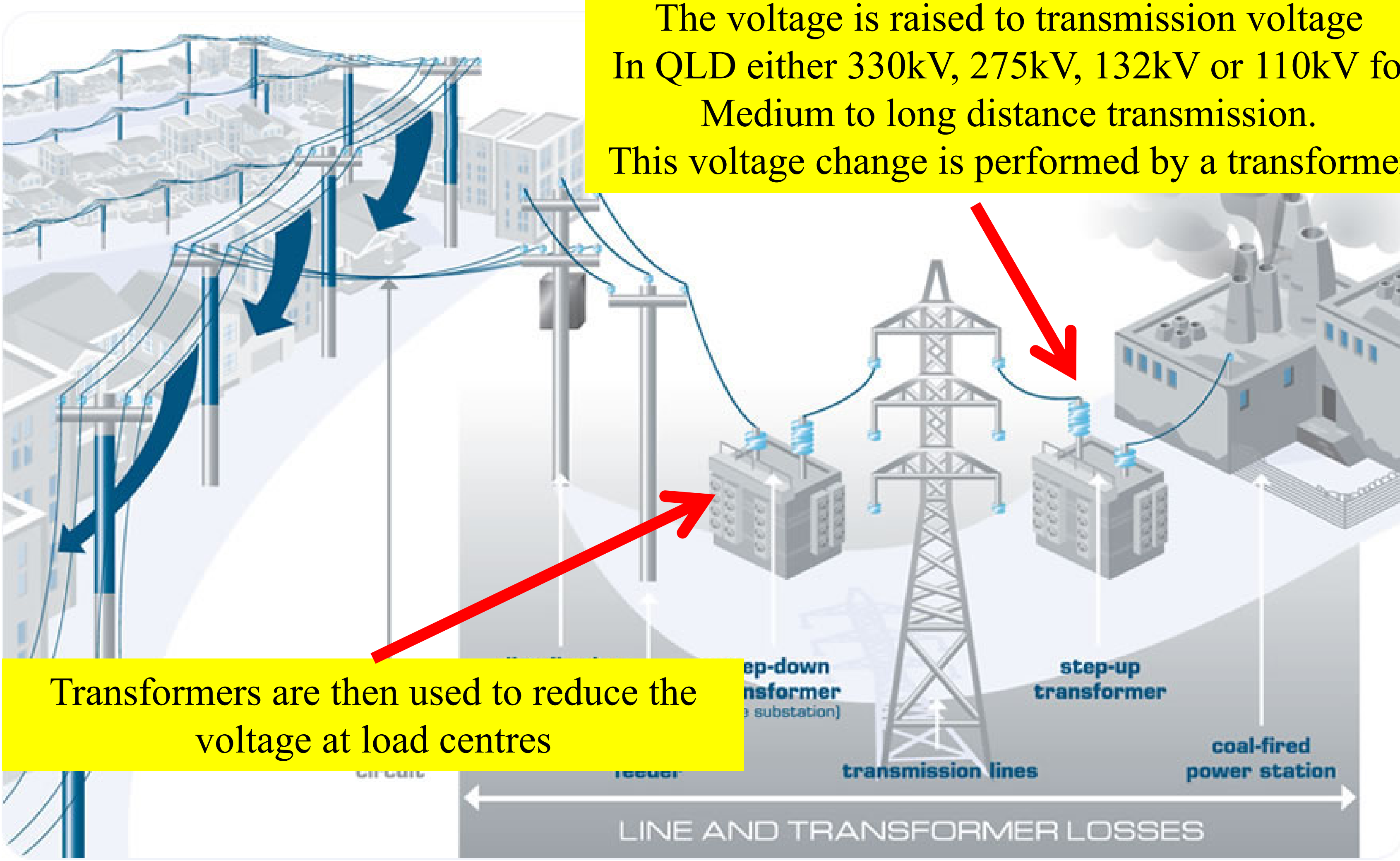
Electricity Network – Transmission

- Power generated at 24kV
- Step-up to 275 kV at power station, and transmit long distances (100’s of km’s)
- Step back down to 240V (in stages) near the point of consumption (i.e. homes)



Electricity Network – Transmission

The voltage is raised to transmission voltage
In QLD either 330kV, 275kV, 132kV or 110kV for Medium to long distance transmission.
This voltage change is performed by a transformer.



Transformers are then used to reduce the voltage at load centres

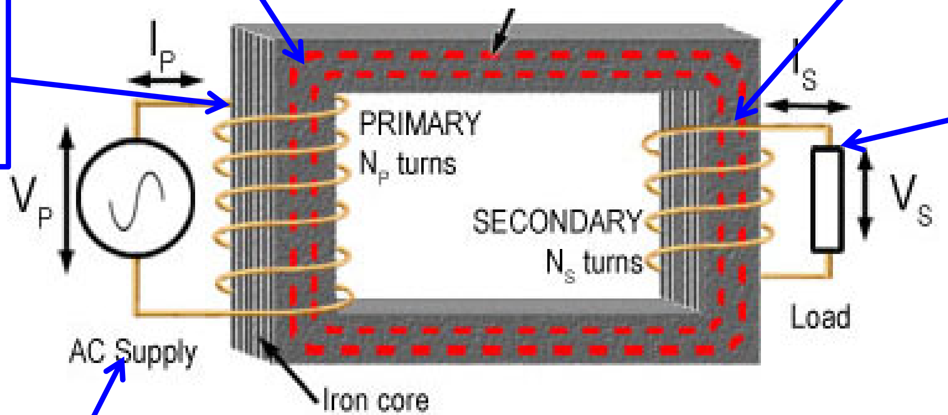
http://www.polepower.biz/features.html

Transformers

Magnetic field H induces a magnetic flux B which passes almost entirely through the iron core.

Therefore we also see B, and consequently H through the secondary coil of the transformer (with N_s turns)

I_P through the primary coil generates an AC magnetic field H



The AC H thus induces a current I_s to flow through the secondary coil, and thus a voltage V_S across the load resistor.

The primary AC voltage source, V_P, causes a current I_P to flow through the primary coil of wire (with N_P turns)

- For an ideal transformer , the ratio of the primary and secondary voltages is exactly proportional to the turns on each coil: $V_S = \frac{N_S}{N_P} V_P$
- There is a similar (but inverse) ratio for currents: $I_S = \frac{N_P}{N_S} I_P$

http://www.learnabout-electronics.org

Transformers

- Example 1: if N_p:N_s=20:1; and V_p=240V, what is the voltage across the secondary coil?
  - $V_S = \frac{N_S}{N_P} V_P$
  - $V_S = \frac{1}{20} \times 240 = 12V$
- Example 2: if N_p:N_s=20:1; and I_S=10A, what is current supplied by the source?
  - $I_P = \frac{N_S}{N_P} I_S$
  - $I_P = \frac{1}{20} \times 10 = 0.5A$
- Thus, if we step-down voltage, we step-up current, or vice versa, and the overall power on each side is the same (i.e. power supplied by source is equal to power dissipated by the load).
- A practical transformer is usually very close to ideal, ie. about 99% of the power is transferred from primary to secondary, 1% lost.
- More detailed examples in Session 11B.

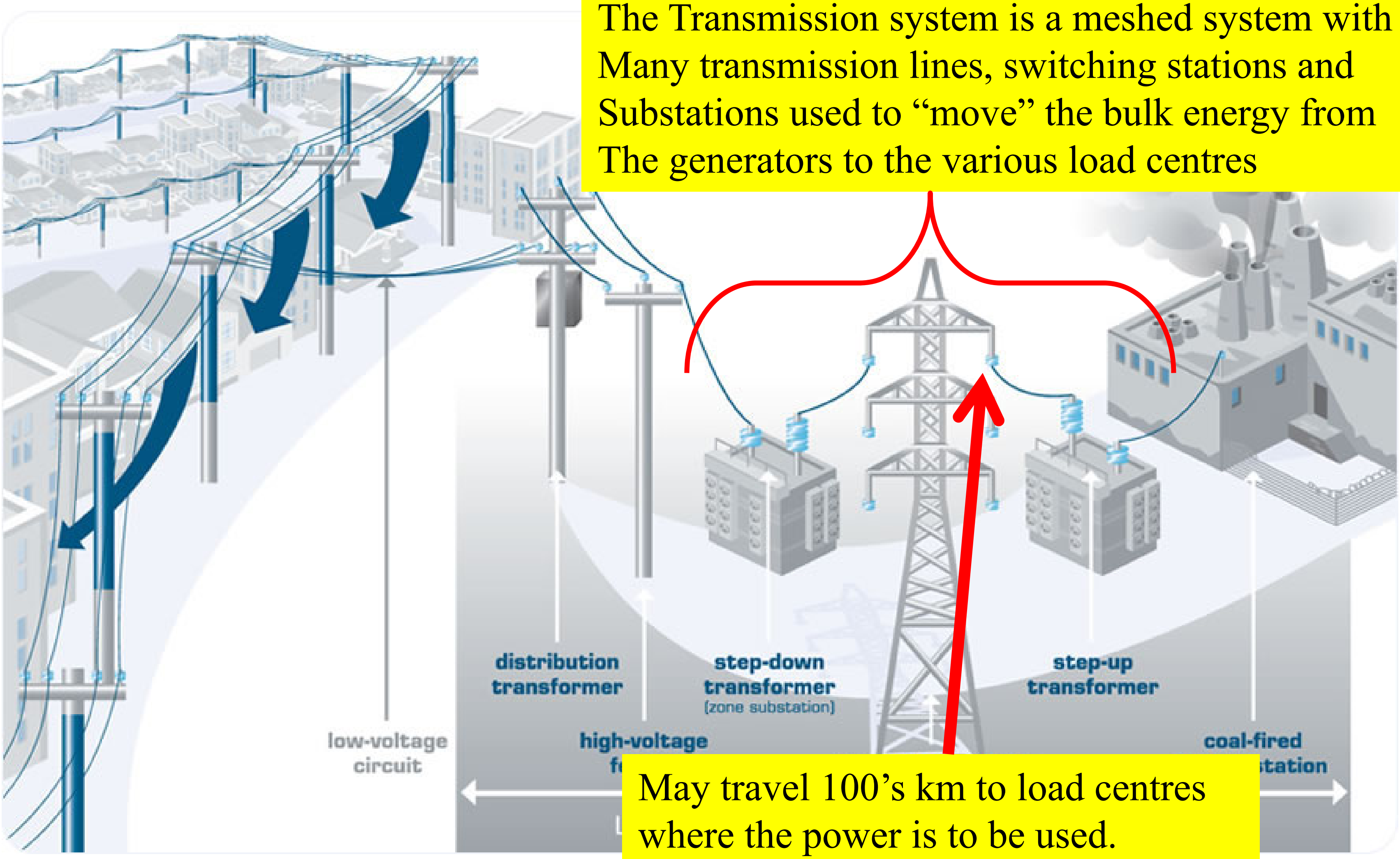
Transmission Network

- Powerlink owns, operates and maintains the Queensland Transmission network.

- Ergon Energy and Energex also own and operate a small number of transmission assets
- The transmission network consists of:
  - Substations & Switching Stations
  - Transmission Lines
  - Protection, Control, metering and Telecommunications Equipment.

Electricity Network - Transmission

The Transmission system is a meshed system with
Many transmission lines, switching stations and
Substations used to “move” the bulk energy from
The generators to the various load centres



May travel 100’s km to load centres
where the power is to be used.
The power is carried via high voltage
transmission lines or cables

http://www.polepower.biz/features.html

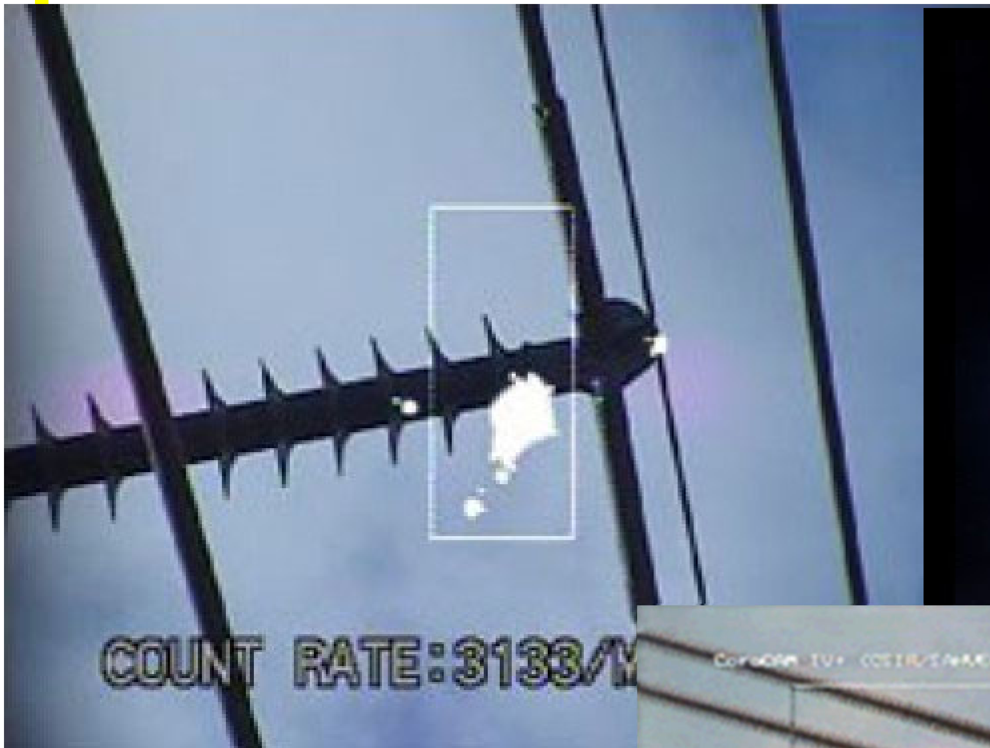
Single Circuit 275kV Feeder (Transmission Line)

Double Circuit 275kV Feeder (Transmission Line)

Higher voltages?

- Queensland is now investigating 500kV transmission lines.
- The higher the voltage, the bigger the insulators are, the harder the transformers and other equipment is to build and the more expensive everything is. So there is a limit to how high we can go.
- At very high voltages, the air around the conductors actually breaks down, buzzes and glows (called “corona”). This is difficult to manage, and also greatly increases losses.

Corona


COUNT RATE:3133/M


synkronized@optusnet.com.au
Photograph by Andre Tan 2006

Tarong Substation

Transmission Substation Equipment

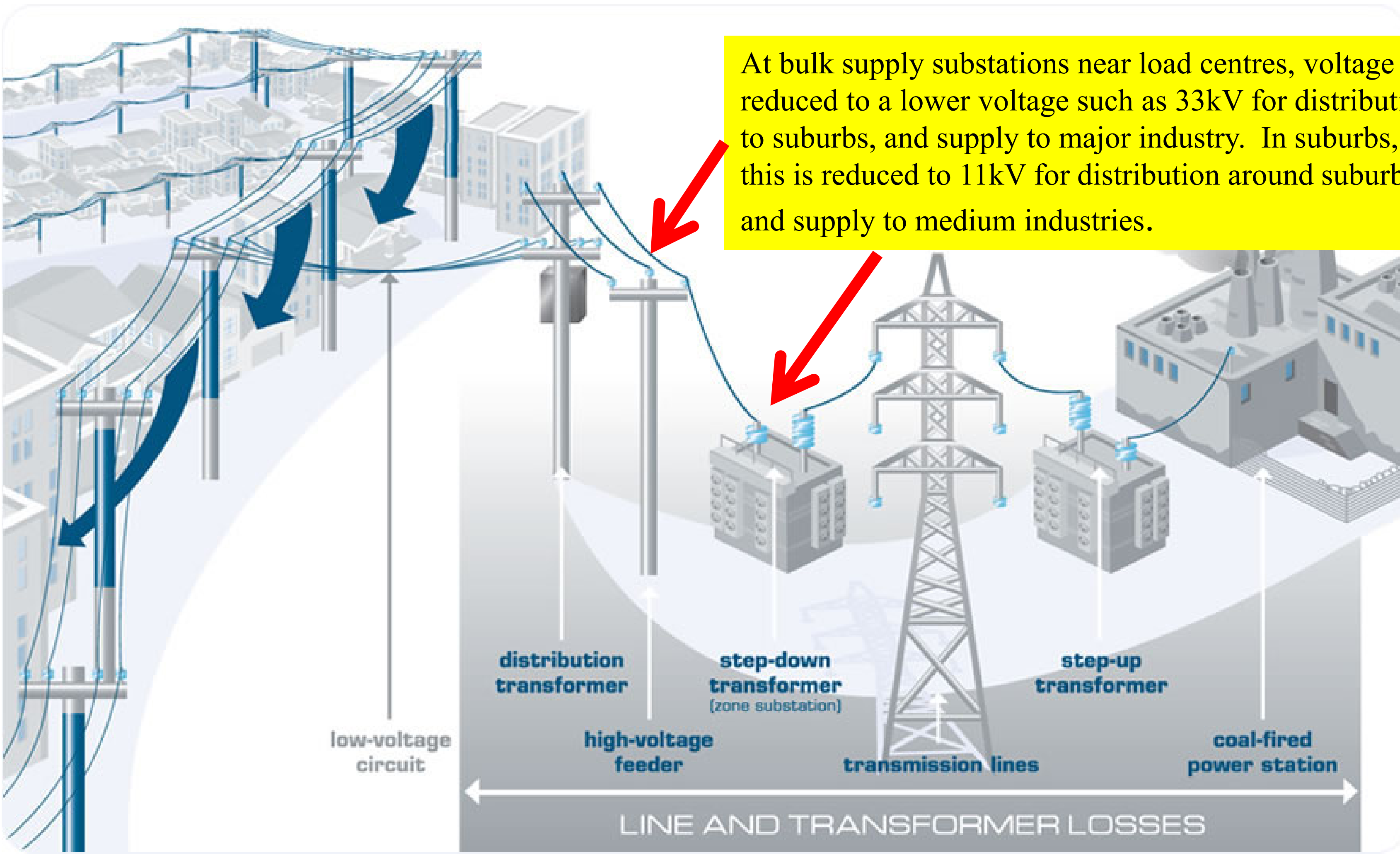
275/110kV Power Transformer 375MVA at
Molendinar substation

VAR compensator

- Most Loads are reactive (inductive) – Shunt capacitor banks to compensate.
- Some very long lines are capacitive – shunt reactors used to compensate.
- Can also use SVC for dynamic reactive compensation – The one pictured can supply anything between +250 MVAR (capacitive) to -100 MVAR (inductive)

Electricity Network Transmission/Distribution

At bulk supply substations near load centres, voltage is reduced to a lower voltage such as 33kV for distribution to suburbs, and supply to major industry. In suburbs, this is reduced to 11kV for distribution around suburbs, and supply to medium industries.

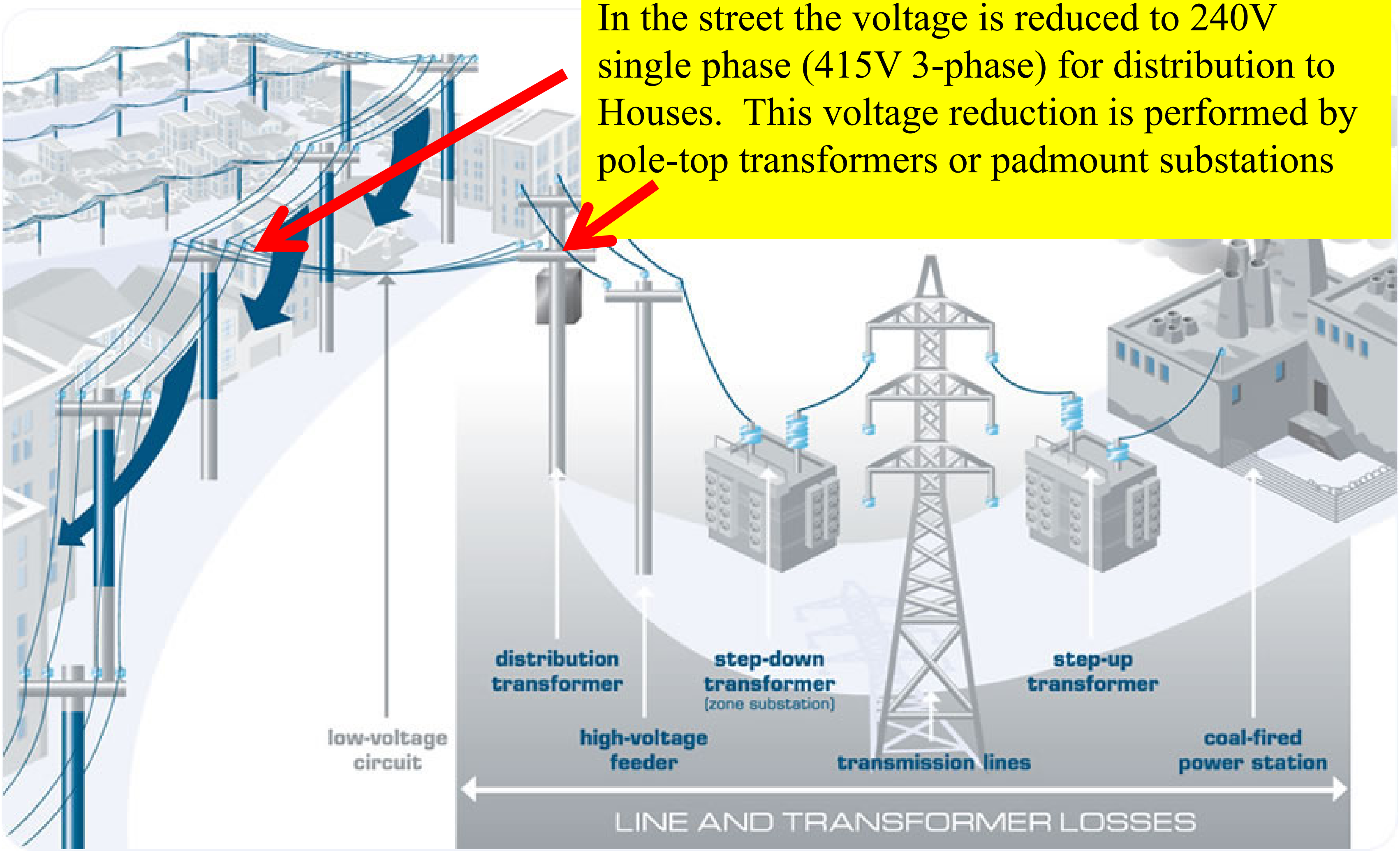


http://www.polepower.biz/features.html

South Pine 275/110kV substation & Brendale 110/33/11kV substation

Electricity Network - Distribution

In the street the voltage is reduced to 240V single phase (415V 3-phase) for distribution to Houses. This voltage reduction is performed by pole-top transformers or padmount substations



http://www.polepower.biz/features.html

Distribution Lines & Transformers

countryenergy

energex positive energy

ERGON ENERGY

- 11kV/240V Transformers

Why AC Power?

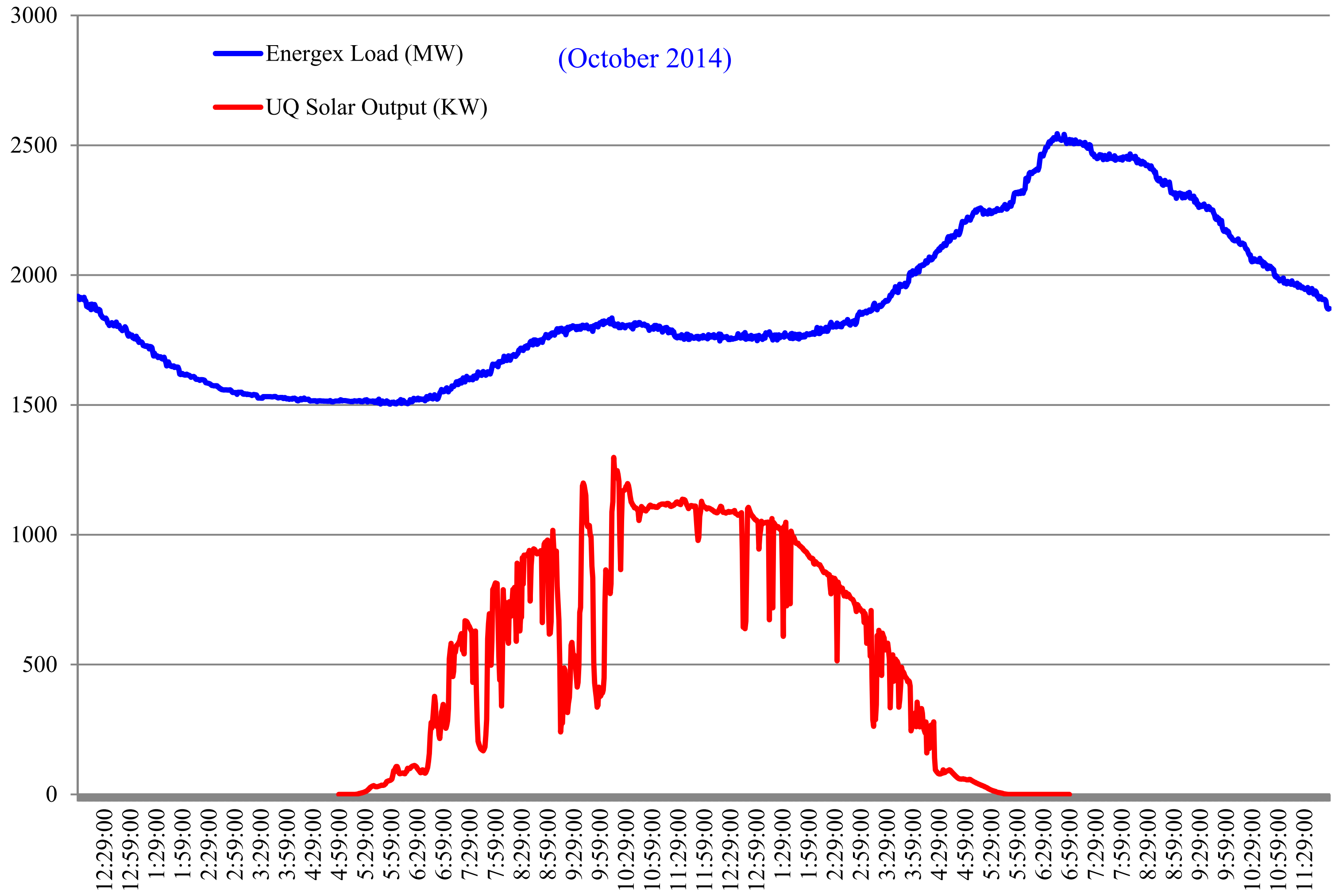
- Simple Answer – AC power is simpler to transform, switch and protect, in fact when power systems were first developed we didn't have the means to transform DC and switching is more stressful on components (some of these systems are now becoming available).
- There are problems with AC power transmission over long distances caused by inductance, capacitance of transmission lines (see activity 2 of Lab XVIII in Session 11B).
- With recent developments in high voltage semiconductors (thyristors, IGTs) and other switching technologies, there are an increasing number of high voltage DC transmission lines in Australia and around the world (BASSLINK)

Topical Issues in Power Engineering: Why can't we just replace coal with solar?

- Extremely limited electricity energy storage – power is generated on demand and must match the load (+ losses).
- Our primary Largest Generators (Coal) are designed for only steady (i.e. well predicted) changes, and for operating at set production levels – the lower the output, the less efficient…. These are called "Base-Load stations".
- Base load stations are expensive, inefficient and slow to turn on and off – coal fired generators 8-48hrs start up.

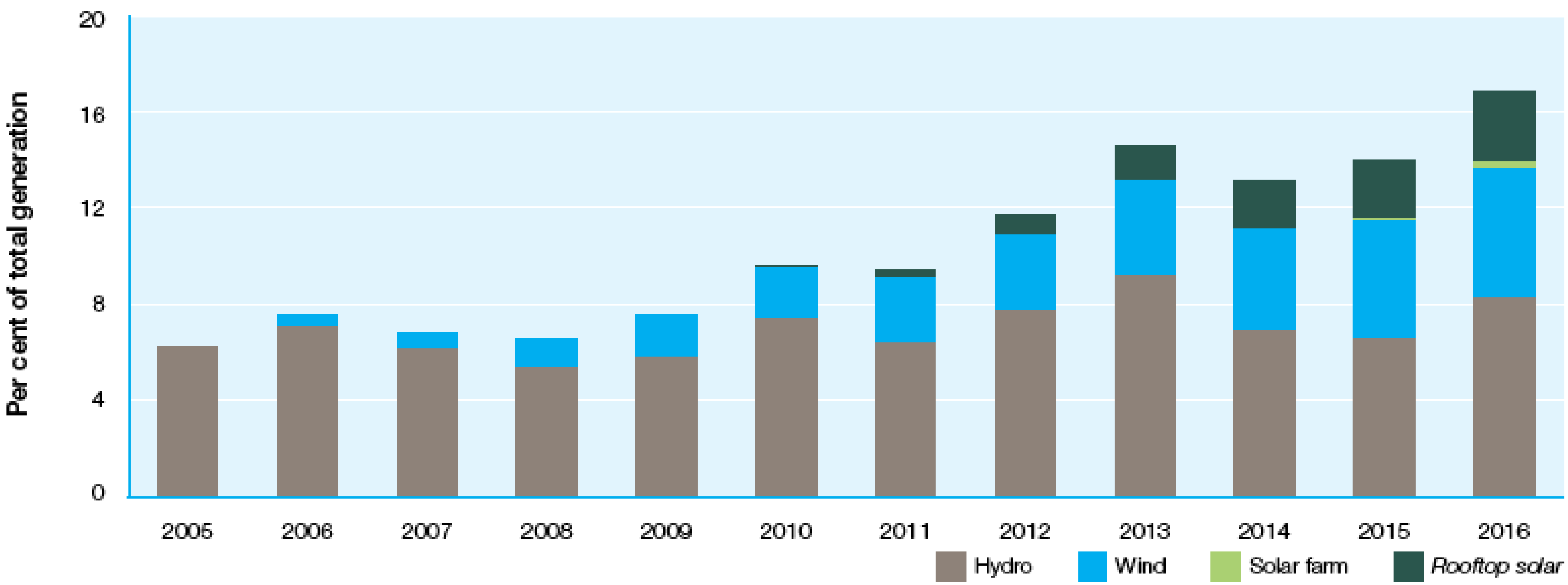
- There are significant technical challenges in moving from these baseload generators to other sources…

Challenges of Solar and Wind



Uptake of Solar and Wind

Figure 1
Renewable generation contribution to NEM electricity supply



Note: Rooftop solar PV generation is not traded through the NEM. Electricity generated from this source acts to reduce the demand for grid supplied electricity.

Source: AER

https://www.aer.gov.au/publications/state-of-the-energy-market-reports/state-of-the-energy-market-may-2017

Challenges of Solar and Wind

- With fluctuating energy production (i.e. solar, wind); when demand may not match supply, and energy needs to be supplied by other sources:
  - "Peaking Stations" (Gas and hydroelectric) to follow the load curve to ensure that voltage and frequency standards are maintained: However peaking stations are expensive!...Particularly if there are gas shortages!
  - Infrastructure has lagged behind as roof-top solar has seen rapid uptake in the last 5-10 years.
- The distribution network (including protection/safety/ switching) was not designed for reversed power flows. This can create power stability problems (i.e. the voltage that you see fluctuates!).
- Safety concerns: a house may be "live", even if external power switched off (new systems now protect against this).

Key Technical Limitations of Renewable Integration

- Significant research into new, more efficient storage systems:
  - Hydro energy storage (pump water up-hill during surplus; generate during shortage) – Snowy Hydro 2.0 (http://www.snowyhydro.com.au/our-scheme/snowy20/)
  - Distributed battery storage:

Lithium-ion/Lithium Polymer

Zinc Bromide Batteries

  - Large Scale Battery Storage (i.e. South Australia - http://www.abc.net.au/news/2017-09-29/elon-musk-tesla-world-biggest-battery-reaches-halfway-mark/9001542)
- We also need to consider environmental costs of batteries (or other storage) over lifecycle (manufacturing/construction, chemical waste) – most people probably don’t want a lithium battery manufacturer in their suburb; or a new dam in their local national park.

Opportunities in the Power Industry?

- the Australian Power Institute (API) offers $4000 bursaries and paid vacation employment for students interested in careers in Power Engineering (electrical, mechatronic, mechanical eng, software/comp sci)
- Professor Tapan Saha has provided a further information video at the course link below ("Learning Resources"->"Additional Resource Videos"->"API bursaries")
- Further details here: https://api.edu.au/bursary/