Base Load Power Stations & their interaction with Renewable Sources in South Australia

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The article discusses the operation and characteristics of coal and gas driven power stations feeding a distribution grid and their interaction with renewable sources coupled into the same grid. The article particularly refers to South Australia and history of power stations in the State.

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Introduction:

Operation is initially described of coal and gas fired steam driven turbines and gas turbines, open and combined cycle. This leads into some brief history of early steam driven power stations in Adelaide, Port Adelaide, Osborne and Port Augusta and on to existing natural gas driven stations at Torrens Island and Pelican Point. We refer to the existing stations as Base Load stations relative to the Renewable Sources, such as wind and solar, which have been introduced in recent years and added to the distribution grids.

The general aim has been to introduce renewable power sources which don't generate carbon dioxide and other pollutants and gradually phase out those which do. But there are definite problems in parallel operation of the two systems on the grid and the problems will increase as the proportion of renewable energy increases and the base load contribution decreases. Further on we discuss some of these problems.

Coal Fired Power Generation Technology:

Coal fired power stations have been around since the 1880s. In most coal fired power plants, chunks of coal are crushed into fine powder and are fed into a combustion unit where it is burned. Heat from the burning coal is used to generate steam that is used to spin one or more turbines to generate electricity. The process is illustrated in the diagram. Coal fired power is still based on the same methods started over 100 years ago, but improvements in all areas have brought coal power to be the inexpensive power source used so widely today.

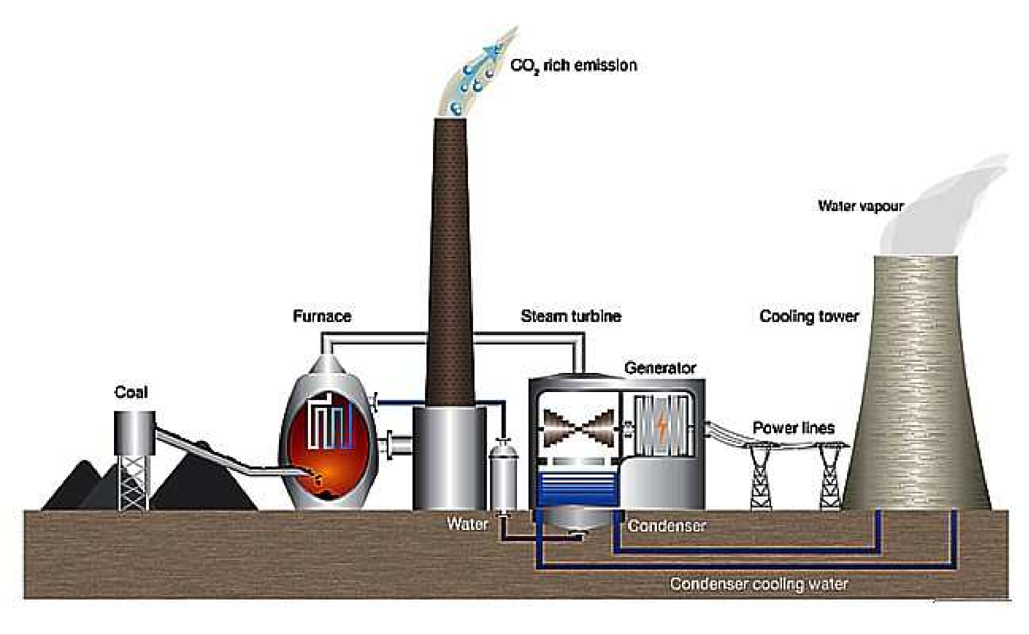


Figure 1
Coal Fired Steam Turbine Power Station

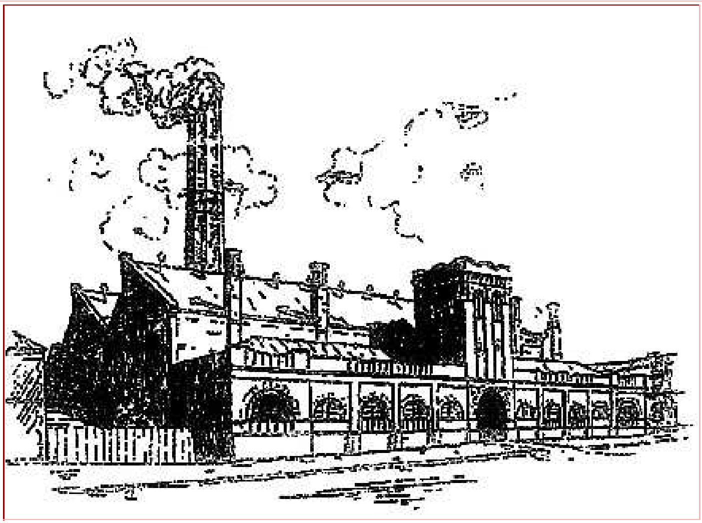
In the 1920s, the pulverized coal firing was developed. This process brought advantages that included a higher combustion temperature, improved thermal efficiency and a lower requirement for excess air for combustion. Pieces of coal are crushed between balls or cylindrical rollers that move between two tracks or "races." The raw coal is then fed into the pulverizer along with air heated to about 650 degrees F from the boiler. As the coal gets crushed by the rolling action, the hot air dries it and blows the usable fine coal powder out to be used as fuel.

The Cyclone Furnace was a further development in the 1940s. Cyclone furnaces were able to provide a thorough mixing of coal particles with the air. This enabled the burning of coal grades that are not well suited for pulverized coal combustion plus burning of other types of fuel with greater overall efficiency.

Some history of Coal Fired Power Stations in South Australia

An early coal fired steam generator was set up in a station in Nile Street, Port Adelaide in 1897. This generated 200V-0-200V DC with a total power output of around 150kw from four steam driven generators, two of of 25 Kw and two of 50 Kw. The supply was apparently loaded across a 500 amp/hour battery and fed to street lighting.

Grenfell Street coal fired power station opened in November 1901 at the corner of East Terrace and Grenfell Street in Adelaide, with a rated power output of 400 kw to supply major Adelaide and suburbs. The power generated was initially 200-0-200V DC, but in 1902, motor generators were installed to convert the DC to AC for transmission to the suburbs of North Adelaide and Walkerville. The power output was later upgraded to 12 Mw in 1917. The station was originally built by the Electric Lighting and Traction Company of Australia Ltd, and in 1904, it was sold to the Adelaide Electric Supply Company Ltd (AES). The station closed down in 1924. The building still exists, occupied by the Tandanya Aboriginal Cultural Institute.



Sketch
Grenfell Street Coal Fired Steam Driven
Power Station 1901

Also in Adelaide, there were two converter stations converting from AC to 600V DC for the Metropolitan Tramways Trust (MTT). No1 Converter at East Terrace, with rated capacity of 2500 Kw, was commissioned in 1909. The No 1 station operated until 1956. No 2 Converter at Thebarton had a rated capacity of 900 Kw but we don't have dates for its period of operation.

The No1 Converter station originally housed 500 Kw transformers to provide the 600V for the tramways. To cope with varying 600V DC loads, a lead acid battery of 293 cells and a 50 ton storage tank of sulphuric acid, was also located there. Power for the No1 Converter station was supplied by Adelaide Electric from Grenfell St. Power Station until the Port Adelaide MTT Power Station was made operational in 1911.

Port Adelaide Power Station opened in 1911 using NSW black Coal. It generated 10,000 volt AC at 25 Hertz to feed Adelaide converter stations, which converted the power to 600V DC for the tramways. By 1958, all tramways in Adelaide (apart from the Glenelg Tram) were phased out and it is assumed that this would have corresponded with the phasing out of the Port Adelaide Power Station.

Osborne Coal Fired Power Station A was opened in August 1923 with a power output of 20 Mw. Osborne B was added in 1942, increasing the Osborne station output to 79 Mw. The Osborne stations were the mainstay of the Adelaide Electric Supply (AES) which supplied Adelaide and its suburbs with AC power. The Osborne stations initially used NSW black coal. However, after the AES company was taken over by the Government, and the Electricity Trust of South Australia (ETSA) was formed in 1946, the station was converted to operate from Leigh Creek brown coal. The Osborne B station was de-commissioned in the 1989-1890 era, superceded by the newer gas fired stations at Torrens Island. The old Osborne A station was probably disabled many years earlier.

Mining of brown coal was commenced at Leigh Creek in 1943. South Australia had two Coal fired stations close to Port Augusta operated from Leigh Creek brown coal. The Playford Station rated at 240 Mw was opened in 1963 and the Northern Station rated at 520 Mw was opened in 1985. The Playford Station, high in atmospheric pollution and not very efficient, was mothballed in 2012. Leigh Creek coal field was getting close to the end supply of coal and it was closed in November 2015. The Northern Station subsequently closed in May 2016. The closures were earlier than previously anticipated by the owner, influenced by competition from the many wind farms which had been commissioned. There are now no coal fired stations operating to the power grid in South Australia.

Gas Steam Generation Units

Natural gas can be used to generate electricity in a variety of ways. The most basic natural gas-fired electric generation consists of a steam generation unit, where fossil fuels are burned in a boiler to heat water and produce steam that then turns a turbine to generate electricity. Natural gas may be used for this process, although these basic steam units are more typical of large coal or nuclear generation facilities. These basic steam generation units have fairly low energy efficiency. Typically, only 33 to 35 percent of the thermal energy used to generate the steam is converted into electrical energy in these types of units.

Steam generation supplies are not quite suitable for ramping up and down to compensate for the variable source of supply provided by the renewable energy sources from wind and the sun. The steam boilers have to be heated and cooled slowly to prevent damage to boiler tubes. Commissioning a boiler from start or shutting it down can take days.

Torrens Island Station

Torrens Island Power Station in South Australia is a typical gas driven steam generation facility. Owned and operated by AGL Energy, and with a name plate capacity total of 1,280MW, the station burns natural gas in boilers to generate steam, which then drives the turbines to generate electricity. The gas is supplied via the SEAGas pipeline from Victoria and from Moomba in the Cooper Basin.
A Station is 480 Mw from four 120 Mw natural gas or fuel oil steam turbines, built in1967.
B Station is 800 Mw from four 200 Mw natural gas or fuel oil steam turbines, built in1976.

Photo 1
Torrens Island Natural Gas/Fuel Oil Steam Power Station

With the recent closure of Leigh Creek coal mine and the two Port Augusta power stations operated from that coal, Torrens Island station is now the largest source of base level power in South Australia apart from the interstate connector link to Victoria. It is not really a suitable base source to be compatible with the renewable sources which vary with the availability of the wind and the loss of sun at night.

Gas Turbines

The Gas turbine, also called a combustion turbine, is a type of internal combustion engine with rotary rather than reciprocating motion. It has an upstream rotating compressor coupled to a downstream turbine, and a combustion chamber in between.

Fresh air from the atmosphere passes through a compressor which raises its pressure up to 30 times ambient pressure. Heat energy is generated by spraying the gas into the air and igniting it so that the combustion generates a high-temperature, high pressure, gas residue. This enters a turbine, where it expands down to the exhaust pressure and rotates a shaft. The energy of the shaft drives the compressor and the electric generator coupled to the shaft. The energy that is not used for shaft work comes out in the exhaust gases, so these have either a high temperature or a high velocity.

There are two types of gas-fired turbines, namely, the open-cycle gas turbine (OCGT) and combined-cycle gas turbine (CCGT). OCGT plants consist of a single compressor/gasturbine that is connected to an electricity generator via a shaft. They generally have fast ramp-up rates and used to meet peak-load demand .They offer moderate electrical efficiency of between 35% and 42% at full load.

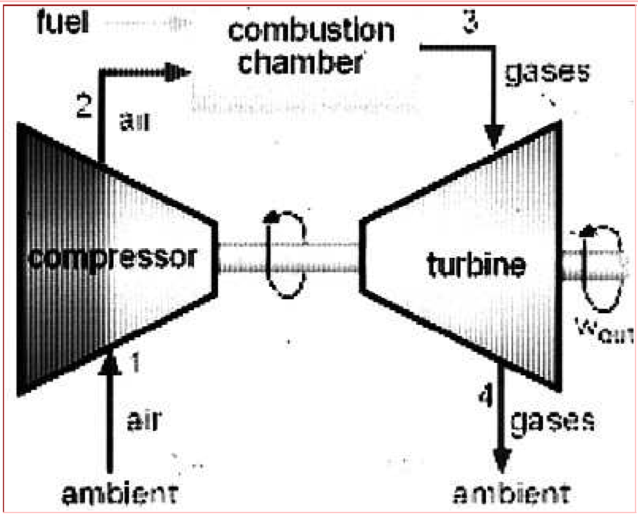


Figure 2
Open Cycle Gas Turbine system

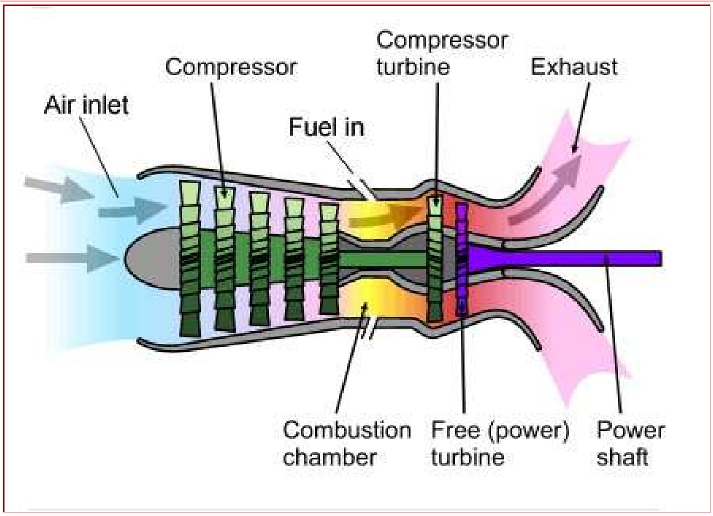


Figure 3
Open Cycle Gas Turbine schematic

The Combined Cycle Gas Turbine CCGT is the dominant gas-based technology for intermediate and base-load power generation. CCGT plants have basic components the same as the OCGT plants but the heat associated with the gas turbine exhaust is used in a heat recovery steam generator (HRSG). This produces steam that drives a steam turbine and generates additional electric power. Large CCGT plants may have more than one gas turbine.

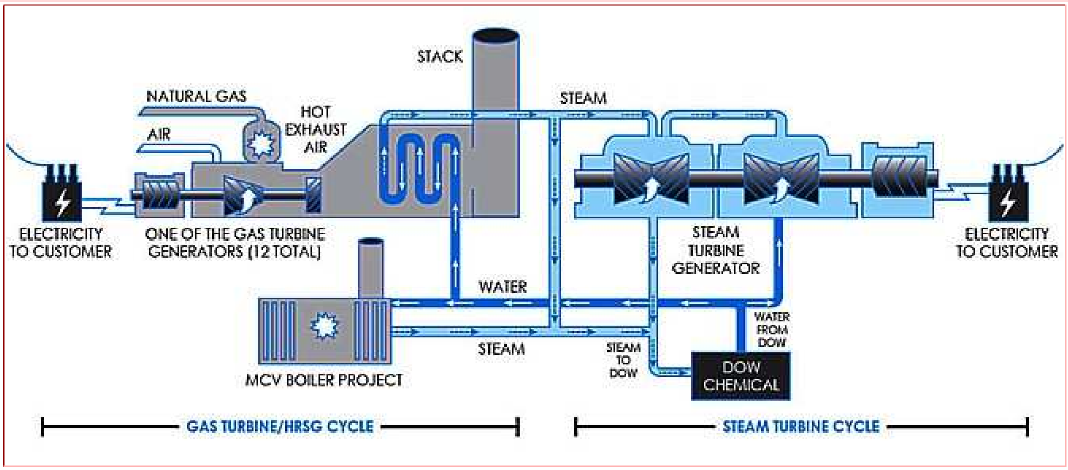


Figure 4
Combined Cycle Gas Turbine

Over the last few decades, impressive advancement in technology has meant a significant increase of the CCGT efficiency by raising the gas-turbine inlet temperature, with simultaneous reduction of investment costs and emissions. The CCGT electrical efficiency is expected to increase from the current 52-60% to some 64% by 2020. CCGT plants offer flexible operation. They are designed to respond relatively quickly to changes in electricity demand and may be operated at 50% of the nominal capacity with a moderate reduction of electrical efficiency (That is: 50-52% at 50% load compared to 58-59% at full load). In general, because of the higher investment costs and the higher cost of using natural gas compared to that of coal, CCGT plants are lower in the merit order for base-load operation. However, the comparison also depends on local conditions, variable fuel prices and environmental implications.

Pelican Point Power Station

Pelican Point Power Station is operated by French based company Engie (previously GDF Suez Australian Energy). It runs two gas turbines (160 Mw each) & one steam turbine 165 Mw), supplied with gas by pipeline from Victoria & by pipeline from Moomba. (It has a total capacity of 485 Mw). With CCGT technology, believed to run at over 50% efficiency and fast ramp up, it would appear to be the most suitable in South Australia to fast track power source variations and operate in conjunction with the renewable sources.

Large Base Load Power Sources

Large Base Load Power stations do more than provide energy to the power grid. They also provide a range of facilities which maintain the stability and security of the grid. These ancillary services allow the market operator to 'fine tune' voltage levels across the system. They also provide synchronous generation which dampens the impact of changes in power system frequency. Inertia effectively stabilises the power system, allowing it to cope with rapid significant changes in frequency which occur in either a supply source or in the load. Overall, they provide a more stable system. Additionally, they provide a system energy sink which can lead the system to restart after a major blackout. In general, smaller wind and solar sources do not offer these facilities to the power system.

One might see the system grid voltage and frequency as being set and controlled by one large base load power station with other power sources locked in to the reference set by the controlling station. There should not be more than one source trying to set the reference. Such a condition would lead to instability in the network.

The fact is: that if the grid system gradually changed to one in which all sources were small, such as individual wind towers and individual house solar panels, and there were no large reference source, there would be no stability and the system wouldn't work.

One idea, which might improve the system, is to select a group of the smaller sources to make up a resultant larger group source and feed them all with the controlling reference data via a control channel. The channel could be either a separate wire communications circuit or a carrier channel superimposed on the power line.

With the variable output of the solar and and wind sources, there is need for energy storage to maintain a more constant output level.In the event that base load stations are phased out, such as is gradually happening in South Australia, large basic storage, such as pump storage, could perhaps operate as the controlling base load power source and stabilise against supply source change or load variation. However, it would need its own controlled and stabilised frequency source rather than acting as a slave to that seen across the grid.

With the variable output of the solar and and wind sources, there is need for energy storage to maintain output when the sun does not shine and the wind does not blow. There are moves to provide many local battery stores at locations of solar panels and windwind farms. This will smooth out the variations in power generated but it does not provide the large stable voltage and frequency reference of the large base load. With all the relatively small sources of solar panels and wind machines, all acting as slaves to what they see on the grid and no large defined reference, one can imagine the whole system out of control with sources hunting for that stable reference.

Synchronisation of the many power sources.

The idea of locking in the frequency and phase with that found on the grid and adjusting the source current to feed power into the grid is illustrated in figures 5 and 6. The first diagram illustrates various energy pathways for wind and solar sources. The second diagram illustrates a Solar Inverter including the feedback loop which picks up a sample of what is seen on the grid and feeds it into the locking oscillator. For the wind turbines, some run at a fixed speed and some at a variable speed which depends on the strength of the wind. In the case of the fixed speed turbine, it uses an induction (or asynchronous) generator which has its field excited from the grid. The variable speed turbine generates power at a frequency which is variable. Its control operates much like the solar circuit of figure 6. The turbine AC output, or that rectified to DC, is fed into a power converter which regenerates the power as AC output at the grid frequency. The multitude of wind farms in Australia are a mixture of both types of the turbine control system. (Ref16)

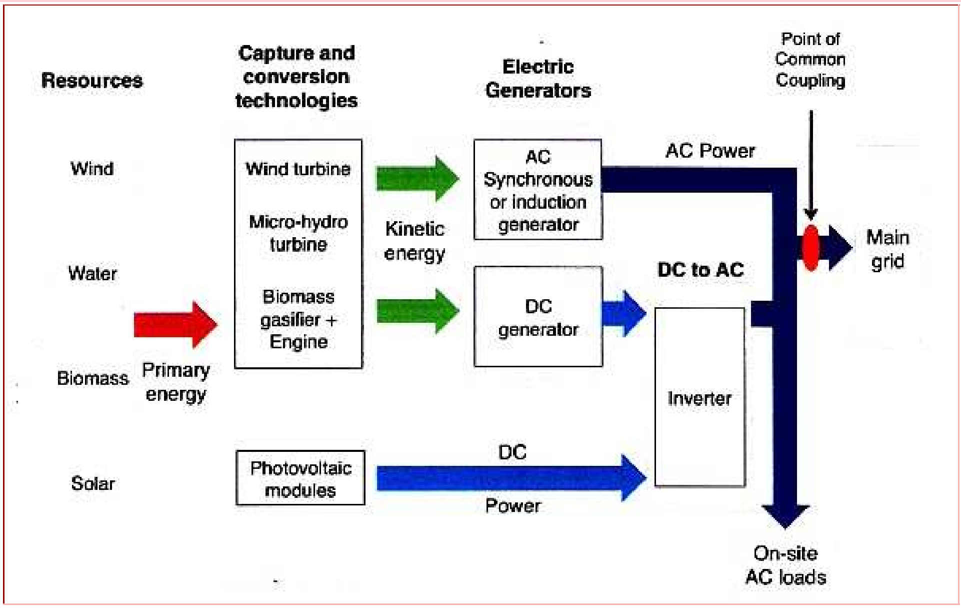


Figure 5
Energy Pathways of Renewable Sources such as Wind and Solar

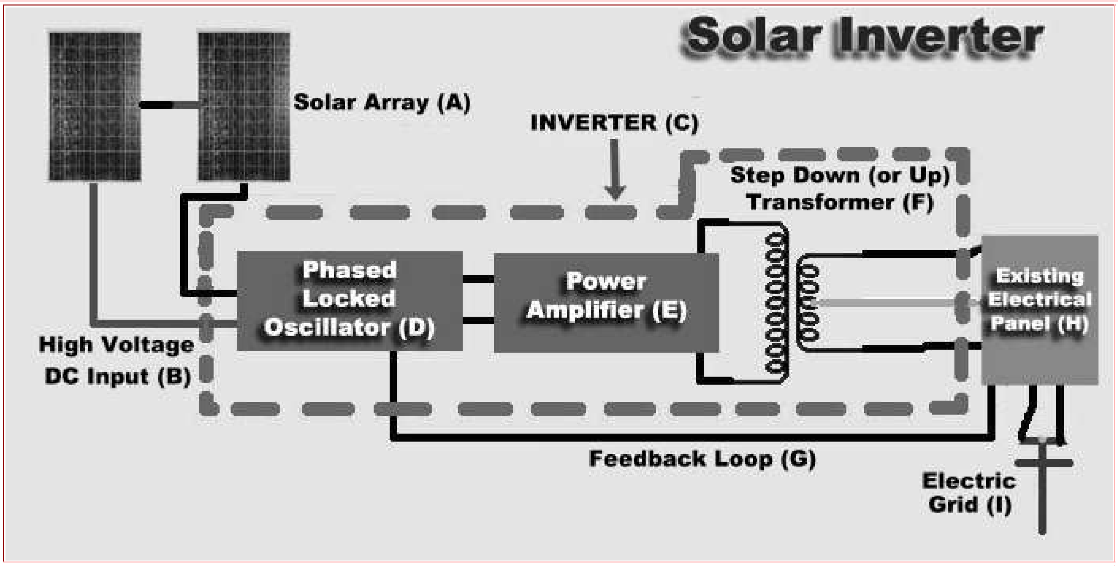


Figure 6 - Solar Inverter
Note the feedback loop from the Power Grid back into the Inverter

To load each individual AC power source into the power grid, the source must be synchronised to what is seen on the power grid before being switched in. This is done in figure 6 by tapping into connected line and feeding that back into the control of the generator. The source phase must be precisely set to that of the grid and the output current (Io), running from the source to the grid, set to that available from the generator at that point in time. To do this, the open circuit output voltage of the source (Voc) will be a little higher than the running grid voltage (Vg). Voc = Rs.Io + Vg, where Rs is the source resistance of the generator. (This simple formula assumes a power factor of 1. Of course, the grid load might look reactive and Voc might have to be higher).

All this is at present working because a large base load generator is locked to the reference frequency and phase as a sort of sink which is holding this reference essentially due to the large power source of this base load generator. But the aim of Governments is to gradually add these solar and wind sources whilst gradually reducing base load stations which generate CO2 and other pollution. But what happens when the large base load stations are no longer there or drop to a level where their output is insufficient to override the levels of the renewables? Control of frequency and phase is lost and this will be sensed by the system which will commence shutting down. **So here is the snag which will stop the system working.**

Having mentioned power factor, I will deviate a little on what is happening in North America concerning power factor correction on power grids. Induction motors look inductive and industries using many of these correct the power factor shift by including a synchronous motor which looks capacitive. Numerous coal fired power stations in USA are closing down as renewable energy systems are introduced. Shift of power factor due to reactive loads is a big factor causing loss of efficiency in the power distribution. Rather than dismantle all of the alternators, some are being re-used as synchronous capacitors coupled across the grids to correct the power factor shift. (See Ref 4).

Another factor which might cause power factor shift on long power connector links, such as the Victoria/SA link, is the line exhibiting its characteristic as a transmission line. If we assume that the 50 hertz transmission velocity is around 0.6 of that in space, a quarter wavelength would work out to be around 900 km, not that much different from the distance between Loy Yang power station and Adelaide. One could visualise the low resistance terminal load causing reflection at the end of a near quarter wave section, creating reactance (and shift of power factor) at the power source, and even the development of a high voltage loop due to resonance of the line for the quarter wave length.

Obviously, the possibility of standing waves being developed is very high on a very large power grid, such as that embracing the States of South Australia, Victoria and Tasmania. The AC isolation between States, using high voltage DC link sections to limit the length of AC interconnectors, would seem to be a good idea, as is done under-sea between Victoria and Tasmania and for the Murray Link between Berri and Red Cliffs.(See Ref 3).

The South Australian likely Power debacle

Over the recent years, the State of South Australia has encouraged industry, with great vigor, to install renewable energy sources such as wind farms. This has been taken up by world energy companies to the extent that when good winds blow, there is enough electric power generated to supply the whole State power grid. And to add to this, at the time of writing, there there were still more farms being installed.

When there is no wind to operate the wind turbines and and when there is no sun to energise the solar sources, the load is taken up by the base load power generators, or purchased from Interstate via the Heywood and Murray Link power connectors. When the wind and solar sources turn on, the load on the base load generators is reduced. These older plants were not designed for this random ramping up and down. And from all accounts, they are not economical to run with the intermittent loads, or to compete with the cheaper sources of renewable energy when it appears on the grid.

We have seen some of the effects of this. Leigh Creek coal used in the two coal fired power stations at Port Augusta was expected to run out in 2018. However, the owner of the coal mine and power stations, Alinta, closed down the mine early in 2015, and closed the remaining Northern Power Station early in 2016. The reason given was that the venture was no longer making a profit. In 2014, AGL had also decided to mothball their 480 Mw gas fired steam station Torrens Island A. (This decision was reversed when the Northern station was closed). And in 2015, the 479Mw gas turbine station at Pelican Point cut back most of its available output.

It is interesting that that the connector to Heywood in Victoria, of 650Mw capacity, provides a sink to supply power when SA is short and to consume power when the renewable sources in SA generate more power than SA needs. One must assume that in the absence of a large base load power source within SA, the connector could provide the reference to stabilise the voltage, frequency, and phase of other smaller sources feeding into the SA grid.

In July 2016, the Heywood Connector was switched off for a lengthy period whilst it was upgraded from its previous capacity of 460 Mw to 650 Mw. During this period, there was a terrific storm, generating wind which exceeded the maximum 90 Km/Hr rating of the wind turbines and they were all turned off. Without the back up power from the Heywood Connector, South Australia was suddenly short of power and sections of the State load were dropped out.

To switch in more power from Torrens Island, their idle steam boilers would have needed time to run up. The Gas Turbines of the Pelican Point power station, with the fastest ramp-up time, were the choice for more power. But the Pelican Point station output had already been reduced, close to a mothball state. The Government had to negotiate with the owners of the Pelican Point station to restore operation from that almost inoperative state.

Photo 2
Pelican Point Combined Cycle Gas Turbine Power Station

It has been the State Government aim for a distributed power system with complete renewable energy. If it is to be mainly wind and solar power, they will need an energy storage system to maintain continuous supply. It would also appear that they will need at least one supply source which will have a large power output capacity to provide a reference sink and maintain stability of the grid system.

In the March issue of OTN we described a Solar Thermal power system which Alinta Energy had proposed for Port Augusta. This was a move to replace the Leigh Creek coal fired stations which would be closed at a future date. The initial station was to be based on a plant successfully established in Seville, Spain. This made use of heated molten salt to store the energy and keep the station operative when there was no sun. The Australian Renewable Energy Agency (ARENA) and the SA Government provided grants for Alinta to carry out a feasibility study. The result was their conclusive report, in April 2015, that the project was not economically viable. So the project lapsed.

Several companies have since put foreword proposals on solar power stations to replace the drop out of power caused by the closure of Port Augusta coal fired power stations. In June 2016 (Ref. 5), it was reported that Australian company Solastor, could build a Sola Thermal plant, initially 100 Mw, of sufficient capacity to replace the output of the coal fired plants. Energy from the sun, directed by concave mirrors, would be stored at 800 degrees C in graphite blocks. Steam to drive a turbine would be generated by water running past the blocks.

In August 2016 (Ref 6), it was also reported that an American company, Solar Reserve, was interested in building a pilot 110 Mw solar thermal plant at Port Augusta to be followed up by five others over the next 10 years. They pointed out that the combined outputs would be equivalent in capacity to the Heywood Connector with Victoria. Possible sites for the five could be Leigh Creek, Woomera, Whyalla and Roxby Downs. Storage proposed was the use of molten salt (as for the Alinta proposal) with a storage time of 10 hours.

In October 2016, the SA Government sent out an invitation for tenders to supply a large scale supply of electrical power, generated either using the concentrated solar thermal system, or generated with natural gas. It is anticipated that companies such as Solaster and Solar Reserve will submit tenders. Refer also to the proposal for the Solar Thermal facility at Port Augusta. (Ref 17).

Whilst the solar thermal stations of these proposals would replace the closed down coal driven supplies, there is still the need for a large energy storage to iron out the ramping up and down of the output from the large number of wind farms, already installed and operating. There is also the question whether the proposed Port Augusta solar thermal plant (initially 100 MW) will be a large enough sink to maintain stability on the SA grid if either of the following takes place:
(1) The Torrens Island station is taken out of service because its intermittent load operation becomes economically non viable (like the Port Augusta Northern Station), or
(2) Because of changes in Victoria affecting the amount of spare power available to feed the interstate connectors.

On the availability of power from interstate, there have been discussions on the likely closing down coal fired stations in Victoria. The 1600 Mw coal fired Hazelwood Power Station and its brown coal mine are already programmed for closure at the end of March 2017. (Much like the closed Playford Station in SA, Hazelwood is considered a highly polluting Australian station). This will reduce the generation capacity within Victoria and could well affect the available power to SA via the Connectors.

The last thing that is worrying everybody is the excessive cost of electricity in South Australia since the State has become so heavily involved in renewable energy. It is not only the low wage earners who are in trouble. Large manufacturing and mining companies have complained that the high electrical costs have threatened their operational viability in SA. A lot of blame has been directed at the wind farms, which is hard to understand, since the wind energy is gratis and there is no energy giving fuel to purchase or transport. The true costs seem to be more to do with the difficulty in economically running the existing power stations in conjunction with the unprogrammable varying power outputs of the wind farms. Also with competition from the wind farms, their plants are under utilised with many of their machines turned off.

But the privatised electricity supply is also a market which takes advantage of situations to sell for the best price that can be bartered. During the July 2016 crisis, the price of electricity rose to excessive levels. According to the operators of Torrens Island, this followed from spikes in the cost of gas fuel supplied.

Having said all of the above, by September 2016, most of what had to be said was done. However in late September another very relevant event occurred when Australia had a series of storms. South Australia had tornadoes, heavy rain, lightning, and flooding from rivers and creeks. The winds damaged or demolished 22 towers supporting three 275V main high tension feeders for supplying power to the north and north west of the State (See Photo 3). The whole State suddenly lost power, which for some areas, took days to restore.

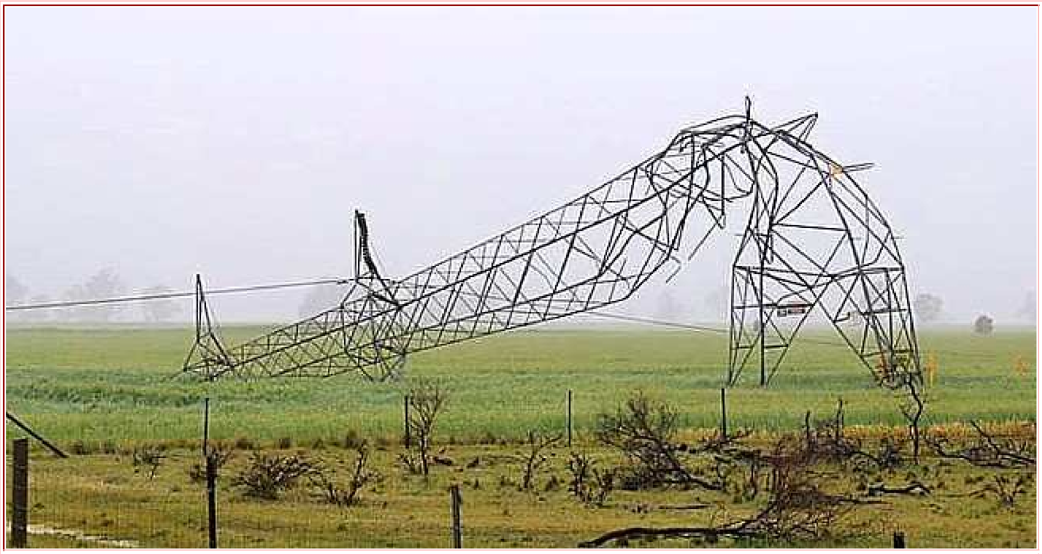


Photo 3
Damaged 275Kv Power Line Tower near Melrose

The question was raised: Why did the whole of the State electricity grid lose power? From what information was available, the following is what I think happened: At the time of the power failure, 70% of the power generated in SA was by the wind sources. Also before failure, about one third of the total power was drawn from Victoria (Ref 13). This was probably mainly from the Heywood Connector which, because of its large power source compared to the many small sources in SA, was probably the one setting the reference for frequency and phase.

The Heywood Connector dropped out, probably tripped off by the surge of increased power reflected from the damaged north lines. With the loss of the connector, there was also the loss of the synchronisation reference it provided. So the rest of the power sources went amuck trying to track the grid frequency under control of the reference source which was no longer there. Sensing frequency deviation outside specified limits, sections of the system progressively shut down as it was designed to do for the protection of its equipment and its safety. We believe that the Heywood Connector was reconnected in but had to drop out because its load went up, beyond its capacity, with the drop out of other power sources within SA. **From this, loss of synchronisation seems to be the main culprit in dropping out all of SA.**

Summary, Conclusions, & Some Comments

The article provides some basic information on the operation of coal fired and natural gas fired power stations, which in the presence of smaller renewable sources such as wind and solar, we have described as base load stations. Also included is some history about some of these stations in South Australia as early as 1897.

The discussion moves on into pointing out problems in the operation and stability of power grid, which can be expected to occur as the number of small output renewable energy sources gradually increase and existing base load sources are phased out.

It is clear that in advancing into the addition of sources of power from the wind and the sun, the installation of storage should proceed simultaneously with the installation of the renewable sources. Estimating the size of the storage could be a conundrum. It should probably be at least large enough to replace the large reference base source, in the event of that failing or being turned off. It should also be large enough to replace the loss of the renewable sources in their power down time (i.e. when there is no wind or no sun). The storage might have to hold the system operational during long periods of wind calm, perhaps lasting weeks.

But installation of solar installations and wind farms in Australia (and particularly in South Australia) has gone ahead, at random, with no provision for storing excess energy to be used in the down times. The expectation has apparently been made that the existing base load power generators (mainly ill equipped to ramp their loads up and down) will compensate for the intermittent down time.

In the 1930s & 1940s, there were no grids extended to the country farms and wind generators were used to power some of their electrical needs. They floated batteries across the circuit, to store generated energy not used by their loads, and supply energy to the loads over that available from their generator. The same principle has always been used in the motor car. When the motor runs, excess current charges into the battery and when the motor is turned off, current from the battery maintains functions, such as lights, in the car. If the battery storage were not there, excess power would have nowhere to go and loads exceeding the generator capacity could not succeed (e.g. the heavy starter motor load). The storage allows the energy generated to be used when it is required and to the extent it is required.

So there is a principle! If you have widely varying loads and widely varying source availability, energy storage is probably needed in the system. Goodness knows who thought up the idea of dumping multitudes of solar sources and wind powered sources at random across existing power grids without storing the intermittent energy generated to be distributed as required by the system.

The idea that they are waiting on a large battery based storage to be developed is all very well. But use of pumped storage of sea water has been well demonstrated throughout the world as a proven option for energy storage. The University of Melbourne Energy Institute (MEI) carried out a survey of pumped hydro projects with particular reference to the States of Australia. As a result of this, MEI produced a report dated February 27, 2014 (Ref 14). In surveying costs for pumped hydro projects globally, they found capital costs as low as $100 to $200 per kWh of useable energy stored. By comparison, they noted that chemical battery makers were aiming to be on the market in 2025 for capital costs in the range of $200 to $500 per Kwh of usable energy stored. A further CSIRO graph showed cost estimates of electricity from pumped storage to be $200 to $300 per Mw/h over time spans in the range of several hours to a full day. These estimates compared favourably with other time span estimates anticipated from various types of battery storage.

The MEI report locates possible coastal sites around Eyre and York Peninsulars in South Australia which might be suitable for pumped hydro installations. However, authorities in South Australia don't appear to have investigated further the feasability of installing this storage somewhere around the State coast.

I have pointed out earlier that to maintain stability on the grid, it needs to be sinked by a large source in control of frequency, phase, and output voltage. It would seem that many base load stations could be gradually phased out because of their CO2 emission, leaving the grid without the large controlling sink needed to maintain stability of the system. The Solar Thermal power stations with the heat storage (as previously discussed) might provide this large reference sink that is needed. But the storage in South Australia should have been programmed to be completed coincident with the large build up of wind farms and solar sources and the de-commissioning of thermal power stations (such as those at Port Augusta).

As discussed earlier, if they continue to add more more solar sources and wind farms without energy storage and continue to phase out large base load stations without some form of replacement to provide a stable reference sink, we can expect future instability in the power grids and power failure. So how can that be fixed? **We have to get away from trying to reference the frequency and phase from the loaded grid line and add a synchronising control channel fed from a single reference source. This would be fed into**

each source to lock its AC generation. This bearer could be any type of transmission circuit, such as a telecommunication line or possibly a carrier circuit superimposed on the AC power line. Referring to Figure 6, the decoded synchronising data could be fed into the phase locked oscillator instead of the feedback loop. However, half of the wind farms in Victoria and South Australia have the induction or asynchronous type of turbine directly phase locked to the grid. For these, some other internal control system might have to be devised.

<u>References</u>

1. http://www.cleanenergyministerial.org/Portals/2/pdfs/A_Guidebook_for_Minigrids-SERC_LBNL_March_2013.pdf

2. New Power for north of the Gulf & South Australia, by Lloyd Butler, OTN March 2015

3.Power transmission the modern way, by Clive Wallis, OTN, March 2015

4. Old Coal's New Role, Peter Fairley, IEEE Spectrum, August 2015

5.Solastor report, Tory Shepherd, Advertiser 2-7-16

6. Solar Reserve report, Sheradyn Holderhead, Advertiser 13-9-16

7. South Australia Energy Crisis July 20167. http://reneweconomy.com.au/2016/mystery-as-south-australia-pleads-with-gas- generator-to-switch-back-on-51097

8. Unfolding Energy Crisis in SA https://decarbonisesa.com/2016/07/15/the-unfolding-energy-crisis-in-south-australia-was-foreseeable-and-foreseen/

9. Power Stations in South Australia https://en.wikipedia.org/wiki/List_of_power_stations_in_South_Australia

10. Power stations in Victoria https://en.wikipedia.org/wiki/List_of_power_stations_in_Victoria_(Australia)

11. Some early SA Power Dates http://www.gawler.nowandthen.net.au/Electric_Lighting_in_Gawler

12. Power developed from the sea by Lloyd Butler, OTN September 2016

13. Power experts red flag on wind by Daniel Wills, Advertiser, 4-10-16

14. Opportunities for Pumped Hydro Energy Storage in Australia - Arup-MEI Research - Melbourne Energy Institute, University of Melbourne

15 Pumped Hydro - The forgotten Storage Solution by Tim Forcey and Dylan McConnell http://reneweconomy.com.au/pumped-hydro-the-forgotten-storage-solution-47248/

16. Wind Turbine Plant Capabilities Report - Australian Energy Market Operator (AEMO)

17. Proposal Repowering Pt. Augusta http://media.bze.org.au/Repowering_PortAugusta.pdf