Macquarie *Generation*

Liddell Power Station

New England Highway
MUSWELLBROOK NSW 2333

Private Mail Bag 2
MUSWELLBROOK NSW 2333

Telephone (065) 420 711
Facsimile (065) 421 840

Electricity Supply Association of Australia Ltd
Level 6
280 Pitt Street
SYDNEY NSW 2000

Attention: Mr Patrick McMullan

Dear Patrick

Please find attached report on the Hydrogen Plant Explosion and Fire at Liddell Power Station on 23 October, 2001.

Please feel free to circulate this report to other members of ESAA as appropriate.

Yours sincerely

J MARCHEFF
MANAGER/LIDDELL POWER STATION
29 / 07 / 2002

Attach

Macquarie *Generation*

Liddell Power Station
Hydrogen Plant Explosion and Fire – 23 October 2001
FINAL REPORT

Introduction

The Hydrogen Plant at Liddell is designed to continuously produce hydrogen at a purity of 99.75% and at a rate of 510 cu metres per day.

Hydrogen is produced in two banks of Knowles cells filled with a strong solution of caustic soda. Current is passed through the cells to produce hydrogen and oxygen. The oxygen is vented directly to atmosphere while the hydrogen is piped to the LP Gasholder.

The LP Gasholder is a low pressure storage vessel capable of storing 28 cu metres of gas. It is constructed in two parts. The bottom section is a large round tank. The upper section is an inverted tank or bell that is free to move within the main tank as pressure increases or decreases. The main tank is filled with water to form a water seal. Hydrogen from the cells enters the gasholder above the water line causing the bell to rise.

The purity of the hydrogen is monitored between the cells and the gasholder. If purity falls below 99.5% the hydrogen is vented to atmosphere.

The plant is installed with two 100% duty compressors. Hydrogen is drawn from the LP Gasholder by the duty compressor via the LP Gas Dryer and the LP Filter. It is compressed to 12.4 MPa and delivered via HP Dryers to the storage banks.

The plant is installed with four storage banks capable of storing 460 litres per bank. Each bank consists of 16 cylinders. Each cylinder is fitted with an overpressure protection device called a "bursting disc".

Details of Incident

At approximately 1550 hrs on 23rd October B Shift Assistant Plant Operators attended the hydrogen generation plant as part of a routine plant inspection. The plant was functioning correctly and no obvious problems were noted.

At approximately 1610 hrs on the 23rd October 2001 a large explosion was heard by contractor staff in the contractor amenities area and the remaining staff in the Macquarie Generation administration building. Calls were received soon after by the duty Shift Manager advising him that there was a fire at the hydrogen generation plant.

The duty Shift Manager activated the site emergency plan. Calls were received by the NSW Fire Brigade at 1623 hrs and site fire fighting teams were on the scene at about the same time.

The fire was attended by a number of local brigades and was declared under control at 0406 hrs on the 24th October 2001.

Gassing of the in service units was suspended for the entire period of the emergency as the gas up stations were in the fire area.

Plant Configuration at Time of Explosion

At the time of the explosion "A" and "B" Banks of Cells were inservice filling the Gasholder.

The LP Dryer and LP Filter were inservice.

"A" H2 Compressor was inservice delivering high pressure hydrogen via "B" HP Dryer to "B" and "C" Storage Banks

Results of Inspections

Visual inspections of the plant found the high pressure pipework had ruptured or parted at the following locations:

- Between valves 11162 and 11011 adjacent to A Compressor
- At the pressure regulating valve 11244 near the compressor room to storage area wall
- Above the B HP Dryer
- At the inlet to the B Bank manifold
- At various bottle fittings in B Bank

In addition the following damage was noted:

- Pipe swelling at the compressor side of the HP Regulating valve 11244
- Pipe swelling at the HP NRV (dryer side)
- Damage to A compressor blowdown pneumatic valve 11056
- Damage to B HP Dryer blowdown pneumatic valve 11242

Twelve of the sixteen B Bank cylinders and six cylinders on C Bank had been affected by the heat of the fire. Many of the copper vent pipes from the cylinders to atmosphere were discoloured or melted indicating that many of the cylinder bursting discs had ruptured. The vacuum and purge pipework around B and C Banks had been destroyed by the fire.

The cladding at the eastern end of the building had been blown out above B and C storage banks. Debris from the site was distributed for 20 metres.

Fire from a blown pipe at the rear of B Bank impinged on the LP Gasholder. Damage to the gasholder was superficial.

Initial Investigation

The damage to the HP pipework suggested that the explosions occurred initially in the pipes between the compressor and the HP NRV. The swelling of the pipes indicated that a pressure wave had travelled along from the pipe from the direction of the compressors towards the storage bottles.

Such an explosion is possible if an explosive mixture of air and hydrogen existed in the pipes. Hydrogen will form an explosive mix with concentrations of hydrogen in air as low as 4% and as high as 76%. Where pure oxygen is the contaminant the explosive limit is less than 5% oxygen in hydrogen. Hydrogen in an explosive mix is well known to ignite inside pipes.

The force of the explosions in the pipes had then caused consequential failures of fittings and joints at B and C Storage Banks. This released hydrogen into the storage shelter which subsequently ignited.

BOC were engaged to give an independent assessment of the incident. The BOC findings are consistent with the above assessment.

Plant Purging

Tests of gas in the LP Gasholder indicated the presence of oxygen at a concentration of 4.7% and a small concentration of nitrogen. It was assumed that there was a possibility that the gas in the remaining A and D High Pressure Storage Banks may have been contaminated. No attempt was made to sample the gas from the storage banks.

The LP Gasholder was purged through the normal vent valves and filled with CO2.

A detailed procedure involving nitrogen purging and remote operation of vent valves was developed for purging of the HP Storage Banks. The banks were successfully purged allowing repairs to the plant to begin.

Detailed Investigation

All possible points of air ingress were identified and checked as the possible cause of the explosive mixture. The main sources are dealt with in detail below:

1. **LP Pipework from LP Gasholder to Compressor** – As the compressor draws a slight vacuum for at least part of the piping from the Gasholder any leak in this pipework is a potential source of air ingress. The pipework was tested under pressure and vacuum for leaks. No leaks found.

2. **LP Filter** – The LP filter is fitted with a U Bend water seal that is open to atmosphere .If the water seal is lost the air could be drawn into the line through the U tube. The seal is fitted with a clear plastic sight tube. The seal is checked regularly and topped up with coloured water if the level is low. The seal was found to be dry after the incident. It is possible that the water had been blown from the tube during the explosion. The seal was dismantled and the elements were found dirty but not blocked. During the inspection it was confirmed that under blocked filter condition the compressor could not draw the seal water into the line.

3. **LP Dryer** – The LP Dryer is also fitted with a U bend water seal that is open to atmosphere. This water seal is a steel tube and can only be checked by dipping the open end. Because it is fed from the dryer it is generally spilling water when in operation. The bend was found full of water after the incident.

4. **LP Pipe low point drain at LP Gasholder** – There are two pot style water sealed drains at the low point in the inlet and outlet pipes from the LP Gasholder. These drains cannot be checked for water level visually or by dipping. The drains were opened and found full of water. The drain lines from the hydrogen pipes were found to be partially blocked.

5. **LP Gasholder** –Maloperation or sticking of the bell may allow air to enter the gasholder. Samples of gas were taken from the top of the gasholder and tested for Oxygen and Nitrogen. The results were 2.4% Oxygen 4.6% Nitrogen. As the proportions are not consistent with air a second test sample was taken from the inlet of the gasholder. The results of the second test showed 4.7% oxygen. Nitrogen was not identified in the sample. The operation of the gasholder was checked with nitrogen. The Gasholder bell was found to operate smoothly with no stiction points. It also maintained pressure when filled with Nitrogen. An internal inspection of the gasholder found that the inlet and outlet pipes extended only 12 to 15 mm above the normal water level. Drawings indicated that this should have been at least 50 mm above the water.

6. **Oxygen Ingress from Cells** – During operation the cells are designed to separate the oxygen from the hydrogen. Under abnormal conditions oxygen can enter the hydrogen system and cause contamination. The LP Purity analyser monitors the purity of the hydrogen and if it falls below 99.5% the analyser opens a vent valve to prevent the contaminated hydrogen from reaching the gasholder. The LP purity monitor was checked. The 240 volt to 220 volt isolation transformer that powers the analyser was found open circuit on the secondary winding. The operation of the LP Purity analyser was confirmed as "non fail safe". On loss of power or sample the analyser output remains at the last recorded value. The indicated purity as found after the explosion was 99.8% with no power to the analyser. The trip signal to operate the vent valve is driven by the indicator and would not have activated under these conditions. Supply supervision alarming was not connected to this part of the circuit. The hydrogen inlet pipework and filter were found choked with water preventing hydrogen from passing to the monitor. These filters are regularly checked by office staff and no abnormalities were noted earlier on the day of the explosion. It is considered that the build up of water occurred after the event due to residual water in the line. Once sufficient repairs had been carried out the cells were returned to service. On initial operation the cells attained a purity of 99.5% which then fell away to less than 92%. Investigations found that a number of cells had low electrolyte levels. Once they were topped up to normal working level the purity returned to 99.5%. This operation was repeated a number of times with the same result. The cause of low electrolyte level was determined to be blocked water inlet pipes at the affected cells. Blockages were occurring

at the inlets due to a build up of magnetite and other contaminants. The low purity associated with low electrolyte levels may indicate that the dividing diaphragms between the oxygen and hydrogen generation cells has deteriorated allowing crossover of gases as the level drops. This will be further investigated. In addition 6 cells (3 on each bank) were found to produce gas at a purity below 99.5% with one on each bank below 97%. This again is thought be a result of deterioration of diaphragms and will be further investigated.

Conclusions

Explosions in the hydrogen HP feed pipes caused the failure of welds and connections at the storage banks allowing hydrogen gas to be released in large quantities from B and C Storage Banks. The escaping hydrogen self ignited resulting in an explosion and fire.

The cause of the initial explosions was due to the spontaneous ignition inside the HP feed pipes of an explosive mix of hydrogen and oxygen.

It is concluded that the ingress of the oxygen to the system was from the hydrogen cells. The prime cause of the contamination was blockages in the water makeup lines to some cells allowing high levels of oxygen to mix with the hydrogen as electrolyte levels fell.

The low purity hydrogen was not detected by the low pressure purity analyser due to the failed isolation transformer.

There are a number of other potential air ingress points on the LP system that could have allowed contamination. These points are however considered unlikely to have been the cause of the contamination resulting in the explosion.

Recommendations

A number of improvement options have been identified following inspections of similar plant at Bayswater and after discussions with BOC

1. Cells

Six cells are producing hydrogen at a purity below 99.5%. The inter chamber diaphragms are suspected as the source of cross contamination of hydrogen and oxygen. Five cells were overhauled in 1998 due to low hydrogen purity. In all cases the diaphragms were found to be in poor condition and replaced. Cells that were overhauled in 1998 were found to be producing at 99.8% during the post explosion testing.

Recommendation 1.1 – Overhaul and replace the diaphragms on all cells showing low purity results. Check on a routine basis the individual cell purity levels to monitor the deterioration of performance of individual cells.

Certain contaminates are produced as a result of the process that settle to the bottom of the cells. These contaminates particularly magnetite can block the water makeup ports and the drain valves. This was found to be the case on 6 makeup ports and on most drain valves. The blocked drain valves made it very difficult to clean the cells and to unblock the makeup ports.

Recommendation 1.2–Replace the drain valves with open port ball valves to improve the drain operation and to allow effective cleaning of the cells. Instigate a routine for the yearly draining and cleaning of all cells.

2. Purity Analysis

The existing Liddell LP purity analyser does not fail safe on the loss of sample, loss of power supply or failure of the device. Bayswater LP purity analysers do not fail safe on loss of sample flow.

Recommendation 2.1– Replace the existing LP purity analyser with a fail safe model that ensures the vent valve is opened under the conditions described above. Carry out a risk assessment of the Bayswater LP purity analysers to determine the level of risk associated with a loss of sample flow.

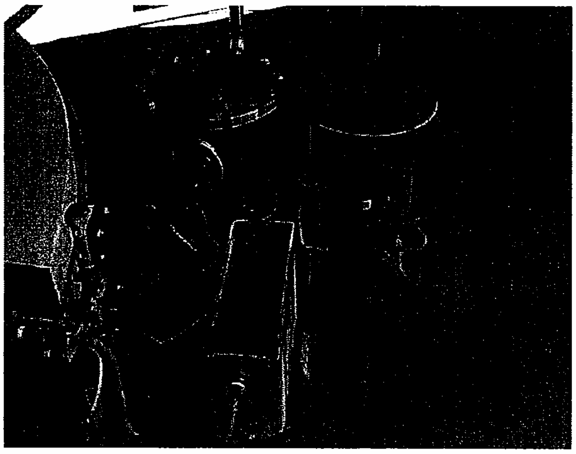
The Liddell plant is not fitted with HP purity analysers to confirm the purity after the compressor. Given the number of possible air ingress points in the pipes under vacuum and the higher probability of explosion of impure hydrogen in the HP System it is essential to be able to detect low purity after the compressors. Bayswater is fitted with IP and HP purity analysers but like the LP purity analyser they do not fail safe on loss of sample flow.

Recommendation 2.2 – Fit hydrogen purity analysers that fail safe either between the stages of the compressor or immediately after the compressor. Carry out a risk assessment of the Bayswater IP and HP purity analysers to determine the level of risk associated with a loss of sample flow failure.

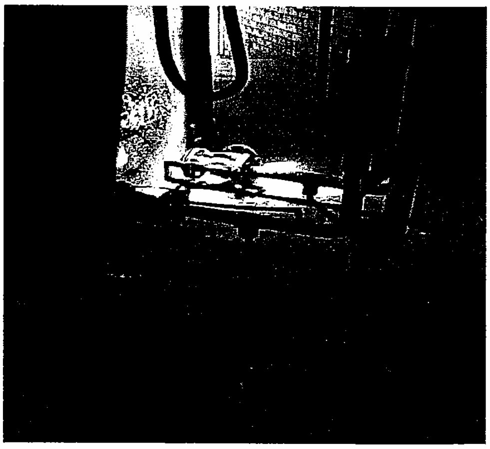
3. Drain Piping

The drain piping installed at Liddell hydrogen generation plant is of two types. The first is a simple U tube arrangement which is installed at the LP Filter, LP Dryer and before and after the LP vent pipes. The second type is a low volume closed pot style that can hold 2 to 3 litres of water. These are installed before and after the LP Gasholder. In all cases the seal liquid level is maintained by the process. There is no external top up facility. With the exception of the LP Filter U tube there is no visible means of checking the water level. Bayswater is fitted with open trough automatic water makeup systems that continually top up closed pot type water seals. The water levels are maintained regardless of the operational status of the plant and have overflows for visual checking of pot water level.

Recommendation 3.1– Fit pot type water seals with open trough water makeup as a replacement for the existing U tube and pot type seals



Bayswater LP Gasholder pot style water seals with makeup trough



Liddell LP Gasholder pot style water seals with no auto makeup or visual check facility

4. LP Gasholder

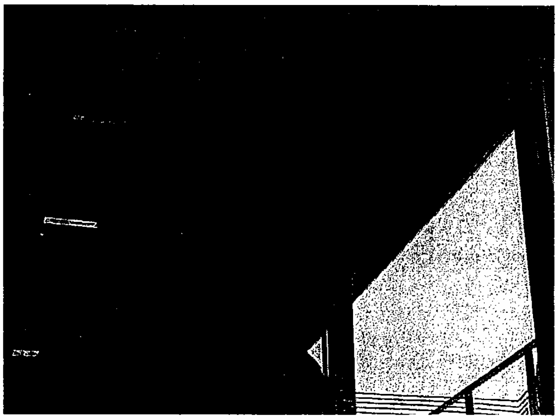
The original design drawings for the gasholder show the inlet and outlet pipes extend 50 mm above the water line. The actual measured extension was less than 20 mm. Small variations in the level control could allow water to enter the lines.

Recommendation 4.1 – Increase the pipe length to extend them to 50 mm above the water level.

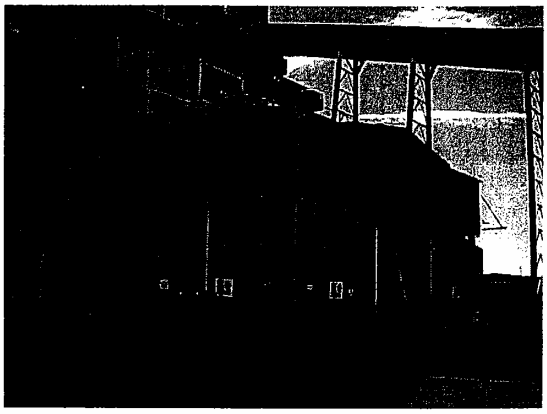
5. Building

The building is fitted with partially closed in ends that can trap the gas under the roof. The current BOC construction standard for this type of facility is to have the storage banks in an open area rather than inside a building of any kind. Any leakage will then quickly disperse into the atmosphere and not form an explosive mixture. This is not practicable at Liddell or Bayswater but improvements are possible.

Recommendation 5.1 – Remove the end sheeting from the building to increase ventilation. This recommendation also applies to the Bayswater facility.



Bayswater Hydrogen storage facility showing partially closed in ends



Liddell hydrogen storage facility showing extent of side panelling

6. Compressor Suction Pressure

BOC recommend investigating the installation of suction pressure trip devices to each compressor.

The suction line of the compressors will operate under vacuum for at least part of the system. An indication of a leak from atmosphere in these lines will be a decay in the vacuum at the suction of the first stage compressor.

This type of protection has proven unreliable in this application at Liddell, causing spurious trips of compressors. The installation of HP purity analysers under recommendation 2.2 and improved drain pots under recommendation 3.1 is considered to provide positive protection against the ingress of air on the suction pipework

Recommendation 6.1 – No further action required

7. Gassing Facilities for Generators

The gassing stations for the generators are located behind the HP storage banks and were inaccessible during the incident. The operating generator hydrogen pressures steadily decayed during this period but remained inservice. If however access into the plant had been delayed further all operational units may have been forced offline.

Recommendation 7.1 – An investigation be carried out into the feasibility of establishing a gas up station away from the Liddell hydrogen generation plant possibly near the CO2 plant to allow the units to be gassed from transportable pallets in an emergency. Carry out a risk assessment to determine if a similar investigation is required for Bayswater Power Station.

Report prepared by Kevin Wykes Resources Engineer Liddell Power Station

Recommendations as they apply to Bayswater have been agreed to by Ralph Kingsley
Performance Engineer Bayswater

Date of report 23rd July 2002

25/7/02
Resources Engineer/ Liddell

26/7
Performance Engineer/ Bayswater