Fuel Cell / Solar Hybrid Power Supply System

Field Trial Final Report

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Field Trial Final Report

1. Introduction

This paper will outline the background, development and operational results of a field trial set up to ascertain the practical implementation of a remote stand alone power supply system utilising a hydrogen fuel cell operating in conjunction with solar PV modules.

1.1 Background

There is a growing demand for energy supplies in relatively remote areas for low power applications including: environmental and technical monitoring equipment; remote control and telemetry; lighting and surveillance, as well as a limited usage of relatively high power equipment such as pumps and lifting equipment for weirs, sluices and similar structures. The average daily power consumption for such applications is relatively low, but the cost and environmental impact of installing mains power is relatively high and can be prohibitive.

Existing solutions include the use of stand-alone renewable and battery systems, which have a number of potential drawbacks, the most obvious of which is being subject to intermittence and the vagaries of ambient weather conditions. In countries such as the UK the size of PV arrays required to sustain a system through the winter months can become quite large, leading to higher costs, more visual impact and greater chance of vandalism. The print out from the PV system design software at the end of this section shows that an array rated at 800Wp would be required to sustain a load of 20W continuous at this location. The limitations of existing battery technology means that during the summer months there is a tremendous waste of generated power. Small wind turbines need a site which is unobstructed by trees, hills etc. which can impede on wind flow. The outputs are unpredictable and each site will perform differently and usually a high mast is required leading to problems with planning permission and maintenance.

Fuel cells offer a practical alternative to these existing technologies, but are potentially constrained by the need for hydrogen refuelling on a regular basis (the rate of which is determined by the power requirements and duty cycle of the application). Frequent refuelling can be expensive, and introduce practical difficulties relating to manual handling of cylinders and the need for regular visits to remote locations.

Therefore, by combining the relative advantages of both fuel cell and PV technology, and optimising the power management regime of the system, it will be possible to offer the market a truly independent and reliable power system that is cost competitive. Advantages would include:

- Continual availability of power on demand.
- Small footprint.
- Low environmental impact – low visual impact, no noise, no emissions, no end of life disposal issues and no vibration.
- Load following capability, consuming power only when the required by the application.
- No moving parts and therefore minimal maintenance requirements.
- Robust, secure and reliable power source.
- Capable of unmanned operation for periods in excess of six months.
- Performance unaffected by variations in environmental conditions.

This hybrid technology would have a number of uses across a broad spectrum of applications and geographic markets (including export potential to remote locations). It would compete positively with incumbent technologies in existing markets, particularly where site access and environmental performance is at a premium, and open up new niche markets where no appropriate solution is currently available.

NSol! System Summary Report

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Site Summary

Site Name:
Location: CAMBRIDGE, , UNITED KINGDOM
Latitude: 52.10 N **Longitude:** 0.10 E **Elevation:** 23m
Array Tilt: 60 S **Azimuth:** 0 E **Tracking:** Fixed
Comments: Meteorological Office (UK), Bracknell, UK

Load Summary

Design Load: 19.5 Ah/day @ 24 VDC system voltage

System Summary

PV Module
Type: BP380 **Rated W(p)** 80
Voc: 22.10 **Vtyp:** 17.60
Isc: 4.80 **Ityp:** 4.55

PV Array
 # Modules: 10 **# Series:** 2
Rated Pwr: 800Wp **# Parallel:** 5
Rated Volts: 24

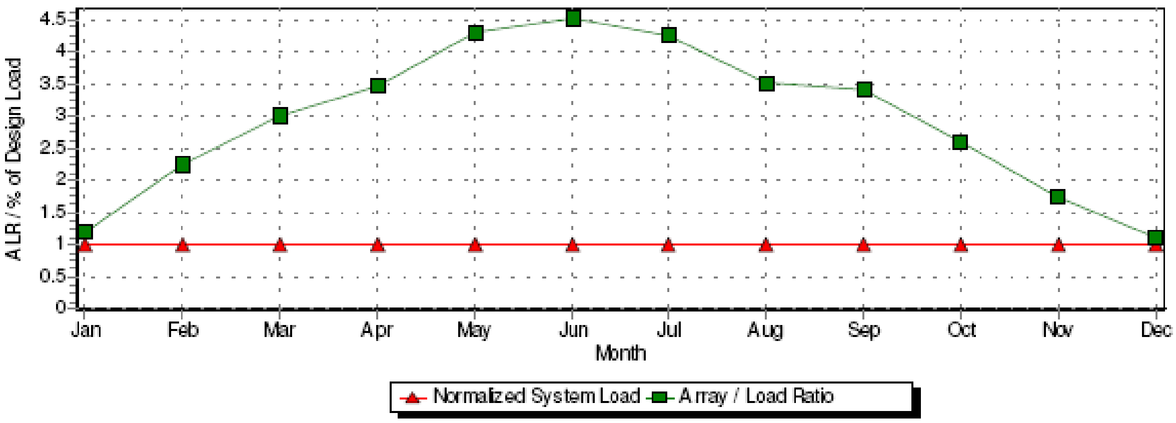
Battery Cell
Model: Generic 12V
Cell Amp hr: 130
Unit Volts: 12

Battery Bank
 # Cells: 4 **# Series:** 2
Rated kWh: 6.24 **# Parallel:** 2
Rated Volts: 24 **Rated Days:** 10.7

System Performance Summary

Month	Array Insol (kWh/m2/d)	Avg Temp (deg C)	Array (Ah/day)	Sys Losses (%)	Load (Ah/day)	Batt Size (days)	Array/Load Ratio	Avg BSOC (%)	LOLP (%)
Jan	1.14	4.2	23.4	10	19.5	9.8	1.20	87	0.1
Feb	2.15	4.4	44.0	10	19.5	9.9	2.26	97	0.0
Mar	2.86	6.6	58.5	10	19.5	10.0	3.00	98	0.0
Apr	3.31	9.3	67.7	10	19.5	10.1	3.47	98	0.0
May	4.10	12.4	83.9	10	19.5	10.3	4.30	98	0.0
Jun	4.31	15.8	88.2	10	19.5	10.4	4.52	98	0.0
Jul	4.04	17.6	82.8	10	19.5	10.5	4.24	98	0.0
Aug	3.35	17.2	68.6	10	19.5	10.4	3.52	98	0.0
Sep	3.25	14.8	66.6	10	19.5	10.4	3.41	98	0.0
Oct	2.47	10.8	50.5	10	19.5	10.2	2.59	97	0.0
Nov	1.66	7.2	33.9	10	19.5	10.0	1.74	96	0.0
Dec	1.06	5.2	21.6	10	19.5	9.9	1.11	83	0.4

System Performance Analysis
ALR and Normalized Load by Month



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1.2 Project Format

The project was divided into two distinct phases. Phase one involved carrying out a detailed design study. This included.

- Supply, distribution and handling of hydrogen.
- Safety precautions and specialist components required for hydrogen installations.
- Suitable monitoring equipment and procedures.
- Detailed design of trial system.
- Locating a suitable site and making necessary arrangements for a field trial.

Phase two involved.

- Establishing the project stakeholders
- Procurement of the necessary equipment.
- Build and installation of the trial system.
- Operational monitoring of the trial system.
- On-going maintenance and replenishment of hydrogen.
- Regular reports to the project partners.
- Preparation of final appraisal and detailed report.

2. Project Format

2.1 Project Stakeholders and their Responsibilities

The stakeholders in the project were:

- Dabbrook Services Ltd.
- Environment Agency (Eastern Region)
- BOC Industrial Gasses

Dabbrook Services Ltd. is a specialist electrical project company who have extensive experience in the design and installation of stand alone renewable energy systems for use around the world. Dabbrook has worked closely with BP Solar both as a distributor and a project partner in solar PV Systems. Dabbrook have also worked extensively with the Environment Agency in the design and installation of automatic systems to regulate river levels and water flow rates.
For this project Dabbrook Services Ltd. provided design, manufacture, installation and continuous maintenance of the system.

Environment Agency is responsible for the maintenance and renewing of river control structures. The Eastern Region flood defence team based at Ipswich is responsible for Norfolk, Suffolk and North Essex. For this project the Environment Agency made the trial site available, carried out the necessary construction work, assisted with the installation of the equipment and contributed towards the cost of the equipment. At the end of the trial period the Environment Agency took possession of the equipment.

BOC Industrial Gasses produce and distribute a wide range of industrial gasses including hydrogen. BOC have an interest in promoting the use of hydrogen as a clean, environmentally friendly fuel. For this project BOC have provided technical support and safety advice on the handling and use of hydrogen and assisted with the funding of the trial.

2.2 Description of Complete System

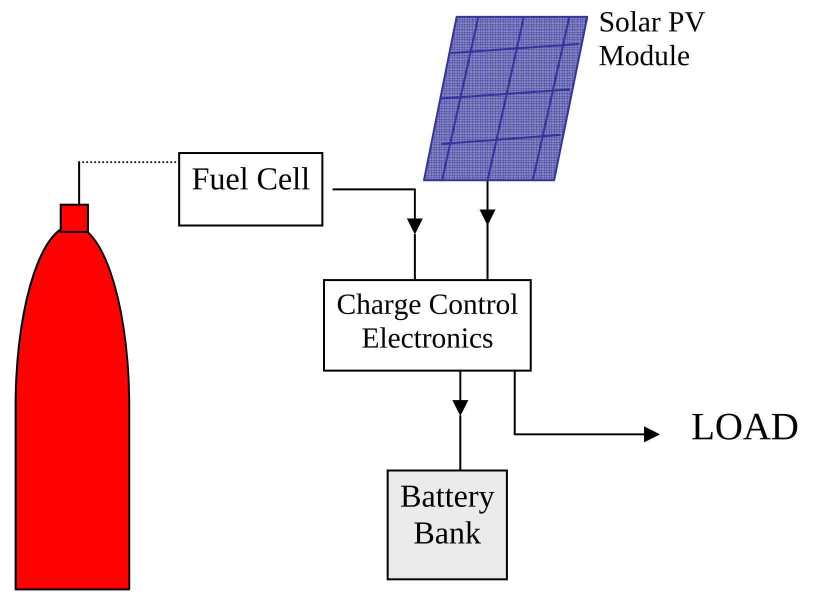
2.2.1 Equipment being Powered

One of the key objectives of this trial was to have a practical, working system. The application chosen was the automation of a tilting weir gate on the river Deben in Suffolk. The gate is used to regulate the flow of water into a by-pass channel to alleviate the flow of water through the main river at times of high rainfall. The existing installation consisted of a steel weir (gate) hinged along it's bottom edge and raised and lowered by turning of a leads screw which has a nut secured to the top of the gate. Prior to automation this required operators to attend site and adjust the height of the gate when high rainfall was anticipated and likewise at times of low rainfall. In order to automate the equipment a motor and gearbox was coupled to the leadscrew and a control panel designed, built and installed to energise the motor when required. The water level is monitored by an ultrasonic transducer connected to a level monitoring device. This device controls relays etc. to energise the motor when the water level is outside of a pre-set band. The system operates on a sleep and wake up principle whereby virtually all components are de-energised during the sleep period. The system wakes up for a pre-set period during which time the level monitoring equipment checks the water level and if this is out of the required band energises the motor to either raise or lower the gate for a pre-set duration, typically 15 seconds.
The control equipment is housed in a GRP enclosure together with power supply monitoring equipment and a telemetry outstation. The telemetry outstation relays the site and system parameters to the Environment Agency offices at Peterborough.

2.2.2 Power Supply System

This trial was intended to ascertain the practicalities of a system providing approximately 500Wh per day. At this stage it was not deemed necessary to reduce the power consumption below 500Wh per day, however efforts would need to be made in future practical applications to reduce the power consumption to an absolute minimum.

Power to the motor and the control equipment is derived from a bank of batteries, these are primarily charged from Solar PV modules. This part of the system is basically designed as a failing system. It is normal when designing stand alone PV system to select sufficient PV modules to provide on average power equal to the power consumption throughout the year. In this system the PV modules selected will only provide sufficient power for the system during mid summer. During other periods the batteries will gradually become discharged. The time taken for the batteries to discharge will decrease further away from mid summer. The output from the hydrogen fuel cell is connected to a battery charging module which monitors the charge state of the batteries. When they reach a specified low state of charge a signal from the charging module will initiate the fuel cell to begin the charging process. When charging is complete the fuel cell is stopped. Any output from the PV modules during the period that the fuel cell is working will supplement the charging and reduce the duration that the fuel cell runs for.



TYPICAL SOLAR PV / FUEL CELL HYBRID SYSTEM

3. Main Power Supply System Components

3.1 Fuel Cell and DC/ DC Converter

A Ballard Nexa, PEM fuel cell was selected. This has an output of 48 volts and a maximum power output of 1.2kW. The high output power of this unit enables the batteries to be recharged in a relatively short period thus reducing the actual operational time of the fuel cell which should extend its life.

The fuel cell was supplied by the manufacturer as a complete and ready to use unit, but there was some concern as to its robustness and suitability for installation in a harsh environment due to it's exposed component boards.

The fuel cell together with the battery charging DC/DC converter was housed in a dedicated section of the gas cabinet (see section 3.4). A major concern was the ambient temperature around the fuel cell. Although the gas cabinet was insulated, an air flow needed to be maintained in order for any leakage of hydrogen to escape safely.

The air temperature on the river bank was anticipated to drop to possibly -5 degrees C. In order to avoid possible damage to or failure of the fuel cell a heater was fitted close to the fuel and a part cover was fitted of the fuel cell. Although it can be argued that the area around the fuel cell does not constitute a hazardous area (see section 5.5) a thermostat which was certified for use in a hazardous area was selected to control the heater.

The DC/ DC converter was a bought in device from a company that had worked closely with Ballard to develop a suitable battery charging system. Consideration was given to designing a bespoke unit for this application but as this was a trial of a system it was felt necessary to utilise equipment that had been tested and operated in similar applications to avoid the risk of failures of one piece of equipment giving the appearance of an unreliable system. The DC / DC converter was supplied with software to enable it to be set up and configured to suit the system parameters as well as interface cable and connectors.

3.2 PV Modules and Charge Controller

Two 80Wp (80W output at standard test conditions of 1000w/m square) were installed on a simple pole mounting bracket at an angle of approximately 50 degrees to the horizontal and orientated to face South. The modules are of the polycrystalline type with a module efficiency of 12.6%. The output voltage from these modules when connected in series and at maximum power point conditions is 35.2 volts. When connected to the batteries via the charge control unit these operate in a battery voltage tracking mode, i.e. the terminal voltage of the modules is held at the same voltage as at the battery terminals thus increasing as the battery becomes charged. The charge controller is a shunt type device which monitors the battery voltage and at the point of reaching a fully charged state shunts the PV modules. Various algorithms are built into the device to obtain optimum charging and provide boost charging at intervals.

3.3 Batteries

Sealed maintenance free, lead acid batteries with a gel electrolyte were selected. These have a very good proven track record in stand alone PV systems. In order to select the capacity of the batteries various factors needed to be taken into account.

1. Sufficient capacity to maximise storage of energy from the PV array at times of high radiant energy.
2. Continuity of operation in the event of a failure of the fuel cell to recharge.
3. Charging rates
4. Physical size.

A capacity of 260Ah at the 100 hour discharge rate for the batteries was selected. Allowing for a maximum discharge of approximately 75% this is equivalent to 10 days operation of the system with no input from either charging source. Accepting that during the worst of the winter months the charging input from the PV array would be very small, typically on average only 4 to 5 Ah per day, it could be expected that the fuel cell would run every 12 days. The output from the DC/DC converter charges the batteries at a maximum of 30A for the bulk charge period, and reduces

significantly for the float period. The complete charge cycle takes approximately 12 hours.
Space was a limiting factor as it was intended to house the batteries with the gate control equipment, monitoring equipment and the telemetry outstation.

3.4 Gas Storage and Distribution

A design of gas storage cabinet that had previously been used by BOC was utilised with some modifications for this project. The cabinet consisted of an insulated stainless steel enclosure approximately 1.8m tall x 1.2m wide and 0.6m deep with two full height lockable doors. A full height partition was fitted to create two dedicated sections, one to house the gas cylinders and one to house the fuel cell, and DC/DC converter. The side panel were fitted with ventilation panels and a raised top was fitted to provide sufficient ventilation to allow minor low pressure seepages of hydrogen to escape to atmosphere.

A specialist company designed, manufactured and fitted the gas regulation and manifold equipment. This consisted of pressure regulation, safety valves, pressure gauges. All pipework was copper with brazed joints. A pressure switch and also an electrically operated solenoid valve were also incorporated. The pressure switch wired to the telemetry unit providing warning of low gas pressure. The solenoid valve is controlled from the gas detection panel (see section 3.5) so that in the event of hydrogen being detected, the source of the leak is isolated as close to the gas cylinders as possible.
Space only permitted the installation of two k size gas storage cylinders. These each have a filling pressure of 175 bar and a volume at NTP (Normal Temperature & Pressure) of 7.21m cubed.

Gas Storage Cabinet

3.5 Gas Detection

It was considered prudent to incorporate into the system a means of detecting any leakage of hydrogen from either the gas manifold or the fuel cell itself. A standard industrial gas detection panel with an ATEX certified detector head was selected. To maintain the reliable life expectancy of the detector head the system designer was advised by the manufacturer that this equipment should be continuously powered and not operated on a sleep and wake up cycle as is the case for the river level monitoring equipment. This was not a problem in this application as the load of the gas detection equipment was ideal as a base load for the system to achieve the required power consumption per day and avoided the need for additional dummy loads.

The gas detector head is located under the raised roof of the gas cabinet in such a way that it will detect any significant leak from either side of the cabinet. The control panel that the detector head is wired to has two settings at which dedicated relay contacts operate. One is set at 25% L.E.L (Lower Explosive Limit) at which an input to the telemetry system is triggered. The other is at 50% L.E.L, at which point the solenoid valve and the battery connection to the fuel cell are both de-energised. This as much as is practical removes the source of gas and the potential source of an ignition.

4. Installation

4.1 Location and Access

The weir described in section 2.2.1 is located on the river Deben in Suffolk. The name by which this site is generally known is “White Bridges,” the basis of this name is simply that there were two foot bridges with white hand railing, one has been replaced by a more modern wooden bridge.

The Environment Agency own a small area of land adjacent to the weir which provided an ideal location for the equipment. Although not directly beneath, this area is very close to overhead power cables from the Sizewell nuclear power station. There was concern from all stakeholders with regard to installation of hydrogen cylinders at this location. The installation was discussed in full with National Grid Transco and their approval was obtained prior to carrying out the installation.

For the construction phase, the Environment Agency obtained an access agreement from the local land owner to enable the transport of heavy plant to the site.
This access agreement had a limited time frame and once expired the access to the site for maintenance reverted back to two routes, A public footpath approximately 500m through an area of natural woodland, or along the side of the field adjacent to the wood along which vehicles can be taken when the ground is dry. Final access to the actual location is across the two foot bridges described above.

Site Prior to Installation

4.2 Construction and Installation.

Work at the site included repairing of some piling and concrete retaining wall, laying of a suitable concrete base on which to stand the equipment, lowering of one of the foot bridges to avoid a step, construction of simple ramps at either end of the other bridge and the erection of a security fence around the concrete base to create a secure compound. This work was completed in the autumn of 2004 and the site left until the spring of 2005 to avoid operating tracked equipment on potentially waterlogged ground. The site work was carried out by the Environment Agency's own in house workforce.

The control equipment and gas cabinet were assembled in the workshops of Dabbrook Services Ltd. and the complete system tested and demonstrated to the Environment Agency. After factory acceptance tests were complete, the gas cabinet and GRP kiosk containing the gate control panel and associated equipment were transported to site at the end of March 2005 where they were lifted into position by the Environment Agency workforce. The temporary access route was utilised to get the equipment as close to it's final location as possible. Once the equipment was in position Dabbrook Services' engineers completed the installation and termination of cables, the normal electrical installation checks such as insulation resistance on individual cable conductors and checking terminations were carried out. Batteries and solar panels were installed and connected but the system left isolated. Following installation of the hydrogen cylinders a leak test using soapy water was carried out prior to electrically energising the system.

Water level set points were programmed into the gate control system and a full functional check completed.

On the 4th April 2005 the site was left active and became an operational site for the Environment Agency, all plant and equipment was removed and normal tidying up of the surrounding area completed.

Access to the site then reverted to the footpath through the wooded area or if ground conditions were suitable via a field and then across the two foot bridges, any equipment for servicing or maintenance and cylinder replenishment had to be carried out via this route.

Access Track

5. Performance

5.1 Reliability

There are a number of aspects that affect the reliability of this system.

- The ability of individual components to continue to function throughout the trial and for the foreseeable future.
- The ability of the power supply system to continue to supply power to the load, in this case the gate control system.
- The ability to maintain and re-fuel the system.

Only one component failed during the trial period. This occurred at the very end of the trial period in March 2006 when the DC/DC converter failed to re-start after a refuelling visit. As in this application the DC/DC converter controls the starting and stopping of the fuel cell it did take some time to ascertain whether the fault was with the converter or the fuel cell. Technical support from the manufacturers was good and the converter was returned to the manufacturers for repair. Whilst the fuel cell was effectively out of action the system then relied on the power stored in the batteries and the power generated from the PV modules. The state of charge of the batteries was quite good as prior to the failure the fuel cell had completed part of a run and therefore partially recharged the batteries. As can be seen from the graph (shown on page 5) the power generated by the PV modules in March is considerably more than that generated in January. Although this is not sufficient to completely power the system, it does extend the duration that the batteries can support the system. Hence at no time during the trial was power lost to the system.

An over riding factor in the reliability of the system is the ability of being able to replenish the hydrogen fuel supply. This is discussed in detail in section 5.4 but for the period of the trial it was always possible to deliver full cylinders to the site.

5.2 Vandalism

Vandalism is a constant cause of problems at this type of location. From experience at numerous other sites installations such as this are a magnet for vandals and graffiti artists. There does not seem to be a pattern and it is often the case that the more remote sites receive less attention than those in more built up areas.
This site, although quite remote is an area where children play but had minimal signs of litter or damage to the river bank etc.
The enclosures used for the equipment were ether stainless steel or GRP which will withstand a certain amount of attack. The most vulnerable part of the installation is the solar modules.
There was a great deal of concern from the Environment Agency about the risk of vandals building a bonfire against the gas cabinet and creating an explosion. This was considered in the risk assessment but with the measures taken such as stainless steel cabinet, trials on cylinders in fires carried out by BOC it was agreed that it was unlikely that a fire would be of sufficient size and maintained for sufficient time to cause a major incident.
One module was smashed in the early weeks of the installation. It is assumed that this was done by a stone.
Any form of protective cover does reduce the power generated, meshes and grilles cause some shading of the cells and rigid plastic covers have transmission losses and reflective losses. It was however decided to fit plastic covers to the modules to prevent further damage. No accurate figures are available for the reduction in power output but from our own experience it is estimated that the power reduction is in the region of 20%.
The site has not been subject to any further vandalism..

5.3 Fuel Consumption.

There was some variation in the Ah produced during a single run of the fuel cell which can be attributed to the ambient temperature, the contribution from the PV modules and if the heater was on during the charge period. A typical run of the fuel cell generated in the region of 180Ah. This reduced the cylinder pressure by approximately 80bar. Again there were variations due to temperature. The fuel consumed during this was approximately 2100litres. With the output regulator from the gas manifold set to 3 bar the useable volume of hydrogen from the two cylinders is approximately 2700 litres.

From estimates and calculations carried out prior to installation based on having two k sized cylinders and an average constant load of 500Wh per day the following refuelling intervals were anticipated.

January – 13 days
February – 20 days
March – 30 days
April to September – 150 days
October – 24 days
November – 16 days
December 13 days

The actual refuelling periods were as follows. There was an initial period when the system was installed, tested and demonstrated which consumed fuel which would give a slightly confusing picture therefore the following has been taken from the first actual re-fuelling.

1st re-fuelling – 14th April 2005
2nd re-fuelling – 8th August 2005. Period from previous – 112 days
3rd re-fuelling – 6th October 2005. Period from previous – 58 days
4th re-fuelling – 14th November 2005. Period from previous – 37 days
5th re-fuelling – 7th December 2005. Period from previous – 22 days
6th re-fuelling – 19th December 2005 Period from previous – 12 days
7th re-fuelling – 3rd February 2006. Period from previous – 45 days
8th re-fuelling – 17th March 2006. Period from previous – 41 days

The actual number of re-fuelling visits are generally in line with that anticipated. There was a rapid use of fuel in December which was attributed to a very cold spell. The original thermostat had a wide differential which meant that when the heater was switched on by the thermostat it remained energised for a much longer period than was necessary to avoid frost damage. This thermostat was changed to one that had a much smaller differential and thus the duration that the heater was energised was reduced considerably even during a very cold spell in January.

It is worth considering at this stage what the comparative fuel consumption would have been had the installation operated totally on the fuel cell. From the schedules of re-fuelling visits noted above the total number of cylinders used were sixteen. Based on the figures for the fuel used for charging, the total that would have been used had the PV modules not been included in the system would have been in the region of 32 cylinders. Therefore fuel consumption was reduced by approximately 50%.

5.4 Maintenance & Re-fuelling

Actual maintenance on the power supply system has been minimal. Site visits were in general attributed to minor modifications such as fitting covers or changing components such as thermostat. Regular visits were made to check the equipment which were not necessarily required but were necessary for assessment of the project during the trial.

Re-fuelling was the biggest maintenance issue. This site was chosen because it was away from the road and only accessible by track as described earlier. When the bottle pressure reached the low pressure set point an alarm signal is initiated on telemetry. During the initial part of the trial period the Environment Agency then advised Dabbrook who arranged to collect two replacement cylinders from the BOC depot in Gt. Yarmouth and take them to site. These were then loaded onto a specially built duel cylinder barrow and manually taken along the track through the wood and then across the bridges to the worksite. The two empty cylinders were then brought back the same way. Although this was a strenuous exercise there were no major difficulties in carrying it out. However it must be recognised that there are some serious manual handling issues in this exercise which must be taken into consideration in the future maintenance of this or other similar installations. Each installation must be fully risk assessed.
As the trial progressed arrangements were made with the Environment Agency for them to collect the cylinders in one of there 4 x 4 vehicles which was then able to drive down the adjacent field thus reducing the man handling of the cylinders considerably.

5.4.1 Re-fuelling Costs

The cost of maintaining the fuel supply to the site are made up of the cylinder rental, costs for the hydrogen and the labour and transport.

Twelve month rental for two cylinders = £145.80
Sixteen cylinders of hydrogen. = £952.24
Eight visits to change cylinders at 104 miles = 832 miles
Labour – Two men for six hours each per visit = 96 hours

Different organisations will have different costs for labour and transport therefore only the time and the distances have been recorded.

There are additional costs which need to be considered such as training and office time to make any necessary arrangements.

5.5 Health & Safety

As with any project that are a number of health and safety issues that need to be considered. These will vary from installation to installation but there is some commonality which must be taken into account.

Two main issues which were considered for this project were the risk of ignition of the gas and the manual handling of the equipment.

A very detailed haz op or risk assessment was carried out with regards to the storage and the use of hydrogen and certain measures and design philosophies undertaken. There is always the risk of a leak of gas and the design philosophy was based around detection of any leak and the removal of any source of ignition whilst gas was present. Because the gate control equipment consists of relays and similar devices which do create sparks and needs to be kept operational, the hydrogen storage and the fuel cell and it's associated equipment was kept entirely separate in a dedicated enclosure. The fuel storage and manifold was divided off from the fuel cell and the DC/DC converter by a rigid stainless steel partition. A gas detector head was installed above a common vent from both sides. This was wired to a control unit fitted within the gate control kiosk. Detection of gas isolated the gas supply to the fuel cell and also isolated the electrical connection to the batteries which were also located in the gate control kiosk. Although this arrangement does create a higher than desirable drain on electrical power it does provide a safe installation. Further discussion and comments are made concerning this in the conclusion of this report.

Manual handling is as previously mentioned an issue that does require careful consideration. However gas cylinders of the same or similar size are handled regularly and equipment is available to reduce the risk of injury. In this application we opted for a double cylinder trolley or barrow. This had the advantage that only one journey was necessary in either direction. It was of sufficient width to enable two people to share the load. A ramp and a raised floor were added to the gas cabinet which enabled the cylinders to be rolled into position. All of the weight of the cylinders is in the cylinder itself therefore if lighter composite cylinders were available the exercise would be come considerably easier.
Areas that require an up hill route to get to the installation would be very difficult to re-fuel manually and would almost certainly require a motorised form of transport.

5.6 Modifications Carried out During the Trial

There were only a few modification carried out during the trial period.

1. Modification to the high pressure hydrogen vent so that it vented outside and well above the cabinet. (This should have been completed prior to the unit going to site but was overlooked).
2. Modification to the monitoring transducers so that they were continuously energised in order to provide better data to telemetry.
3. Covers fitted to PV modules as explained above.
4. Adjustments to the voltage settings on the DC/DC converter to avoid over running of the fuel cell. If the switch off setting was slightly too high the unit did not detect that the battery was fully charged and continued to run the fuel cell thus wasting hydrogen.

6. Conclusions

6.1 Achievements

One of the main objectives of this trial was to gain practical experience and knowledge in the use of hydrogen fuel cells in practical applications. This has been fulfilled. The design of future projects and the anticipated costs can now be based on the information and knowledge gained on this project.

Based on the trial it is considered that this arrangement could be a practical solution in certain areas where there is a problem of getting a power supply to remote electrical equipment. Careful consideration does need to be given to the application, and as with any power supply system some applications will be more suitable than others.

Equipment and component development will increase the number of practical application. Although the fuel cell itself has worked well and reliably it has always been felt that this particular piece of equipment lacked a professional and commercial finish. Although for the installation it was housed within a large kiosk it would heave been far better had it had some form of case in the same way as a large power supply unit or similar. The general construction made it difficult to install and terminate the types of cables that are used in these types of application.

As mentioned above the cast steel cylinders are very heavy and there is therefore a need for some form of light weight version. It is understood that BOC are working on such development.

The fuel cell manufacturers advised that the ambient temperature around the unit should not be allowed to drop below 1 or 2 degrees C. It was only possible to keep the temperature above this by installing a heater which even at 50W consumes a great deal of power at times of very cold weather and hence increase the gas consumption greatly. Although the cabinet was insulated there is of course the need to have good ventilation in the cabinet so heat is continuously lost.

6.2 Improvements in Design

There are a number of improvements that could be made to this design and that of future systems. The object of these improvements would be:

- Reduce fuel consumption.
- Reduce maintenance / servicing costs.
- Reduce manufacturing and installation costs.

Reducing fuel consumption could be achieved by selecting fuel cells with greater efficiencies and reducing power consumption. One of the parameters laid down at the start of this trial was for a system to provide approximately 500Wh per day. The gate control system that was powered by the fuel cell and solar modules consumes considerably less than this and so the extra load was to be made up of the additional monitoring equipment, safety equipment and possibly some fixed load in the form of resistors. Therefore there were no efforts made at the time of design to reduce the power consumption. However if the equipment is to remain in use in its present location certain measures should be taken to reduce the overall power consumption. This can be achieved by isolating the additional current transducers which were fitted and modifications to the gas detection equipment. The gas detection equipment is continuously energised and does have a significant demand, more than 50% of the total load in fact. Although future designs for the general arrangement of the equipment may, after carrying out the necessary risk assessments and haz ops may not require permanent gas detection it is unlikely that this installation will be substantially modified to a point where this would be an option. It is suggested that subject to a detailed design study that the system be modified so that gas detection is normally off and the solenoid valve that is in the supply line to the fuel cell is off and the DC/DC converter is moved into the gate control kiosk. When there is a demand for the fuel cell to run the system would activate in the following controlled manner:

1. Activate gas detection and allow time to settle
2. Energise solenoid to allow gas into the fuel cell
3. Energise power to the fuel cell
4. Activate the fuel cell to charge the battery.

This would significantly reduce the fuel consumption and hence reduce the number of service visits per year.

Another way to reduce the re-fuelling visits is to increase the quantity of gas stored on the site. It was originally intended to have four cylinders in this cabinet but due to the design of the manifold this was not possible. Four cylinders would half the number of re-fuelling visits which although not reducing the fuel costs the extra time to change four cylinders as opposed to two is insignificant hence running costs considerably reduced.

It has been suggested that the manifold arrangement could be changed so that only one cylinder is in operation at any one time and when a cylinder is empty a signal is sent to telemetry and the other cylinder comes into operation. Although this would possibly improve the reliability of the system it would in fact increase the number of visits per year thus increasing quite significantly the running costs. This would be a preferable option if four cylinders were installed. Three could operate in tandem with the fourth acting as the back up / standby cylinder.

Future designs should consider having three distinct enclosures, one for the gas storage and manifold, one for the fuel cell and one for the equipment being powered and the DC/DC converter.

Two of the most significant costs in the building of this trial system were the gas cabinet and the gas manifold. It is debatable whether any advantages were gained by having the cabinet insulated. The air flow probably negates any improvements in internal temperature that are gained by the insulation. By separating the fuel cell away from the gas storage the enclosure for that becomes considerably smaller and thus easier to keep above freezing.

The gas manifold for this was assembles using individual regulators and valves which were interconnected with brazed copper pipework. This was labour intensive and hence very expensive. A much simpler method is needed for future projects such as possibly a manifold block machined from solid material.

6.3 Potential Future Applications

This type of equipment does have practical potential uses in fixed applications where the power consumption is very low and solar power is not possible throughout the year. The additional power consumption that is created by the fuel cell control and monitoring system must be kept as low as possible. On site storage must be kept as high as is practically possible, ultimately aiming at one service visit per year.

There is probably a market for such equipment in applications that require to be powered for an extended period but not forever. These might include traffic monitoring camera, counters etc. scientific research such as weather monitoring, air quality monitoring, noise monitoring where it is necessary to gather data for a specific period such as twelve months.

Organisations such as the Environment Agency have their own in house engineers and maintenance personnel which enables them to service and maintain equipment such as this. Other organisations that may operate monitoring systems such as those described above would not necessarily have these services at their disposal. In order to develop the market for fuel cell power supply systems it is also necessary to develop the support infrastructure and service ability.

7. Summary

The trial met all of the criteria laid down in the original proposal. There could have been some improvements in the monitoring equipment and format although the data acquired was sufficient for evaluation purposes.
A review of commercially available fuel cells is now necessary to ascertain if more recent designs and models would be more suitable for integration into remote field applications.