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Experimental Analysis of H_2 Generator as a Back-up Power to Implement for National Broadband Network (NBN) in Australia

Kannan Jegathala Krishnan[1], Akhtar Kalam[2] and Aladin Zayegh[3]

[1-3]*School of Engineering and Science, Faculty of Health, Engineering and Science, Victoria University, Footscray Park Campus, Melbourne, Australia -3011*

[1]Kannan.Jegathala-Krishnan@vu.edu.au
[2]akhtar.kalam@vu.edu.au
[3]Aladin.Zayegh@vu.edu.au

Abstract **-Greater digital economy can boost Australia's productivity, global competitiveness and improved social well-being. The Australian government's aim is that, by 2020 to build the enabling infrastructure for the digital economy, in particular the commitment to build the National Broadband Network (NBN). Digital communities, broadband for seniors, smart grid, smart city, sustainable Australia-managed motorways, telework forum, telehealth trails are some of the government initiatives to advance the digital economy goals. Since NBN will be rolling out several hundred points of presence (POP's) there will be need for reliable back-up power supply. When called upon power at telecom sites ideal choice being diesel generatorrequires fuel storage, produce combustion emissions, noisy and maintenance costs are high. The valve regulated lead –acid battery banks (VRLA) prone to self-discharge, need replacement every 3 years, are bulky, heavy and costly to maintain. New battery technologies, ultra capacitors and flywheels have been employed recently but disadvantage of each technology are significant. The authors of this paper suggests that the use of EL100 H_2 Generator and T-1000 PEM Fuel Cell is capable to compete with traditional technologies to offer back-up power by producing H_2 on-site and can be implemented as a back-up power in telecommunication systems and in the recent layout of NBN. This paper examines a thorough laboratory testing of H_2 generation, H_2 delivery system, process and safety signals in a back-up power operational Power Systems Research Laboratory, Victoria University, Melbourne. This paper presents the planning of laboratory testing, analysis and evaluation of the laboratory results of EL100 H_2 Generator. Reliability, long service life, outdoor operation capability, compact design, minimum maintenance, reduced environmental impact compared to current technologies are some of the advantages of using Hydrogen Energy and Fuel Cell solutions for emergency power supplies.**

Keywords **- National Broadband Network (NBN), EL100 H_2Generator, T-1000 PEM Fuel Cell, H_2, H_2 storage tank,load and batteries.**

I.INTRODUCTION

As mobile telephones, computers and high-speed internet have become more common and the telecommunication industry has expanded rapidly. Therefore, telecommunication facilities and number of cell phone towers has increased dramatically. The number of mobile telecommunication network stations worldwide was 4.7 million in 2011 and the telecommunications site layout is shown in Fig. 1 [2], [3]. Base Transceiver Stations (BTS), Base Switching Centre (BSC) and Mobile Service Switching Centre (MSC) are the most important parts of wireless networks for mobile phone services. BTS as shown in Fig. 2 are needed for direct connection to the users with mobile phones. Users between wireless and wired network are connected by MSC and also BSC are needed to control several Base Stations. To keep their towers, equipment and networks operational from power outages most telecommunication providers install some form of back-up power [1], [3].

Energy can be accumulated in various forms like electric charge in capacitors and ultracapacitors, superconducting magnetic electric storage, pressurised air, hydro power, kinetic energy in fly wheel and electrochemical in batteries. Batteries and fly wheelsare mostly used in uninterruptible power supply (UPS) systems. For uninterrupted service, back-up power systems consists of UPS and electric generators. Lead acid batteries are used for accumulating electric energy in most of the UPS. Only batteries are used in most of the UPS installations for power supply of several minutes. UPS must be coupled with a diesel generator as a prime mover for longer back-up time. In the case of power net outage the UPS is used to bridge the power from net and generator and provide time to start the generator [3].

Factors like high start-ability, large costs of periodic checks and exercises for diesel and gasoline fuelled generators and the price of base material for lead acid batteries as shown in Fig. 3 are some of the drivers for H_2 Energy and Fuel Cell technology deployment in back-up power market. The effect on CO_2 reduction will be significant, if battery UPS are replaced by H_2 Energy and Fuel Cell technology. Fig. 4 shows that average for one replacement of battery system by fuel cell reduction in CO_2 production is about 0.789 ton a year in Europe. The total reduction in CO_2 emissions would be 329 thousand tons CO_2 yearly, multiplying 0.789 ton by number of base stations in Europe [3].

P-21 GMBH (Germany), Dantherm Power A/S (Denmark), Plug Power Inc. (USA) and Hydrogenics (Canada) are some of the companies already offering Fuel Cell back-up power sources for base stations in mobile communication networks by using H_2 bottles [3].Currently it is expensive to run distance trucks requiring several site visits per year in order to refill the diesel or even carrying H_2 bottles to a rural site.The EL100 H_2 generator generates H_2 on-site and can be implemented as a back-up power in telecommunication system and also in NBN [4].

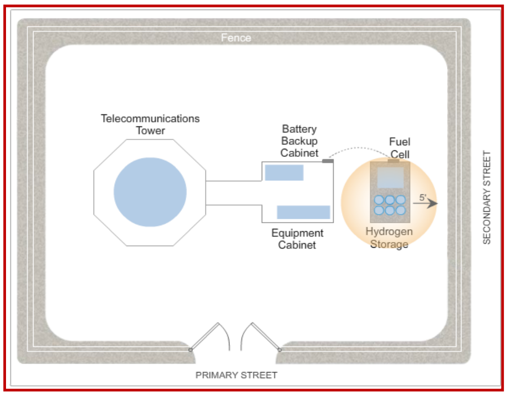

Fig. 1 Telecommunications site layout [2]

Fig. 2 Mobile base transceiver stations [3]

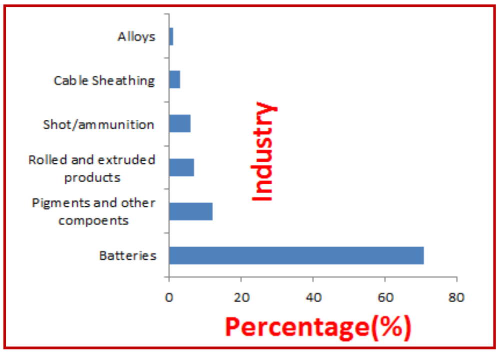

Fig. 3 Lead Industrial Consumption [3]

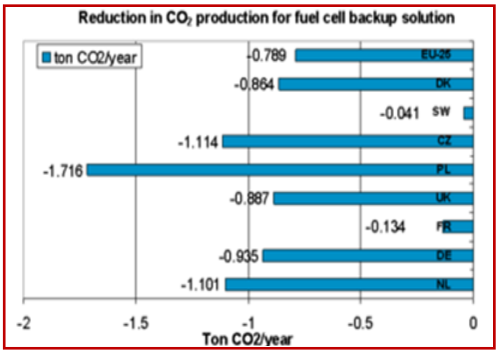

Fig. 4 Reduction in CO_2 production for Fuel Cell back-up solution [3]

Section 2 of the paper highlights the vision and strategy of NBN. Hydrogen Energy and Fuel Cell technology are discussed in Section 3. Section 4 of the paper describes the EL100 H_2 generator and its advantages. The planning of Laboratory Testing at Power Systems Research Laboratory, Victoria University are explained in Section 5 and Section 6 describes the system installed in detail. Section 7 points out the analysis and evaluation of the laboratory results. Finally, Section 8 provides the conclusions as well as directions for future work.

II. NATIONAL BROADBAND NETWORK (NBN)

The establishment of NBN will provide the vital enabling infrastructure to achieve the government's vision to be among the world's leading digital economies by 2020. The Australian Government invites industry, state and territory governments and local council to focus on the eight 'Digital Economy Goals' to maximise its benefits. Online participation by Australian households, online engagement by Australian businesses and non-profit organisations, smart management of our environment and infrastructure, improved health and aged care, expanded online education, increased teleworking, improved online education delivery and engagement and greater digital engagement in regional Australia are the eight areas of 'Digital Economy Goals' set by the Australian Government [5], [6].

The downloading internet speed up to 1 Gigabit a second, the support for high-speed download and upload services, the capacity of future upgrades, the stability and reliability of internet service, ubiquitous coverage and uniform national wholesale pricing are the several specific characteristics of NBN. Radio-broadcasters and television took 38 and 13 years to reach an audience of 50 million but internet took only 4 years [5], [6].

A. Vision

The Australian Government said the digital economy refers to **"*Internet, mobile and sensor networks are the information and communication technologies that enables the global network of economic and social activities*".** By 2020,Australia will rank in the top five OECD countries using online opportunities in households, business and not for profit organisations to enable jobs growth, expand their customer base and to improve productivity. Opportunity for online virtual learning, narrow the gap between households and business in capital cities and those in regional areas and double its level of teleworking are some of the goals set by the government to measure the progress in realising the vision by 2020 [5], [6].

1) Government Initiatives

The government has provided $10.4 million over 4 years from July 2011 to Broadband for Senior Program, to ensure that older Australians will participate in an NBN-empowered digital economy. Towards the implementation of Smart Grid, Smart City project, in 2009 the government has provided $100 million to investigate the synergies of the NBN and other utilities. To reduce congestion and improve traffic demand management and overall efficiency of the transport network the government has already provided $61.4 million over 3 years for Sustainable Australia-managed motorways to implement in major cities [5], [6]. To establish a 'Digital Hub' in each of the 40 communities the government will provide $23.8 million over 3 years to participate safely and securely and have trust and confidence in the digital economy for local residents. To investigate and test some preliminary developments to improve people's ease of access to government services the Australian government will provide $2.3 million and $12.4 million over 3 years to provide advice and support services to Australian business and not-for-profit organisations.Google and MYOB, the Getting Aussie Business Online campaign and the recent Australian Retailer Association's Engage in e-tail seminar series has already helped more than 10,000 small business to setup new websites and 150 retailers to engage in the online market place. These are some of the government initiatives to advance the Digital Economy Goals by 2020 [5], [6].

B. Strategy

In 2008-09, Australians aged 15 years or over (26%), retired persons (69%), low-income earners (34%) and people living in outer regional and remote areas (34%) did not use the internet. ABS reports 2009 indicated that only 27.1% of Australian business took orders via internet. The Skills Australia Report 2010 stated that 66.9% TAFE staff were aged 45 years or more in 2005 and concluded that in future TAFE sector would be without qualified and experienced staff. About 69.5 million (62%) transactions are made onsite in Australian Government, Department of Human Services (Centrelink) currently. Due to the rapid growth of our cities the vehicles (cars and trucks) are under congested conditions on urban roads use more fuels and emit more pollutants than

By 2020, 90% of high priority consumers such as older Australians, mothers and babies can access individual health records including those with a chronic disease. To remote patients about 25% of Medical specialists will be participating in delivering telehealth consultations. Students and learners who cannot access courses via traditional means in Australian schools, TAFE's, universities and higher education online virtual learning facilities will be offered. These are some of the essential strategies towards positioning Australia as a leading digital global economy by 2020 [5]-[8].

Allen consulting Group (ACG) commissioned by the Department of Broadband, Communications and Digital Economy estimates that Australia would gain $2.4 billion a year in current prices, if the numbers of Australian household connect to the internet by 10% points through time saving activities (price/product discovery, education and knowledge, online shopping, media, engagement in online community etc.). [5], [6].

II. HYDROGEN ENERGY AND FUEL CELL TECHNOLOGY

Fossil fuels which met dominant portion as main energy source to fulfill world's energy demand is depleting fast. Global problems such as pollutions, greenhouse effect, ozone layer depletion and acid rain are caused by the waste combustion products of fossil fuels. One of the solutions to these global problems is to replace the existing fossil fuel energy systems by Hydrogen Energy and Fuel Cell technology [7]-[12].

A. Hydrogen Energy

H_2 is most abundant, efficient and clean fuel but the problem is that it is not free. Electrolysis is required to separate H_2 from H_2O. Non-renewable or renewable energy sources are required for electrolysis process to decompose H_2O into H_2 and O_2 gas. In future particularly H_2 can play an important role by replacing the imported petroleum we use in our cars and trucks currently [7]-[12].

Between two electrodes separated by aqueous electrolyte H_2 is produced by decomposition of

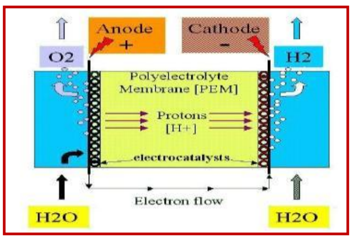

Fig. 5 PEM Electrolyser [9]

vehicles under free-flow conditions [5], [6].

H_2O by passing an electric current. The two main types of electrolysers which are well developed are proton exchange membrane (PEM) electrolysers as shown in Fig. 5 and alkaline electrolysers. At anode, H_2O reacts to form O_2, electrons and positively charged ions (protons) as shown in equation (1). The electrons flow through external circuit and H_2 ions move across the PEM to the cathode, where they recombine to form H_2 as shown in equation (2). The total reaction for H_2O decomposition is shown in equation (3)[7]-[12].

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^- \quad (1)$$

$$4H^+ + 4e^- \rightarrow 2H_2 \quad (2)$$

$$H_2O + \text{electrical energy} \rightarrow H_2 + 1/2\, O_2 \quad (3)$$

B. Fuel Cells

A Fuel Cell is an electrochemical energy device which produces electricity, H_2O and heat as long as there is a supply of fuel. H_2 gas flows into the Fuel Cell on the anode side. The separation of the H_2 gas into electrons and protons (hydrogen ions) is facilitated by a platinum catalyst. The hydrogen ions pass through the membrane and the electrons which cannot pass through the membrane, flow from anode to cathode through an external circuit containing a motor or electric load. At cathode side, hydrogen ions with the help of a platinum catalyst again combine with O_2 and electrons producing H_2O [7]-[12].

The voltage from one single cell is about 0.7 Volts. The operating voltage increases to 0.7 Volts multiplied by the number of cells stacked in series. In conventional car the gasoline engine is less than 20% efficient in converting the chemical energy in gasoline into power. Fuel Cell vehicles using H_2 gas use 40-60% of the fuel's energy and are2 to 3 times more efficient than the conventional gasoline engine car. For back-up power, power from remote locations, distributed power generation and co-generation stationary Fuel Cells can be used. Among all Fuel Cells, Proton Exchange Membrane Fuel Cell (PEMFC) is attracting much attention because of its several advantages such as high efficiency, quite operation, its small volume and low working temperature [7]-[12].

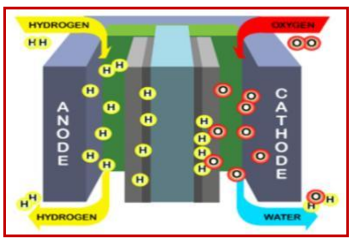

Fig. 6 Fuel Cell [11]

III. EL100 H_2 GENERATOR

The EL100 H_2 generator as shown in Fig. 7 is a device that produces H_2 directly from H_2O by means of an electrolysis process. Both compressed gas tanks and metal hydride absorption tanks can be used for storing H_2 gas. The EL100 unit serves to produce a clean, low cost fuel,requires little maintenance, easy to use and is the first H_2 generator that can be installed in any setting. It produces H_2 that powers electrical equipment such as power generators (Fuel Cells) and electrical vehicles (scooters, craft with outboard/inboard and work vehicles) in a complete safe and environmentally sound manner. Electricity from the mains or from renewable sources and demineralised H_2O are supplied to produce H_2 gas which can also be used in home [13].

The EL100 unit is contained in a metal casing with a quick socket to connect to the device requiring H_2, power lead and H_2 relief valve. The control unit of EL100 contains On/Off main switch (C), button (D) to start H_2 production and red light (E), warning of malfunctioning of the unit, indicating the device must be repaired at an authorised help centre. The depletion of the H_2O is indicated by orange fixed light [need to restore the liquid level in the reservoir (G)], the blinking orange light indicates over heating of the device (need to shut down the device to restore operating temperature) and the green light indicates the tank is full (stop adding any more liquid in the tank G). The green LED on the button (D) flashes during the electrolysis processas shown in Fig. 8[13].

The EL100 solution (made up of demineralised H_2O with the addition of 1% in weight of electrolyte non-consumed K_2CO_3) through an electrochemical process generates about 83.6 slph of H_2 is during the process. The output and the pressure of H_2 produced are controlled by the safety system inside the unit making the EL100 unit to use both indoor and outdoor settings.EL100 unit is a completely automated system and this technology is ideal for remotely located homes and can be used in NBN and telecommunication sites [13].

The specifications of EL100 H_2 generator is shown in Table I. The advantage of this unit includes

- Acquiring a considerable independence from power distribution networks
- Reduction of pollution and greenhouse gases.
- Clean and silent technology.
- No more noisy polluting engines and
- Self-contained energy supplies using H_2O and electricity by means of a simple and safe instrument [13].

IV. PLANNING OF LABORATORY TESTING AT POWER SYSTEMS RESEARCH LABORATORY, VICTORIA UNIVERSITY

The testing of EL100 H_2 generator for back-up power solution in telecommunication application like NBN was the goal of the project. The evaluation and testing was performed at Power Systems Research Laboratory at Victoria University. After the installation of EL100 unit, system commissioning included several checks for the leaks in the gas line planning.

TABLE I

SPECIFICATIONS OF EL100 H_2 GENERATOR [13]

Product Specifications EL100	
Flow rate for Hydrogen produced (max)	83.6 slph
Operating pressure	15 bar
Purity of Hydrogen	99.52% @ 15 bar
Internal accumulation of Hydrogen	none
Power Supply	220/50
Power Consumption	440 W
Quality of Electrolyte	K2CO3 solution – 1% in weight
Tank Volume	4.5 L
Quality of Demineralized Water	
Max conductivity at 250C	5-10µS/cm
pH	6 - 7
Water consumption (max)	0.068 L/h
Size	3460*260*500mm
Weight	27 Kg

Fig. 7 EL100 H_2 generator [13]

The initial point of testing was to demonstrate a very high reliability of EL100 unit compared to the traditional systems (battery banks and diesel-generator sets). To determine the complete back-up power solution all aspects of EL100 H_2 generator were studied and evaluated including starting logic, gas line planning, H_2 delivery procedure and maintenance [14].

A. Phase I

The EL100 H_2 Generator was started and stopped at regular intervals. The aim of Phase I was to verify the behaviour, reliability and long run capabilities of H_2 Generator when called upon for back-up power in telecommunication sites like NBN.

B. Phase II

The purpose of Phase II was to verify the safety signals of EL100 H_2 generator like green light (F), orange light (F), red light (E) and green light (D) off as shown in Fig. 8[13].

C. Phase III

The purpose of the Phase III was to verify the automatic switching 'OFF' process and over-long charge time of EL100 H_2 generator [13].

D. Phase IV

In this phase EL100 H_2 Generator was started to fill the H_2 storage tank of capacity 150 litres at 215 PSI. The main focus was to monitor how much bottles of H_2 is generated and the H_2O consumed between the maximum and the minimum liquid level of the H_2 generator.

E. Phase V

The aim of Phase V was testing of EL100 H_2 Generator and T-1000 PEM fuel cell and its integration into telecommunications site for back-up power solution when both are working together simultaneously.

V. DESCRIPTION OF THE SYSTEM INSTALLED

The experimental setup at Power Research Systems Laboratory at Victoria University consists of EL100 H_2 generator, 150 litres of H_2 storage tank at 215 PSI, T-1000 1.2 kW PEMFC, battery bank of 48V, resistor load which provides a variable load to T-1000 is used to test its dynamic performance, circuit breakers, voltmeters and ammeters.

The H_2 delivery system installed at Power Systems Research laboratory complies with all applicable local, state, federal or internal codes and standards. During the installation T-1000 PEM Fuel Cell system and EL100 H_2 generator UL252 listed regulators for the use of H_2 are used. To monitor excess residual H_2 gas T-1000 PEM Fuel cell is equipped with internal and external H_2 sensor. An alarm will activate and block the operation of the system in the event of excess H_2 gas is detected. The installed H_2 piping systems adhere to NFPA Article 5.5 and ASME B31.3. For all threaded pipe joints anaerobic sealant is used. All H_2 connections are tested for leakage using approved soap solution [14].

The H_2 storage tank is connected to two pressure regulator at 50 PSI and 5 PSI and is connected to a safety valve in order to avoid accidental gas depletion. A 48V battery with 60Ah is used for Fuel Cell start-up. H_2 is generated from EL100 H_2 generator and stored in 150 litres of H_2 storage tank at 215 PSI.T-1000 PEM Fuel Cell is a solid state DC power that converts H_2 and O_2 into electricity and the only by- products are heat and H_2O [14].

Fig. 8 Power Systems Research Laboratory, Victoria University

VI. ANALYSIS AND EVALUATION OF THE LABORATORY RESULTS

A. Phase I

The most important result of laboratory testing after the installation of EL100 unit was the verification of reliability: when start-up required and several checks for leaks in gas the line planning. The EL100 unit performed as designed when start-up was required throughout laboratory testing resulting in 100% reliability and several leaks was found in the gas line planning and was fixed without any leakage thereafter [15]. Experiments were conducted several times to fill the H_2 storage tank of 150 litres at 215 PSI. The results obtained from Phase I of laboratory testing were satisfactory behaviour of long run capabilities of EL100 H_2 generator.

B. Phase II

The results obtained from Phase II of the laboratory testing were

1. Green light (F): when maximum liquid level was reached [13].
2. Steady orange light (F): The process automatically interrupted when the liquid level for the process has reached the minimum level and was noted during the laboratory testing [13].
3. Blinking orange light (F): The internal temperature is higher than the maximum allowed and EL100 unit was stopped for few hours to restore the working conditions [13].
4. Red light (E): A serious error was noted few times and the EL100 unit was stopped and started again. The EL100 unit was working again in either case when started immediately or after few minutes. The ACTA Energy help centre was contacted to check the system if there is any safety system or sensor seriously malfunctions [13].
5. Green light (D) Off: During installation, EL100 unit has passed all safety checks andthe signal ‘green light (D) Off’ was not found during laboratory testing [13].

C. Phase III

As mentioned earlier, the third phase was performed to verify the automatic switching off of the process. The process was automatically interrupted indicating different signals as discussed in Phase II, when the liquid level for the process reached the minimum level and also due to serious malfunction in the system during the laboratory testing [13].

The automatic switching off of process **before completion of the charging** and **due to over pressure** was not achieved during the laboratory testing (H_2 generator generates H_2 at 15 bar and the storage tank used to fill H_2 was 14.5 bar). Another goal of this phase was to determine over-long charge time; due to serious malfunction of the EL100 unit as discussed in Phase II ACTA Energy help centre was contacted to check the system [13].

D. Phase IV

Experiments were conducted several times to fill the H_2 storage tank of 150 litres capacity at 215 PSI and time consumed to fill the tank increased every time (31.5, 39.73, 60 and 75.10 hours to fill 200 PSI) resulting in unsatisfactory behaviour of Phase IV during laboratory experimentation. Fig.9 shows the H_2 generation in PSI and time consumed in minutes for first 100 PSI (21.5hours behaviour).

The main focus of this phase was to monitor H_2 generation and H_2O consumed between maximum and minimum liquid level of EL100 H_2 generator. The capacity of the tank is 4.5 litres and approximately 3 litres of H_2O is filled few times between the maximum and minimum liquid level during experimentation and about 2 bottles of H_2 is generated at 208 PSI of capacity of 150 litres.

E. Phase V

During Phase V of the laboratory testing period, the most important result is the satisfactory behaviour of EL100 H_2 generator and T-1000 PEM Fuel Cell when both are working together simultaneously and excellent interface with the other devices like batteries, H_2 storage tank, load and measuring units. Fig. 10 shows the generated power trend: 5.5 hours behaviour of the system. Therefore Phase V represents that on-site H_2 can be produced in telecommunication sites for back-up power and also can be used in NBN.

VII. CONCLUSION

At the end of the current laboratory testing period, the most important result is the satisfactory behavior of EL100 H_2 generator in terms of reliability, long run capability, safety signals and excellent interface with other devices. The unsatisfactory results obtained from laboratory test were over-long charge time and automatic switching off of process before completion of the charging and due to over pressure.

Future work will mainly focus to run EL100 H_2 generator and T-1000 PEM fuel cell system for long run capabilities to meet back-up power for telecommunications site and also can have satisfactory usage in NBN.

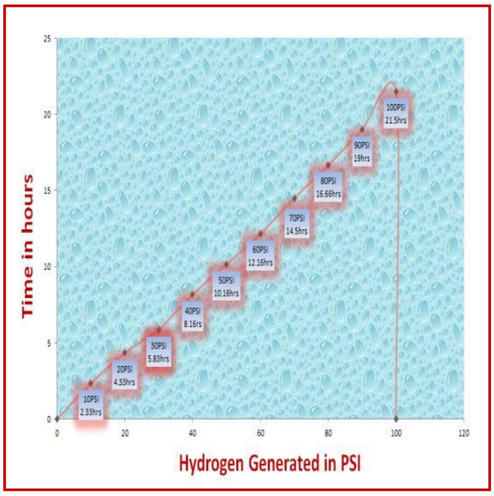

Fig. 9 H_2 generation in PSI (VS) time consumed in minutes for first 100 PSI

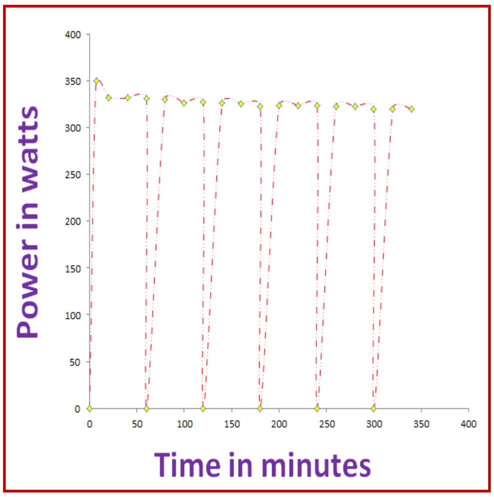

Fig. 10 Generated power trend: 5.5 hours behaviour

During laboratory experimentation currently VRLA batteries are used to start T-1000 PEM Fuel Cell.Experiments are continuing in the next phase to use Red Flow Zinc-Bromine Module (ZBM) batteries. The key advantage is that without significant degradation ZBM batteries can be fully discharged and fully recharged regularly [16].

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