Field Applications: Fuel Cells as Backup Power for Italian Telecommunication Sites

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***Abstract* - Fuel cell technology has often been viewed as a promising alternative to batteries and generators for the backup power requirements of the telecommunications industry. Recent collaboration between ReliOn – a fuel cell manufacturer with more than 850 kW of product sold to customers to date, SGS Future – the Italian distributor of ReliOn's fuel cell products, Telecom Italia and Pirelli Labs has resulted in thorough field testing and data compilation of fuel cells in a backup operation. This paper presents the team's experiences at three installations in Northern Italy where the fuel cell solutions are providing backup power for point-to-point digital link applications. This joint-authorship approach provided unique perspectives from both the manufacturer, ReliOn and the end-user, Telecom Italia Spa across the phases of the field trials. Conclusions on battery plant reduction and efficiency of integration over the 6-month trial will be shared.**

I. Incumbent Backup Power Solutions in TLC (Telecommunications) Stations

Due to practical and economic advantages, TLC stations are usually powered through the public electric grid line. Because the grid provides AC voltage and TLC equipment needs DC voltage, a station is equipped with a rectifier for power conversion. Backup power is generally provided by either battery banks or, in some higher power situations, diesel generators with a small battery bridge.

II. Disadvantages of the Traditional Approach

TLC stations generally use lead acid batteries as their primary source of backup power due to the inexpensive initial cost of capital of batteries. Batteries, however, can present high maintenance and management costs, as well as environmental hazards. Furthermore, the short life and inability to monitor the status of most batteries can result in failure to provide power at sites when called upon

III. Fuel Cell Technology

Fuel cells are electrochemical devices able to convert chemical energy of hydrogen and oxygen into electrical energy without any pollutant or harmful by-product. The fundamental element in a PEM fuel cell (Proton Exchange Membrane fuel cell) consists of two electrodes (a cathode and an anode) connected through a polymeric membrane.)

Gaseous hydrogen is piped to the anode side of the membrane and ambient air is piped to the cathode side. Hydrogen atoms are stripped of their electrons at the anode side and the positively-charged protons migrate through the membrane to the cathode side. In order for this reaction to take place, a platinum catalyst is used on both sides of the membrane. The hydrogen electrons pass from the anode side to the cathode side through an exterior circuit, producing electric power along the way. At the cathode side, the electrons, protons and oxygen from the air combine to form water, the main fuel cell by-product.

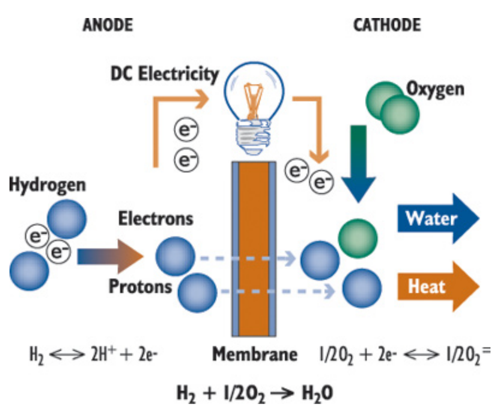

Fig. 1: Schematic working principle of a fuel cell.

IV. Benefits of a Fuel Cell

No pollutant emissions: Fuel cells are easy on the environment. They work through electrochemical reactions instead of combustion or storage, which is the traditional approach to backup power delivery typical of the traditional solutions. With combustion, pollutant substances like CO_x, NO_x, SO_x and particulate are produced; as stated above, the by-products of fuel cell usage are simply water and heat. If hydrogen is produced through renewable sources (photovoltaic panels, wind generators, etc.), the entire cycle is completed without generating hazardous emissions or adding to the carbon footprint resulting from fossil fuels. Where hydrogen is produced through the "reformation" of fossil fuels (methane, GPL) or alcohols (ethanol, methanol), the reaction is cleaner than traditional solutions. In fact, no particulate and SO_x are produced.

Noise emissions: Fuel cells are quiet, with noise near 55 dBA, which corresponds to a normal conversation level. This makes fuel cells suitable for installations indoors as well as outdoor locations where noise must be constrained.

High electrical efficiency: fuel cells are characterized with a very high electrical efficiency, up to 50%. This very important characteristic is due to the nature of the reaction in the fuel cell systems: a direct transformation of the chemical energy into electric energy without an intermediate step of thermal and mechanical (an engine) transformation.

V. Telecom Italia Guideline for the Fuel Cell System Choice

After an extensive market analysis, Telecom Italia started the project described in this document, choosing the ReliOn fuel cell system. These units, distributed exclusively in Italy by SGS future, were selected based on the comparison with another fuel cell system, due to the following aspects:

Reliability: backup systems for TLC stations shall be characterized with a very high reliability because the working life isn't continuous, but the systems will work only in case of grid disconnection. In case of fault in the startup of a backup solution, the TLC energy station is quickly out of service.

Interface with energy station's pre-existing devices: in order to make the interfacing with pre-existing electrical devices function as easy as possible, it is fundamental that the fuel cell system be compatible with Telecom Italia standards and that the connection with other devices (rectifiers, battery banks) is simple to implement. During the selection process, particular attention was dedicated to the connection of the fuel cell system to Telecom Italia's central alarm network.

Reduced maintenance: one of the most important characteristic of the system Telecom Italia selected and installed was the reduced maintenance procedures of the ReliOn system. In fact, due to the extensive number of TLC sites, great importance was placed on this aspect of planning to minimize the maintenance scheduling and costs.

VI. RELION I-1000® FUEL CELL SYSTEM

The I-1000®, exclusively distributed in Italy by SGS future, is a modular 1kW PEM hydrogen fuel cell utilizing ReliOn's patented hot-swappable Modular Cartridge Technology®. This modular approach provides parallel redundancy for the backup solution and provides for a very high reliability, not seen in other commercial fuel cells. The I-1000® offers a simple, air-cooled, self-hydrating solution with very few moving parts. The design of the ReliOn fuel cell allows users to scale solutions from 500 Watts to 12,000 Watts to meet their requirements. The I-1000® has been deployed in commercial applications for over three years. In that time, more than 850kW of backup systems have been sold to sites worldwide.

Fig. 2: ReliOn's I-1000® hydrogen fuel cell

ReliOn's modular cartridge approach, shown in figure 3, allows the fuel cell to selectively enable and disable cartridges as needed. The I-1000® normally operates with six cartridges connected to a common BUS. Each cartridge contains multiple elements (ANODE-MEMBRANE-CATHODE) and is able to supply a nominal power of approximately 200 W. In the event that a cartridge is damaged, the replacement procedure can be performed in few seconds while the fuel cell continues to provide power to the customer load

Fig. 3: Modular approach in ReliOn I-1000® systems.

The unit is capable of be monitored through a LAN connection and, with the clean contact logic integrated, the connection with the Telecom Italia alarm grid is very easy to perform. These specifications have convinced Telecom Italia to choose the ReliOn fuel cell for the field testing along with strong collaboration and support with SGS future.

Technical specifications are reported in the following table:

Product Specifications I – 1000®		
Physical	**Dimensions (w x d x h)**	17.5"x 27.13" x 20" 44.5cm x 69cm x 51cm
	Weight	146 lbs / 66 kg
	Mounting	19" or 23" rack
Performance	**Net power**	Continuous 1000 Watts
	DC voltage	24 or 48 VDC nominal
	Current	20 or 40 A dep. on voltage
	Estimated MTBF	22,000 hours
Fuel	**Composition**	Standard industrial grade hydrogen (99.95%)
	Supply pressure	25 to 100 psig 172 to 689 KPag 1.72 bar to 6.89 bar
	Consumption	7.7 slpm @ 500 Watts 15 slpm @ 1000 Watts
Operation	**Ambient Temperature**	32°F to 115°F 0°C to 46°C
	Relative humidity	0 - 90%
	Altitude	- 197 ft. to 13,800 ft.
	Location	Indoors or installed in Outdoor Enclosure
Safety	**Compliance**	UL CE
Emissions	**Water**	Max. 30mL / kWh
	Noise	53 dBA @ 1 meter

Table 1: Technical specifications of ReliOn I-1000® unit.

VII. ADVANTAGES OF THE RELION I-1000® SYSTEMS

In the comparison between commercial fuel cell systems evaluated by Telecom Italia, several strong features of ReliOn fuel cells stood out:

- Modular system: ReliOn's 1kW scalable fuel cells enable the station load to be supplied with elevated precision. The customer purchases the power capacity needed and does not pay for unused capacity. Furthermore, the high reliability due the internal modular design meets a fundamental specification.

•High redundancy: all the auxiliary components of the system (management cards, air blowers) are redundant in the unit. In this way, the maintenance stops of the fuel cell system are minimized.

•LAN and "clean contact" interface: the connection with the pre-existent electrical devices is easy and fast to do. Maintenance and control procedures are reduced also with the possibility of an Internet remote connection.

•Air-cooled system: The simplicity of the ReliOn design negates the need for water pumps and other cooling devices.

•Focused system: the ReliOn I-1000® is designed to work in the TLC field and has met the severe specifications for installation inside a Telecom Italia station.

VIII. Purpose of the Field Testing

The goal of the project, which involved strong collaboration between Telecom Italia and SGS future, was the testing of the fuel cell system and its integration into TLC stations for backup power solutions. The starting point of the testing was the need to demonstrate a very high reliability as compared to the traditional solution, of the battery banks. While the traditional battery solution provides a measure of high reliability, this solution is characterized by high weight and the very low predictability of oncoming failures. With this assumption, the project tested the possibility to achieve similar performance behaviour without the weak points of the traditional battery approach.

The described evaluation was performed on the units integrated in the Telecom Italia TLC plants. These units were studied to determine the complete backup power solution including the integration of the fuel cell with the other site devices. All aspects of the fuel cell solution were evaluated, including gas line planning, hydrogen delivery procedure, interface with the other components, starting logic and maintenance.

IX. Codes & Standards Regarding Italian Hydrogen Installations

International and Italian regulations regarding hydrogen installations are very incomplete and precise guidelines about this type of installation are not readily available. The reference rules for Italian regulations, are the Minister Decree DM 24 Nov 1984 and DM 24/05/2002, which refer to natural gas. Therefore, hydrogen installations are considered like natural gas plants, because both gasses have a density lower than air density. The Minister Decree fixes the maximum amount of gas (750 liters, geometrical capacity in water liter) it is possible to install without the approval of the Italian Fire Department and the acquisition of a CPI permitting document (Certificato Prevenzione Incendi – Fire prevention Certificate). Below this quantity, an installation may follow the rules of good installation and risk prevention. UNI and ISO Working Groups are working to prepare a reference regulation about hydrogen installations: the most important are the Technical Committees:

- ISO/TC 197: focused on hydrogen technologies
- ISO/TC 22: focused on mobile applications fuelled with gaseous fuels (included hydrogen)

The first one has prepared a preliminary guideline (ISO/TR 15916:2004): SGS future, during installation of the fuel cell units, also considered this reference for correct planning. In Germany, the reference rules (TRB and TRG) suggest an installation procedure. In the U.S., NFPA 50 and NFPA 50B standards are referenced.

SGS future engineers and technicians, during the installations of hydrogen plants also follow suggestions proposed into technical documentation like, for example, the EIGA (European Industrial Gas Association) technical sheet.

PED and TPED rules regarding the use of compressed gas and ATEX/ATEX II were followed in consideration of the installation of electrical devices into classified areas.

X. Planning of the Field Testing

Before the field testing was started, Telecom Italia and SGS future worked together to plan all four phases of this project, which would take a total of six months.

Phase 0: After the installation of the systems into the three sites chosen by Telecom Italia, system commissioning included several checks of the alarm systems, the calibration of the control units, and the remote transmission of data generated from the fuel cells.

Phase 1: The purpose of Phase 1 was to verify the behaviour of the systems. In this phase, the fuel cells were started and stopped at different time increments until the initial hydrogen pack (108 Nm^3) installed at each site was consumed. Each site ran for approximately 100 hours of testing during this phase.

Phase 2: After replacing the first bottle pack at each site, phase two was started. The aim of this phase was testing the long run capabilities of the backup systems and continued until the second hydrogen pack at each site was emptied. The results obtained from the field testing were:

- Self-sufficiency of each fuel cell backup system in each selected site;
- Electrical efficiency of the systems;
- Definition of the thresholds of the monitoring systems (i.e. the hydrogen depletion signal of the gas packs).

Phase 3: Specific tests were performed in order to study and monitor the systems in comparison with typical tests performed on traditional backup solutions. The tests performed are as follows:

1) Attainment of the nominal conditions of the systems.
2) Fast turn on/off cycles.

3) Recharge to float voltage after heavy discharge (44 VDC) of the battey packs.
4) Repeated and frequent grid disconnection and consequent turning on of the units.
5) Automatic startup procedure in case of low battery voltage.
6) Start up of the units after long inactivity (one month).
7) Tests in case of severe enviromental conditions.

Phase 4: This last phase was performed after the replacement of the pre-existent battery packs with a smaller one (150 Ah), required only for the transient start up procedure of the fuel cells.

XI. Site selection

Telecom Italia chose the test sites considering the following principles: the centrals are non-nodal in the Italian grid but characterized with a sufficient number of connected users. The distance from a technical support center able to attend in case of malfunction defined the total capacity of the pre-existent battery packs. The size of the battery packs influences the economic viability of a switch to fuel cells and influenced the final site selection. The three sites chosen for the field testing are explained in the following table:

Site's name	I_{TLC} [A]	Pre-existent battery packs [Ah]
VEZZANO	27	2x24 SMF/10 (2x530 Ah)
CALAVINO	31	2x24 SMB/12 (2x1200 Ah)
MATTARELLO	74	2x24 6ST/100 (2x600 Ah)

Table 3: selected sites.

Telecom Italia's energy stations are MD6 type equipped with Alcatel commutation devices and IRSU technology. The population of the three villages are respectively 1,000, 1,500 and 5,500. As shown in Table 3, the pre-existent battery packs were able to grant a self-sufficiency of more than two days at each site.

XII. Description of the installed systems

The interaction of the fuel cell backup systems installed by SGS future with the equipment at Telecom Italia sites is explained in the following picture: the fuel cell systems are connected in parallel with the batteries (in the first half of the project to the pre-existent batteries, in the second one to the smaller one) directly on the rectifier bar.

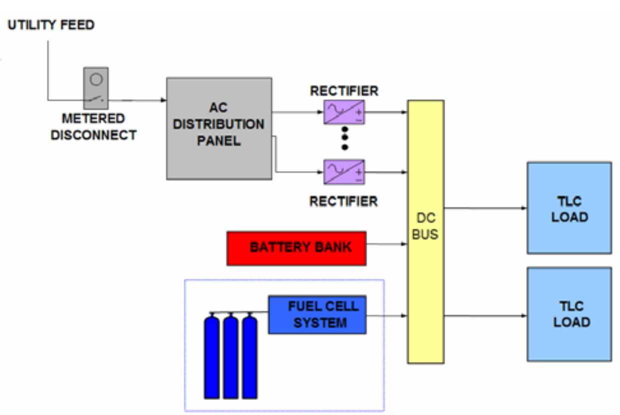

Figure 4: Diagram of the fuel cell's installations.

Considering the requested power in each site, four ReliOn I-1000®'s were installed in the central of Mattarello and two units in each of the other two Telecom Italia sites.

The fuel cells are configured for startup on loss of electrical grid as well as in case of low backup battery voltage. The I-1000® allows the customer to configure the fuel cell to start at one of four different voltage levels (44; 46; 48; 50 VDC): if the battery voltage drops below this fixed value, the fuel cells are turned on and continue to supply energy until the float voltage (also able to be configured) is reached. If the float voltage value is reached and stable for twenty minutes, the fuel cells shut down and return to stand-by operation. For this project the low voltage start was set at 48 VDC.

In each station, SGS future installed specific racks according to Telecom Italia specifications: each one is able to contain two units and the small battery pack. Furthermore, the rack contains the outdoor venting required to remove the warm air produced while the fuel cells are running.

Figure 5 shows the SGS-designed rack used at the project sites.

Figure 5: Mattarello's fuel cell systems.

Hydrogen was stored outside of each building, using bottle packs. Each pack is capable of storing approximately 108 Nm^3 (cubic meters in standard temperature and pressure conditions) and is connected to a safety valve in order to avoid accidental gas depletion. A pressure regulator is installed in front of each safety valve in order to reduce this to the final pressure value (ranging from 1.7 to 6.9 bar). Hydrogen pack replacement is performed after the emptying of the installed one: a special pressure regulator transmitted an alarm to Telecom Italia's Emergence Call Center when the gas amount dropped below a fixed value.

The plants are equipped with two redundant electrovalves in series: these are normally closed in order to obtain a complete safe situation: the opening command follows the start command to the fuel cell systems. The electrovalves are connected to a hydrogen sensor located inside the buildings. This ensures that the gas line outside the building would be closed in case of a detected hydrogen leak.

The systems are connected to Telecom Italia's central alarm network and are considered in the network like a genset: the alarms transmitted are "SYSTEM TURNED ON", "MAJOR ALARM" and "END OF FUEL". Furthermore, management software was installed by SGS future in order to acquire data from the fuel cells: the fuel cells are connected via ethernet ports to the ADSL modem.

XIII. Analysis and Evaluation of the Testing Results

The most important result of the field testing was the verification of reliability: when startup was requested, all fuel cells performed as designed throughout the field test, resulting in 100% verified reliability.

Figure 6 shows the power characteristics of the incumbent battery solution (green line) compared to the fuel cell solution (blue line). The graph references a working period of 50 minutes.

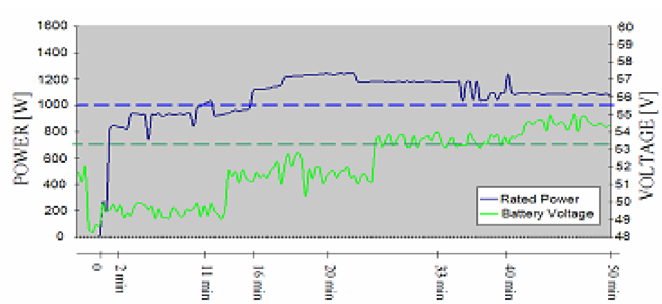

Figure 6: Trend of power and voltage for a ReliOn fuel cell vs. battery.

The nominal condition of the system was reached in around eleven minutes: but around the 80% of the nominal power was provided in less than two minutes.

Float voltage value of the battery packs are fixed to 53.3 V[1]. Starting from a partially discharged battery pack, the complete recharging was reached in around twenty-five minutes.

A. *Phase 2 Results*

As mentioned earlier, the second phase of the project was performed using Telecom Italia and SGS future technicians in order to verify the reliability of the systems in extended tests.

[1] This value is referred to lead-acid batteries (2,22 Volt per element).

Another goal of this phase was the determination of the efficiency (η) of the units. In order to do this, the stations are equipped with devices able to report the hydrogen depletion and with an energy counter.

The tests were performed in all three sites through the grid disconnection and the subsequent start up of the units. This situation was maintained until the complete depletion of a new hydrogen pack and the shut down of the units due to hydrogen absence. An appropriately calibrated manometer was able to transmit the forthcoming hydrogen depletion and the time remaining until the fuel cells would shut down. This parameter represents the effective self-sufficiency remaining in case of a backup operation: when this situation is achieved, the hydrogen pack replacement shall be performed. Depending on the logistical situation for hydrogen replacement (geographical position, distance of the site), this threshold was fixed with different values at each site.

The results of this phase are displayed in the following table:

Vezzano's installation	
Initial hydrogen pack pressure	190 bar
Alarm sent	after 70 h and 27 min
System shut down (end of fuel)	After 79 h and 10 min
Total electrical energy produced	117,6 kWh
Electrical efficiency	38,4 %
Calavino's installation	
Initial hydrogen pack pressure	195 bar
Alarm sent	after 72 h 04 min
System shut down (end of fuel)	after 77 h 16 min
Total electrical energy produced	131,7 kWh
Electrical efficiency	40,6 %
Mattarello's installation	
Initial hydrogen pack pressure	175 bar
Alarm sent	after 24 h 08 min
System shut down (end of fuel)	after 30 h 57 min
Total electrical energy produced	116,6 kWh
Electrical efficiency	39,1 %

Table 4: Phase 2 results

At the end of this phase, the first result obtained was the verification of electrical efficiency: the values obtained were greater than the nominal value presented in the technical specification supplied from ReliOn.

The values obtained at the three sites differed slightly due the difficulty of a correct estimation of the real amount of hydrogen stored in the gas bottle packs.

B. *Phase 3 Results*

In this phase, in order to obtain a greater amount of data, the tests at the three sites were diversified with this program:

• Remote run tests were repeated in the Mattarello' station site for a period of three weeks. The duration of the working interval was changed periodically in order to obtain a greater casuistry and additional experimental results.

• The systems installed in the Calavino' site were kept in stand-by condition for a month in order to test the automatic procedure for a maintenance periodic start-up, configured by SGS future. The behaviour of the fuel cells after prolonged inactivity was also studied.

• Specific tests planned by Telecom Italia and SGS future were performed in the Vezzano's station.. The results are shown below.

The test indicated that the answer of the fuel cell systems was positive in case of fast transient and also in case of protracted activity requested from a complete recharge of a battery pack.

In the following picture is displayed the behaviour of the two ReliOn's fuel cells unit installed in the Vezzano' site.

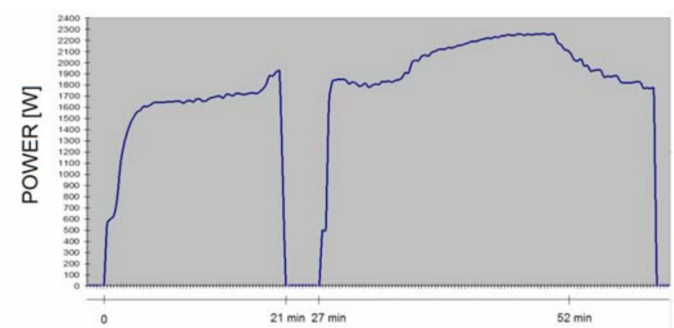

Figure 7: Power generated in the Vezzano site.

Note that the fuel cells are able to answer quickly when a sudden change of the requested power is performed: in fact, after twenty-one minutes from the start of the test, the grid was re-inserted and the fuel cells started the shutting down procedure. Six minutes later the grid was disconnected again and the fuel cell started another time and reached the nominal power immediately.

Also the automatic procedure (low battery level) was correctly tested. The opportunity of a specific regulation of the starting and float voltages permit a fast and easy installation when the clean contact model is not available. The continued monitoring of the battery voltage represents an adequate solution in the hydrogen back up systems.

The periodic tests performed in the station of Mattarello were realized in order to stress the systems and perform accelerated testing. The tests, with a duration of three weeks, are detailed below:

- A starting procedure every hour (from 08.00 to 16.00) with a duration of fifteen minutes (14-15-16-17 February 2006).
- A starting procedure every hour (from 08.00 to 16.00) with a duration of thirty minutes (14-15-16-17 February 2006).
- A starting procedure every hour (from 08.00 to 16.00) with a duration of thirty minutes (14-15-16-17 February 2006).
- A starting procedure every hour (from 08.00 to 16.00) with a duration of forty five minutes (14-15-16-17 February 2006).

The behaviour of the battery voltage and generated power (for example the case of thirty minutes) is below reported:

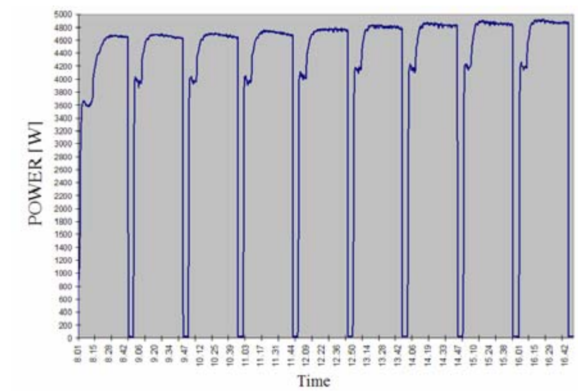

Figure 8: Generated power trend: one day behaviour

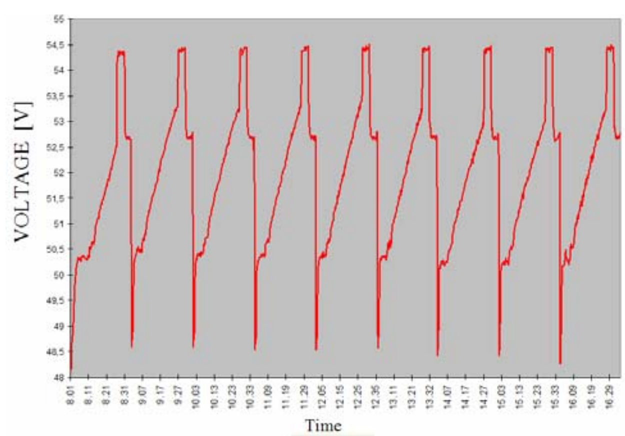

Figure 9: Battery voltage trend: one day behaviour.

This test also re-confirmed a fuel cell reliability of 100%.

The environmental conditions over the six month test period changed substantially, from 0°C to 30°C: in all cases, the results were satisfactory.

In the Calavino' station the systems were kept in standby for one month and then started remotely. In order to further stress the units, after the starting command, the grid was disconnected so that the full site power load was supplied by the fuel cell. In fact, if the cells runs with the grid connected, the systems do not supply energy to the station due to the priority of the rectifier.

The results of this test are explained below: the units answered quickly to the energy request and in fifteen minutes, nominal power conditions were reached.

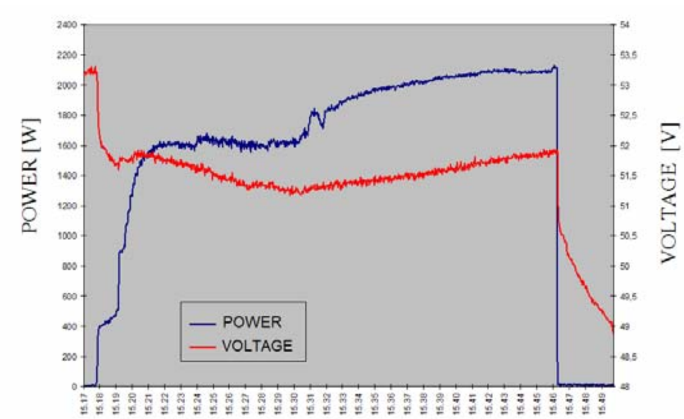

Figure 10: Behaviour of the units after a month of standby.

C. *Phase 4 Results*

The same tests performed in phase 3 were performed using a smaller AGM battery pack with a nominal capacity of 150 Ah at each site. The results obtained were satisfactory due the quick startup capability of the fuel cell systems.

XIV. Conclusions

At the end of the testing period, the most important result is the positive behaviour of the systems and the excellent interface with the pre-existent devices present in the sites. The field results were in agreement with the specification declared from SGS future and no malfunctions or anomalies were registered.

The most important results obtained from the field test were:

- Reliability: fuel cells answered any time correctly with a tested reliability of 100%.
- Interaction with pre-existent devices: with the different starting procedure (grid disconnection and battery voltage level), the systems are able to supply different critical situations in the Telecom Italia' stations.
- Rumour registered on the bars: with another specific test, performed with a FLUKE SCOPEMETER, a mean rumour of 7, 2 mV with a peak-peak value of 22 mV was registered. These values are in according with the Telecom Italia' specifications.

A. *Economic Evaluations*

The field testing demonstrates that fuel cells are a good alternative choice for telecom backup systems. The services offered represent a quality service, better than the traditional systems with minimal maintenance and managing costs. For these reasons fuel cells are a good solution in the situation where service continuation is a priority, winning over incumbant battery banks.

Fuel cells represent an economical solution in the case where backup self-sufficiency is much extended, as well. The developmental trend in the fuel cell industry is going toward price reduction and a consequent increase of the reduction of the convenience threshold of fuel cell systems.

B. *Future Developments*

Telecom Italia, at the end of these field trials realized in collaboration with SGS future, will extend the project to an additional twenty sites in order to have a greater experience with the ReliOn fuel cell system. If the results continue to be positive, an additional increase of the installation is planned.