Presented at Intelec 2007, Rome, Italy. Will be published in IEEE 2007 Intelec Proceedings.

Site Reliability:
Fuel Cells Add Reliability to Telecom Sites

Joe Blanchard
ReliOn, Inc
Spokane, WA 99216 USA
jblanchard@relion-inc.com

***Abstract* - Communications, especially emergency communications, is about making sure the call goes through, no matter what. Recent natural disasters demonstrate the need to further improve reliability at communication sites. Backup power systems are a key component for continuity of service during disasters and emergencies. Additionally, the deployment of advanced communication systems and service has increased the importance of backup power systems. Network operators have multiple methods and technologies available to them to meet their backup power needs. These include VRLA and wet cell batteries and mechanical generators, but also include fuel cells. Proton Exchange Membrane (PEM) fuel cells are being deployed at an increasing number of communication sites to improve the overall reliability of the DC power system. Criteria for selecting a fuel cell backup system for a given site range from frequency or duration of outages, critical traffic, environmental restrictions, or even serviceability of current backup systems. In addressing these criteria, the added layer of protection provided by the fuel cell should be viewed as a complimentary solution instead of supplementary solution.**

1. INTRODUCTION

Communications, especially emergency communications, is about making sure the call goes through, no matter what.

Recent natural disasters are a dramatic demonstration of the need to further improve reliability at communication sites. Police departments and other emergency responders in many States and Countries are beginning to use commercial devices like cell phones and BlackBerry® units in their work and offer a day-to-day reason to harden sites against downtime. The stated downside of using these devices is that at times there is poor coverage and communications are unreliable from a public-safety perspective.[1] Backup power systems are a key component for continuity of service during disasters and emergencies.

According to a national U.S. survey commissioned by Emerson, power outages resulting in downtime are common. Forty-seven percent of survey respondents said their large businesses experienced a power outage that resulted in downtime in 2005. Of those, 44 percent were without power for at least 8 hours during the longest outage. Yet, more than 20 percent of large U.S. businesses have not budgeted to prepare for and maintain operations during natural disasters, according to the same study.[2]

Major network operators have taken a critical look at the power needs of their networks. In their own words, “Critical cell sites should be equipped with backup generators with a week’s worth of fuel, backup battery power, and monitoring 24 hours a day, seven days a week.”[3]

As a result of the report of the Katrina Panel, issued in June, 2006,[4] the U.S. Federal Communications Commission issued order FCC 07-107, requiring 24 hours backup for central office equipment and 8 hours for remote equipment, including cell sites, DLCs, and similar equipment. While the effective date of this Order has been extended until October 9, 2007, the importance of adequate reliable power and backup power continues to receive consumer, corporate and government attention.

As they implement their site hardening plans, network operators have multiple methods and technologies available to them to meet their backup power needs. These include VRLA and wet cell batteries and mechanical generators, but also include fuel cells. Proton Exchange Membrane (PEM) fuel cells are being deployed at an increasing number of communication sites to compliment existing technologies and improve the overall reliability of the DC power system and thus the continuity of service carried by the sites.

Criteria for selecting a fuel cell backup system for a given site ranges from frequency and duration of outages, critical traffic, environmental restrictions, or even serviceability of current backup systems. In addressing these criteria, the added layer of protection provided by the fuel cell should be viewed as a complimentary solution instead of supplementary solution. This concept is analogous to a layered network security architecture where each layer of security, e.g. firewalls, intrusion detection devices, etc., add to the overall network protection.

II. RELIABILITY AND AVAILABILITY DEFINITION

Reliability and availability are the lifeblood of the communications network. In a system containing hardware or hardware and software, there are known lifecycle phases where failure rates are distinctly different, as shown in Figure 1.

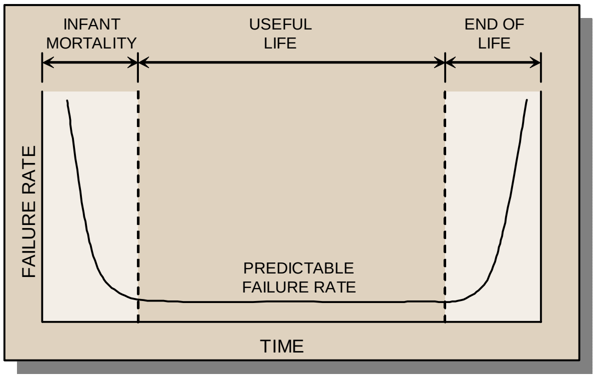

Figure 1: Lifecycle phases

The first phase is where defects or infant mortality show up and the last phase is where wear-out or end-of-life occurs. The middle phase, or useful life, is where the system has a predictable rate of failures over a unit of time (also known as FIT rate when calculated over a billion hours). The Mean Time Between Failures (MTBF) is the reciprocal of the failure rate and is typically expressed as time per failure during this useful life period of a product or system. For example, with an MTBF of 250,000 hours per failure and a population of 150 units in operation, you could expect a unit failure every approximately 1670 hours.

In some cases, reliability and availability are used interchangeably, but clearly do not represent the same information. Reliability, often expressed as MTBF, refers to a system performing its intended function as expected. Availability is the probability that a system will work at a given time. Availability is derived from MTBF and the Mean Time To Repair (MTTR). MTTR is an estimation of the time needed in order to get the system running after a failure.

Availability is essentially the percentage of time the system is operational. Availability is typically specified by using “nines”. A system with 5-nines availability is available 99.999% of the time. Another way of examining availability looks at how much downtime per year a system has. At 5-nines, a system is down just 5 minutes per year. At 4-nines, downtime increases to 52 minutes per year.

Availability can be calculated using the following formula (Figure 2):

$$\text{AVAILABILITY} = \frac{\text{MTBF}}{\text{MTBF + MTTR}}$$

Figure 2: Availability calculation

III. CALCULATING AVAILABILITY OF A SYSTEM

To calculate the availability of a specific system, one must consider whether the system components are operating in series or in parallel.

In a system operating in series[5], a failure in one part results in both parts becoming unavailable. An example of a series system is a single string of batteries where each cell is in series with the next, shown in Figure 3.

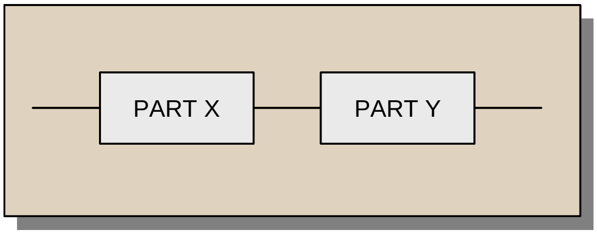

Figure 3: Series operation

System availability would be calculated as follows:

$$A_S = A_X * A_Y$$

In a system operating in parallel, the failure of one part leads to the second part taking over operations. The system as a whole remains available as long as one component is available. An example of a parallel system, Figure 4, is redundant controllers on an optical system where each controller can perform the full function of the other and only one controller is therefore needed.

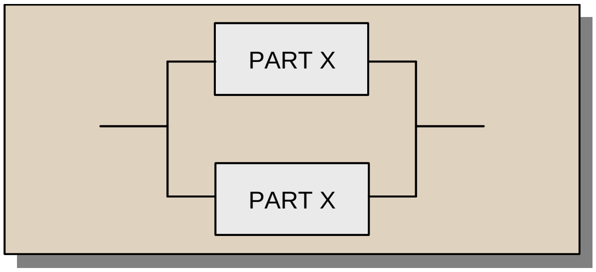

Figure 4: Parallel operation

System availability would, thus, be calculated as follows:

$$A_S = 1 - (1 - A_X)^2$$

A modern power system is made up of different combinations of series systems, parallel systems, as well as parallel or load sharing systems and even K-out-of-N systems and must therefore be modeled as complete system to reflect actual operation. An example of a K-out-of-N system, Figure 5, represents a grouping of components or sub-systems where some number K of the total N must work in order for the system to function.

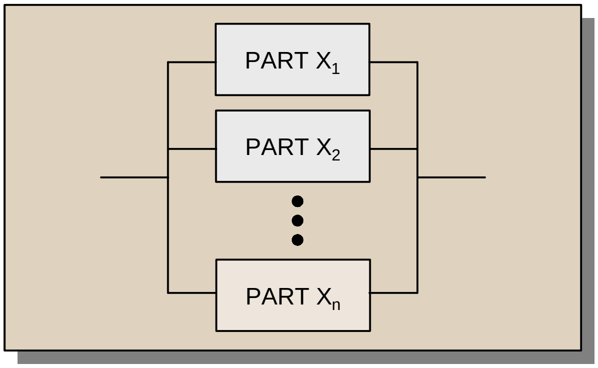

Figure 5: K out of N operation

System availability would, thus, be calculated as follows:

$$As(k,n,A)=\sum_{\gamma=k}^{n}\binom{n}{\gamma}A^{\gamma}(1-A)^{n-\gamma}$$

Where: n is the total number of units in parallel
k is the minimum number of needed units
A is the availability of each unit

IV. CHARACTERISTICS OF VARIOUS BACKUP POWER SOLUTIONS

A. Energy Storage

An energy storage device is generally defined as one which can be charged initially and repeatedly and which will deliver that stored charge as needed. Batteries are the best examples of energy storage units, with ratings defined in Amp-hours. Batteries are charged using electricity and can supply an output on demand, depending on the amp/hour rating of the battery. Energy storage technologies can be difficult to monitor in terms of power/runtime remaining. Batteries have been the traditional choice for short duration backup power support as these devices tended to be relatively inexpensive in terms of an initial cost of capital, but due to their requirements, particularly in outside plant applications, of frequent replacement, result in a higher lifecycle cost. The most common incumbent power storage device for low to medium-sized power systems and most outside plant applications is the valve regulated lead-acid (VRLA) battery.

Common modes of failure of VRLA batteries are opens, shorts and reduced capacity. VRLA failure mechanisms have been well documented at previous Intelec and other conferences.

B. Power Generation

Power generation refers to energy produced at the point of use. Generally speaking, these technologies convert a fuel, in the form of diesel, propane or natural gas, to electricity. The quantity of stored fuel dictates the length of runtime, though fuel may be replenished as needed for additional or extended runtime. Fuel can be difficult to obtain during or following a disaster event, due to increased need and decreased availability. The incumbent power generation device is the internal combustion engine generator set.

Common modes of failure for generators are failure to start, fuel supply, or electro-mechanical component failure. Engine generators also have relatively high ongoing maintenance costs and in some cases are limited on runtime due to air quality restrictions.

C. ReliOn Fuel Cell Backup Power Solutions

Proton Exchange Membrane (PEM) fuel cells generate electricity through an electrochemical reaction using hydrogen and oxygen. The benefits of fuel cells include their environmentally friendly operation. They generate energy without producing harmful emission by products – the only by products are water and heat – and without combustion, fuel cells are a quiet alternative for backup power. Runtime with a fuel cell is determined by the amount of fuel storage capacity at a site. A benefit to fuel cells is that, since the fuel is hydrogen, it tends to be more readily available than other, more widely used, types of fuel during a disaster situation. Based on technology available today, sites can be set up with up to 96 hours of runtime fuel, with replenishment more easily accomplished than with other generation technologies.

Though fuel cells have sometimes been referred to as a “future technology”, there are a handful of companies with commercial products, thousands of which have been installed into communications networks in the United States, Europe and worldwide. ReliOn is at the forefront of the companies supplying telecommunications customers with commercial fuel cell solutions. Reliability and successful performance of ReliOn fuel cell solutions has been verified operationally through hurricanes, ice storms, earthquakes and other weather events. Safety and performance also have been verified through compliance and certification programs including CE, UL, CSA, FCC, and NEBS Level 3.

As the communications industry drives or is driven for more network reliability and survivability, and seeks reliable and environmentally responsible options for backup power solutions, new technologies like PEM fuel cell systems offer advantages for increasing run-time and reliability. We can expect that future disruption of the power grid will happen. The question is whether network operators will choose technologies to protect the integrity of operation and performance of their communications networks.

Fuel cell availability may be calculated by means of two methods: mathematical and operational. Using Telcordia guidelines, ReliOn engineers have calculated the MTBF of ReliOn fuel cells at 22,000 hours. ReliOn fuel cells are designed with Modular Cartridge Technology® which cuts the repair time (MTTR) significantly over other fuel cell models, minutes in most cases compared to a full day or more for engine generators or other competing fuel cells. Additionally, the fuel cell system can be deployed as a load shared, k-out-of-n system further increasing the reliability and availability. For a ReliOn fuel cell, a repair to the system is accomplished by pulling and replacing a fuel cell cartridge or electronics card. Either of these can be accomplished in minutes using no tools. If we are conservative and estimate a 24 hour repair time, using the equation shown earlier, availability would be calculated at 99.89%. Using a 2 hour repair time, the value jumps to 99.991% availability.

In determining system performance, ReliOn has been able to use field data. Results of Telcom Italia testing of three sites was presented at Intelec 2006 showing 100% success over a span of 6 months and updates to that testing will be presented at Intelec 2007. Additionally, ReliOn has participated in test programs funded by the U.S. Department of Energy for a number of years. The test protocol called for one or more starts each day over a period of many months and involved several different test sites.

As seen in Table 1 below, by using a calculation of Availability = (Actual Run Time in Period)/(Scheduled Run Time in Period), ReliOn had much higher actual Availability numbers than the mathematical calculations projected for in four of five sites, 100%. When the data from all five sites was combined, the total Availability number was 99.796%.

Fuel Cell Site	Configuration	Total Requested Run Time July 2004 thru December 2005 (hours)	Total Run Time Accumulated July 2004 thru December 2005 (hours)	Total Attempted Starts	Total Actual Starts	Fuel Cell Availability	Fuel Cell Reliability
Ft. Lewis ILS 1	1 kW System	394.7	394.7	408	408	100.0%	100.0%
Ft. Lewis ILS 2	1 kW System	405.5	400.4	405	401	98.7%	99.0%
Ft. Lewis ILS 3	1 kW System	404.0	404.0	405	405	100.0%	100.0%
Ft. Lewis ILS 4	1 kW System	366.5	366.5	374	374	100.0%	100.0%
Gabreski ANGB Base Communications	4 kW System	367.0	367.0	377	377	100.0%	100.0%
			Demonstration Program Averages			**99.7%**	**99.8%**

Table 1: ReliOn U.S. Department of Energy program test data

V. IMPROVING SITE RELIABILITY & AVAILABILITY

A viable site-hardening plan would involve combining one or more incumbent technologies in parallel, increasing the availability of the site by providing a highly reliable “backup” to the backup power source. For instance, a site that would generally run off AC power and is already equipped with VRLA batteries connected to the DC bus in case of AC power failure would benefit from a fuel cell also connected to the DC bus to carry the site load and charge batteries when the batteries dip below a certain voltage at loss of AC power or in the event of a rectifier failure. The fuel cell minimizes the deep level of discharge on a battery string and allows the site to operate on backup power for much longer than on batteries alone.

The diagram below, Figure 6, shows a fault tree analysis of a generic backup power system showing major components from the grid to the load. The fuel cell provides another parallel DC solution to the battery and rectifier systems. Making some assumptions of reliability numbers for the three main components in the DC power plant that the batteries are at .95 for a k-out-of-n plant, the rectifier is at .999 for a k-out-of-n system, and the fuel cell is .999 for a k-out-of-n system. For a backup system, only one of the three systems has to work, and then the formula is a simple parallel system.

The calculation without the fuel cell is:

$$\begin{aligned} Rsystem &= 1-[(1-.95)x(1-.999)] \\ &= .99995 \end{aligned}$$

The calculation with the fuel cell is:

$$\begin{aligned} Rsystem &= 1-[(1-.95)x(1-.999)x(1-.999)] \\ &= .99999995 \end{aligned}$$

The addition of the fuel cell, in this model, added three additional “nines” of reliability to the DC power system. The specifics, e.g. A+B busses, number of parallel battery strings and the number of “k” of the k-out-of-n needed to carry the load, etc. of a power system design would ultimately dictate the reliability of a system. Many implementations by service providers are eliminating the IC generator since the fuel cells are proving reliable and not only backup in case of grid failure, but also rectifier or battery discharge events, but are environmentally more acceptable. In some cases the IC generators have been restricted due to noise or emissions and a fuel cell system is the only generator option to provide a reliable long runtime backup solution.

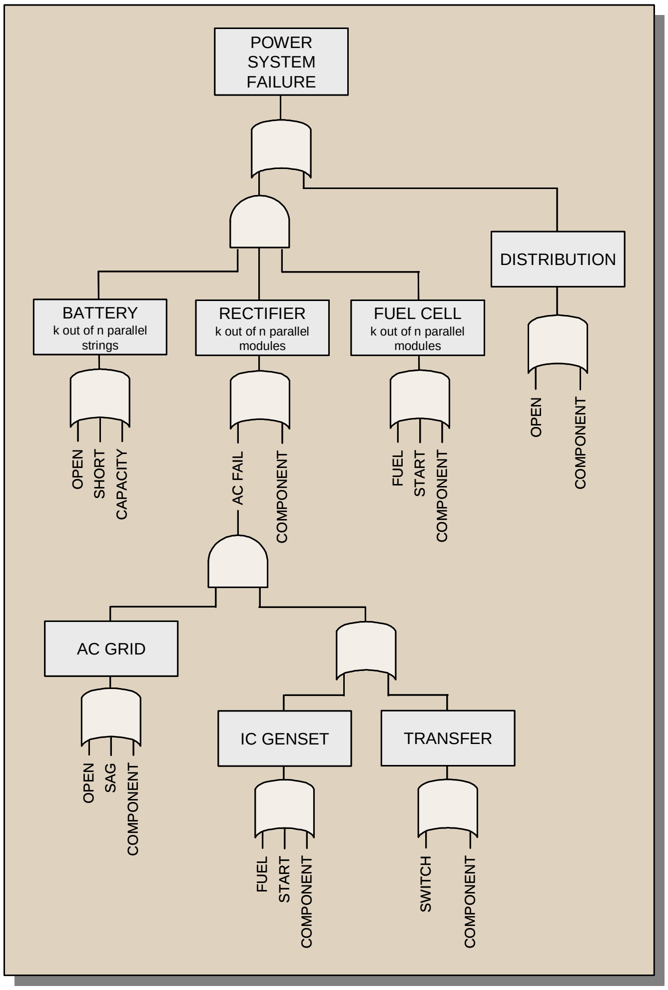

Figure 6: Fault tree analysis

VI. CONCLUSIONS FOR TELECOM SITES

The selection and deployment of backup power solutions at a telecom site will inevitably be a result of more than just the reliability of the solution or combination of solutions. Both capital (CAPEX) and operational (OPEX) expenses will certainly come into play as well. Commercial fuel cell solutions from ReliOn and other vendors are not only cost effective today, but offer the benefits of lower maintenance and positive environmental attributes.

Whether a communications provider increases its backup power capabilities at individual sites due to federal mandates or a desire for greater commercial success, the winners are the customers. The ability to get a call through to a 911 call center, a colleague or a loved one is the end means for judging success.

REFERENCES

[1] R. J. Hayling II, “Sold on Cell Phones,” in Mission Critical, May 2007.
[2] Emerson, 2006 Business Continuity Poll Summary.
[3] S. Black, Cingular Wireless, Mission Critical, November-December 2006.
[4] “Recommendations of the Independent Panel Reviewing the Impact of Hurricane Katrina on Communications Networks,” Federal Communications Commission, FCC 07-107, June 8, 2007.
[5] “System Reliability and Availability,” EventHelix.com.