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Reliability considerations of a fuel cell backup power system for telecom applications

Mustafa Fazil Serincan

Department of Mechanical Engineering, Istanbul Bilgi University, Kazım Karabekir Cad. No: 2/13, Eyup, 34060 Istanbul, Turkey

HIGHLIGHTS

- A fuel cell backup power unit is tested in real-world conditions at a GSM base station.
- Reliability of the fuel cell system is found to be 98.5% following 260 cycles.
- Inverter in the base station is redesigned to attenuate the current harmonics.
- Reliability of the system under fault conditions is studied.
- Sizing of system components is critical for an isolated operation during faults.

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ABSTRACT

A commercial fuel cell backup power unit is tested in real life operating conditions at a base station of a Turkish telecom operator. The fuel cell system responds to 256 of 260 electric power outages successfully, providing the required power to the base station. Reliability of the fuel cell backup power unit is found to be 98.5% at the system level. On the other hand, a qualitative reliability analysis at the component level is carried out. Implications of the power management algorithm on reliability is discussed. Moreover, integration of the backup power unit to the base station ecosystem is reviewed in the context of reliability. Impact of inverter design on the stability of the output power is outlined. Significant current harmonics are encountered when a generic inverter is used. However, ripples are attenuated significantly when a custom design inverter is used. Further, fault conditions are considered for real world case studies such as running out of hydrogen, a malfunction in the system, or an unprecedented operating scheme. Some design guidelines are suggested for hybridization of the backup power unit for an uninterrupted operation.

1. Introduction

Fuel cells have emerged as promising alternatives to conventional power generation technologies because of their high power and energy densities and environmental friendly operations. Contrary to these positive implications about fuel cells, economic maturity of the technology is far from being competitive to the conventional counterparts. Indeed, the commercialization progress is expected to be sluggish until the mass production of the fuel cell systems can be realized.

On the other hand, there are some sectors where fuel cells are shown to be commercially more feasible alternatives already, compared to the conventional technologies. Material handling and backup power applications can be given as examples to *early-markets* for fuel cell technology. As a matter of fact, fuel cell forklifts and fuel cell backup power generators have been increasingly used worldwide in commercial applications [1]. Fuel cell systems have been demonstrated as more viable business cases compared to alternative technologies such as diesel and battery power units [2–6]. Deployments of fuel cell backup power systems for telecom applications have been on the rise throughout the world [7–15]. While fuel cell technology has become cost competitive in early market applications recently, studies are still going on to improve system efficiency and reliability and reduce return of investment durations.

Reliability for telecom equipment is conventionally defined as "the ability of an item to perform a required function under given conditions for a given time interval" [16]. This definition can also be

E-mail addresses: fazil.serincan@engr.bilgi.edu.tr, mfserincan@gmail.com.

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interpreted as the probability of the system functioning as desired for a specified duration. However, it has been discussed that lumping the reliability concept to a single parameter may have limited practicality in telecom applications [17] and new metrics for reliability focusing on fault analysis have been proposed [18].

Reliability is a very important concept in the context of energy management of the base station. Alsharif et al. [19] discuss that one of the main drawbacks of diesel generators is the very low reliability of the technology when used as an energy source for an off-grid telecom base station. Kanzumba and Vermaak [20] report that diesel generators are responsible for 65% of the loss of telecom service due to failures of these devices. In this regards, fuel cell backup power units which have superior reliability compared to both diesel generators and batteries are more advantageous in telecom base stations.

Reliability is a main concern for the design and implementation of a hybrid fuel cell system. Sulaiman et al. [21] conclude that apart from the economical concerns, main issues and challenges in a fuel cell hybrid system are due to the peripheral system components; such as the battery lifetime, energy management system and power electronics interface. It is asserted that most of the research regarding validation of the energy management system has been limited to simulations while ensuring the reliability of the systems in real world applications is required.

In this regards, hybridization of a fuel cell system is of a key concern for a reliable and efficient operation [22–26]. Xhan et al. [27] proposed an energy management system for a hybrid UPS system which alternates operating modes between the fuel cell, the battery and the supercapacitors for a reliable power output. Li et al. [28] present a power sharing strategy for a fuel cell-battery-supercapacitors hybrid tramway in which the proposed system distributes the power demand to each source appropriately to guarantee a safe operation and extend the lifetime of each source. Xie et al. [29] developed an energy management algorithm for a hybrid powertrain which stabilizes the DC bus voltage via a fuzzy logic controller to protect the fuel cells and the batteries. The controller is also responsible for power distribution during a dynamic load cycle. Vasallo et al. [30] implemented an energy management strategy to determine the sizing of a hybrid UPS system for optimal power sharing between the fuel cell and the batteries. As stated earlier most of these studies are based on simulations while validation of power management system in real world applications and its influence on reliability is still of great interest.

On the other hand, integration of the fuel cell system to the ecosystem of the application is also very critical. Guilbert et al. [31] study the interaction between the fuel cell and DC/DC converter in case of a faulty operating scheme in an electric vehicle application. They address that malfunction in the system at open circuit not only increases the fuel cell current ripples but also induces stresses on the inductors. They emphasize on the selection of the DC/DC converter for a reliable and efficient operation. Fontes et al. [32] studied the effects of current harmonics on a fuel cell stack. They conclude that although a fuel cell stack can filter high frequency current harmonics due to its double layer capacitance, impact of this operating scheme on the durability of the fuel cell and the maximum RMS current that can be tolerated by the fuel cell stack need to be investigated in more detail.

Faults encountered during the operation may affect either the fuel cell system or the radio equipment in the base station or both. Hence malfunctions in the fuel cell system or unprecedented operating schemes have an imminent impact on the reliability. There have been a number studies recently focusing on the detection and isolation of the faults in hybrid fuel cell systems [33–41]. Most of these studies propose the use of sophisticated electronics designs and control techniques to minimize the effects of the faults on the operational reliability of the systems. While active fault prevention methods like these are proven to be effective, they require complex system architectures and indubitably exacerbate the economic feasibility of a commercial fuel cell system. Hence, passive fault isolation techniques would be much more desirable, while reliability concerns with them are yet to be addressed.

This study focuses on the reliability analysis of a commercial fuel cell backup power unit installed in a base station run by a Turkish GSM operator, Turkcell. Apart from a lumped system level approach, reliability of the fuel cell backup power unit is considered in real-life case studies; e.g. integration issues of the unit with the base station ecosystem, running out of hydrogen, and inadvertent interruption of the fuel cell operation by the site personnel. Unlike the controlled laboratory experiments, on-field tests present a unique environment for evaluating the reliability of the fuel cell backup power unit that endure a wide range of environmental conditions and unprecedented operating schemes, dynamic site loads and different levels of grid quality.

Operation of the backup power system is elucidated in the following sections. Load sharing between the fuel cell and the batteries is examined for various operating conditions. Effects of utilizing an inverter to generate alternative current are discussed in the context of integration of the fuel cell backup power unit to the existing base station ecosystem. Inverter design is found to be decisive to get a high quality and stable power output from the backup power unit.

Moreover, system responses are examined for separate cases when fuel cell exhibits a failure mode and recovers from a failure. Load sharing during a fuel cell failure is investigated to see how an uninterrupted system operation is sustained without any power loss. Finally, effects of hydrogen depletion on the system operation is discussed in a real-life case study for which the fuel cell is forced to respond to a power outage while the hydrogen in the tank is completely depleted.

2. System configurations and test setup

A fuel cell backup power system has been installed in a base station of Turkish mobile telecom operator Turkcell in Bursa. A schematic of the installation can be seen in Fig. 1. The fuel cell backup power unit is comprised of a fuel cell power module and a startup battery, which are connected in parallel. There is a boost converter after the fuel cell stack increasing the voltage to the nominal operating range of the base station. Fuel cell power module also includes peripheral equipment accounting for thermal management and hydrogen and air supply to the stack.

Main specifications of the tested backup power unit are given in Table 1. Rated power of the system is 6 kW at a nominal DC output voltage of −48 V while the typical load demand for the base station is about 1.5 kW. Also, the system is equipped with an inverter to provide the AC power to the air conditioner inside the base station cabinet during the grid failures. Note that negative potential is an industry standard in telecommunications. However, to avoid any confusion we have chosen to report positive voltage values in this study.

A low temperature PEM fuel cell stack is exploited in the backup power unit with an operating temperature around 60–65 °C. Heat generated during the backup operation is rejected from the fuel cell stack via liquid cooling. There is an external liquid to air heat exchanger connected to the backup power unit supplying cold water to the system.

Hydrogen consumption of the fuel cell is about 14 slpm kW^{-1} at the rated conditions while this value increases at the partial loads. Hydrogen is generated at the test site with an alkali electrolyzer