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Design of fuel cell powered data centers for sufficient reliability and availability

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HIGHLIGHTS

- Various fuel cell system configurations for a data center are identified.
- A generic system is analyzed to verify its ability to meet reliability minimums.
- Optimum component redundancies are calculated to ensure high reliability.
- A sufficiently reliable fuel cell system can be designed for use in a data center.

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ABSTRACT

It is challenging to design a sufficiently reliable fuel cell electrical system for use in data centers, which require 99.9999% uptime. Such a system could lower emissions and increase data center efficiency, but the reliability and availability of such a system must be analyzed and understood. Currently, extensive backup equipment is used to ensure electricity availability. The proposed design alternative uses multiple fuel cell systems each supporting a small number of servers to eliminate backup power equipment provided the fuel cell design has sufficient reliability and availability. Potential system designs are explored for the entire data center and for individual fuel cells. Reliability block diagram analysis of the fuel cell systems was accomplished to understand the reliability of the systems without repair or redundant technologies. From this analysis, it was apparent that redundant components would be necessary. A program was written in MATLAB to show that the desired system reliability could be achieved by a combination of parallel components, regardless of the number of additional components needed. Having shown that the desired reliability was achievable through some combination of components, a dynamic programming analysis was undertaken to assess the ideal allocation of parallel components.

1. Introduction

Surging Internet use and the growing dependence of business and computational sources on the Internet caused U.S. data center electricity demand to double from 2000 to 2006 [1]. The electricity use of data centers increased by 56% from 2005 to 2010 [2]. In 2008, they accounted for 69 billion kWh; this is approximately 2% of total US electricity use [2]. Data centers worldwide account for 2% of global CO_2 emissions; a number that is expected to increase [3].

Data centers house the information technology and telecommunications equipment necessary to provide Internet and cloud services, as well as data storage. Data center owners looking to lower energy use and emissions face the challenge of providing continuous power to highly sensitive computer equipment. In a traditional data center, electricity powers the continuously operating equipment required to provide Internet access, together with power standby and backup equipment designed to cope with electrical grid failures, and equipment to provide cooling to the electronics. These extensive backup systems, typically comprised of a large battery system and several large diesel engine power generators, ensure sufficiently reliable and available power for the data center's computer systems.

Fuel cells, specifically solid oxide fuel cells (SOFCs), present a promising solution for data center power. Like all fuel cells, SOFCs convert chemical energy from fuel, e.g., hydrogen or natural gas, directly to electricity through electrochemical reactions. SOFCs are reliable, efficient at almost any scale, modular, and produce ultra-low criteria pollutant emissions. Furthermore, generating electricity onsite and using DC electricity from the fuel cell could eliminate a large

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portion of the excess power conversion and inversion equipment in data centers.

To implement such a system, it is essential to show that SOFCs can provide the highly reliable electricity that data centers need to maintain sufficient server availability without the support of the traditional backup topology. It is the goal of this paper to determine if a sufficiently reliable SOFC system could be designed to meet data center requirements. This is accomplished through the reliability analysis of a simplified SOFC system. A preliminary analysis is accomplished to address two basic questions: is the desired three-9 (0.999) availability for an SOFC system attainable? And, under what conditions is this availability attainable? The goal of this project is not only to develop an SOFC system which can reliably power a data center, but also to facilitate a more sustainable design paradigm for data centers.

2. Background

2.1. Data centers

Anthropogenic greenhouse gas (carbon dioxide, methane, nitrous oxide, ozone, etc.) (GHG) emissions are the extremely likely cause of the increasing temperatures observed in the last three decades [4]. Information and communication technologies (ICT) have the potential to provide 655MtCO_2e of emissions reductions in the U.S., or a reduction equivalent to 7% of U.S. total GHG emissions for 2010 [3]. However, the emissions from ICT are expected to rise at a faster rate than overall global emissions and data centers are expected to have the fastest growing emissions rate of all the ICT sectors, increasing at a rate of 7% yearly [3]. Data center emissions are expected to double by 2020 [3]. Annual Internet traffic is expected to reach 1.6 zettabytes per year in 2018, in other words, more than 1 billion gigabytes per month [5]. As Internet use grows, data centers require more electricity, and account for more GHG emissions, it is necessary for them to make efficiency improvements and reduce their carbon footprint.

Traditional data centers get their electricity from power plants and require backup diesel generators and therefore also contribute to criteria pollutant emissions. Criteria pollutant emissions are air pollutants that are regulated on the basis of public health and welfare concerns [6]. It is important that data centers become powered by a technology that produces both low-CO_2 and low-criteria pollutant emissions.

Traditional data center power systems are expensive to build, operate, and maintain. The electrical grid provides 99.9% of electricity uptime in places where the utility grid network performs well and less than this in most places around the world. Data centers desire 99.999% uptime. To achieve the desired uptime when relying on grid electricity, the backup systems become complex. Fig. 1 shows the layout of a typical data center power system. In this system many backup power sources, such as batteries, uninterruptible power supplies (UPS), and diesel generators, are required to ensure sufficient server availability.

A data center which utilizes distributed generation, as opposed to the traditional architecture that relies on the electrical grid, has the potential to lower overall electrical losses. Due to inefficiencies in the electrical system and of the data centers themselves, 20% of the fuel energy input at a power plant makes it to powering a server and less than 1% makes it to doing useful work on that server [7]. A data center which operates on clean power generation sources, such as photovoltaics, wind, or fuel cells has the potential to lower its GHG and criteria pollutant emissions. Data centers which utilize clean generation sources in a central topology in parallel with the utility grid network have been built and studied [8,9]. However, these studies have not considered the removal of the extensive systems of redundant equipment that contribute to data center inefficiencies. The large array of redundant equipment is still necessary for data centers which utilize intermittent renewable energies such as wind or solar, in addition to the energy storage required to handle the intermittency of the wind and solar power. The distributed application of many individual fuel cell systems each powering a small number of servers could sufficiently reduce the failure domain to allow elimination of the redundant backup systems. While the reliability of fuel cell stacks has been studied, the reliability and availability of fuel cell systems has not been well studied.

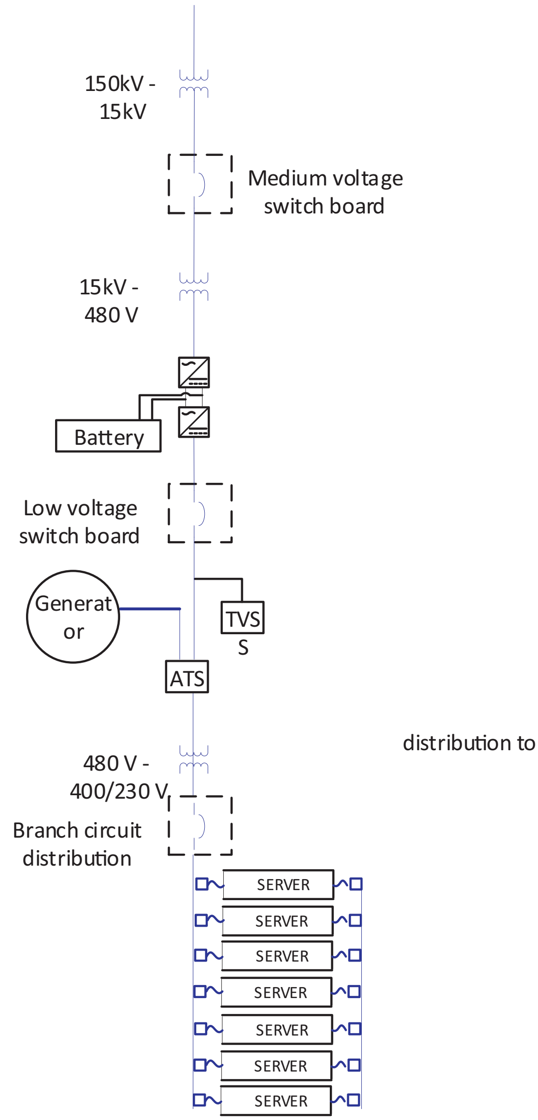

Fig. 1. Typical data center power architecture.

Solutions to high power consumption within data centers have been made around the traditional data center power structure described above where power from the electrical grid must be converted several times and which rely upon multiple back up power sources [13]. Many studies of solar, wind, or fuel cells build upon this central type arrangement with multiple back-up systems (e.g., batteries, diesel generators). These solutions have provided large improvements in data center power usage effectiveness, but they all rely on the same central arrangement that introduces many inefficiencies, and includes the high cost of very under-utilized back-up power systems. This study is concerned with investigating a new power providing configuration where the fuel cells might be placed throughout the data center in a distributed fashion allowing for individual servers or individual racks to be powered directly by a fuel cell without any back-up (since single servers can fail and be repaired without consequence to continuous data center operation). This architecture allows for a smaller space footprint for the data center, higher overall electrical efficiency, and a lower total cost of ownership (TCO) compared to both traditional data center arrangements and central fuel cell placements with back-up power

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