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Recent advances and challenges of fuel cell based power system architectures and control – A review

Vipin Das[a], Sanjeevikumar Padmanaban[b,*], Karthikeyan Venkitusamy[a], Rajasekar Selvamuthukumaran[c], Frede Blaabjerg[d], Pierluigi Siano[e]

[a] Department of Electrical Engineering, MNNIT, Allahabad 211002, India
[b] Department of Electrical and Electronics Engineering, University of Johannesburg, Auckland Park, Johannesburg, South Africa
[c] Technology Development Department, Power Grid Corporation of India Limited, Gurgaon 122001, India
[d] Center for Reliable Power Electronics (CORPE), Department of Energy Technology, Aalborg University, Pontoppidanstraede 101, 9220 Aalborg, Denmark
[e] Department of Industrial Engineering, University of Salerno, Via Giovanni Paolo II, 132 - 84084 Fisciano, Salerno, Italy

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ABSTRACT

Renewable energy generation is rapidly growing in the power sector industry and widely used for two categories: grid connected and standalone system. This paper gives the insights about fuel cell operation and application of various power electronics systems. The fuel cell voltage decreases bit by bit with expansion in current because of losses associated with fuel cell. It is difficult in handling large rated fuel cell based power system without regulating mechanism. The issue connected with fuel based structural planning and the arrangements are widely investigated for all sorts of utilization. In order to improve the reliability of fuel cell based power system, the integration of energy storage system and advanced research methods are focused in this paper. The control algorithms of power architecture for the couple of well-known applications are discussed. Additionally, the paper addresses the suitable processor utilized as a part of the energy unit application on the premise of fuel cell characteristics. In this paper, the challenges to improve the dynamics of controller in fuel cell based applications are mentioned.

1. Introduction

The price of fossil fuel is increasing step by step because of absence of accessibility. The power system industries are restructuring to renewable energy based power generation as an alternate solution. By considering environmental factors, the fuel cell based energy generation is a most suitable renewable system than solar and wind energy system [1]. Recently, fuel cells are rapidly developed and commercially available with high, medium and low power range applications. In order to reduce the cost of fuel cell, researchers have been focused to improve the reliability and efficiency of the fuel cell based power system [2]. The analysis report shows that the fuel cell market is increasing every year [3].

The first fuel cell was accidentally invented in 1839 by Sir William Robert Grove, however, no down to earth's utilization was found for one more century [2]. General Electric Company (GE) started creating fuel cell in the 1950s and was granted the agreement for the Gemini space mission in 1962. The 1 kW Gemini energy unit framework had a platinum stacking of 35 mg Pt/cm^2 and execution of 37 mA/cm^2 at 0.78 V [3]. In the 1960s enhancements were made by joining Teflon in the impetus layer specifically contiguous the electrolyte, as was finished with the GE fuel cell unit at the time. Extensive upgrades were made from the mid-1970s, forward to the reception of the completely fluorinated Nafion layer.

The department of energy (DOE) and national energy technology laboratory (NETL) are mainly concentrated on developing fuel cell based power plants for standalone and grid connected applications [4].

The overall commercialization of fuel cell has not yet come. The two biggest obstructions for commercialization is life time and expense [5]. The lifetime needed by a commercial fuel cell is more than 5000 working hours for light-weight vehicles and more than 40,000 working hours of stationary power with not as much as a 10% decay [6,7]. At present, most power devices display real execution rot after around a thousand hours of operation [8,9]. The DOE targets are to accomplish an existence time of 40,000 h by 2011 with 40% effectiveness for distributed power and 5000-h life by 2015 to 60% efficiency for transportation.

Fuel cell technology has many advantages as compared with the

* Corresponding author.
E-mail address: sanjeevi_12@yahoo.co.in (S. Padmanaban).

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Table 1
Comparison of Fuel cell/wind/solar.

Technology	Capacity factor (%)	Life (year)	Payback (Year)	CO_2 Emission reduction (kg)
Fuel cell	95	20	7.9	979,526
Wind	17.5	25	36.5	268,175
Solar	25.8	20	8	539,954

other conventional renewable energy sources. Table 1 shows the comparison of fuel cell technology with wind and solar technology.

From the Table 1 it is clear that fuel cell based power system has an upper hand over other renewable energy technology.

Many literatures are available in the field of fuel cell, operation and applications. A comprehensive review about the fuel cell technologies, applications and challenges are mentioned in [10–15]. Power generation is one of the major fields of application of fuel cell. The major challenges and opportunities of fuel cell in the power generation area is detailed in [16]. Since the fuel cell voltage is very low, it required power electronic interfacing to boost up the voltage. Many power electronics converters have been developed particularly for the fuel cell applications. [17] gives clear idea about the power electronic interface and their challenges in the fuel cell area. The challenges associated with power management in fuel cell power generation applications and electric vehicles are explained in [18,19]. Power electronics converter with adaptive controllers and energy storage systems are the best remedy for power management system in the fuel cell. A strategy to manage power in hybrid power system is explained in [19]. The control strategy mentioned in [19] can be improved by considering power quality while managing the real power.

The paper provides an overview of the current status, applications and advancements in fuel cells. A number of literatures are available in the field of fuel cells. The main issues which are not mentioned in the existing literature are addressed in this paper. Some major field of fuel cell applications, application of power electronic converters and their control are discussed in detail. The major challenges and remedies are also mentioned as a matter of interest.

A detailed survey of the fuel cell based converters has been presented in this paper. The fuel cell technology and different types of fuel cells are organized in Section 2. In Section 3 recent researches in fuel cells and the major applications of fuel cells are discussed. In Section 4 the challenges associated with the fuel cell and its remedies are explained with the help of recent literatures. In Section 5 the fuel cell based power system and in Section 6 different controllers used for fuel cell power system are discussed and finally the paper is concluded by Section 7.

2. An overview and types of fuel cells

Fuel cells are static devices, which converts chemical energy of Hydrogen and Oxygen directly into electrical energy through an electro-chemical reaction. The fuel cell will generate electrical energy as long as the fuel is supplied to the system, i.e., it can produce electricity without recharging unlike battery.

2.1. Fuel cell operation

The working principle of the fuel cell is simple, however, it has complicated design. Fuel cell essentially comprises of cathodes, electrolyte and fuel. The positive and negative terminals are known as cathode and anode, respectively. These are two terminals are contacted with the electrolyte inside and external electric circuit. The fuel is continuously fed to the anode while oxidant supplied to cathode. Generally, the fuel is pure hydrogen or contains some hydrogen gases like methanol, ethanol and natural gases. The oxidants are pure oxygen or contains oxygen gases like air or halogens like chlorine [20–22].

In most of the cases, the combustion of Hydrogen and oxygen produces the water and it will split into two electrochemical reactions at the electrode independently, which are termed as two cell reaction. The basic reaction taking place in a fuel cell is given in Eqs. (1)–(3).

At anode,

$$H_2 \rightarrow 2H^+ + 2e^- \quad (1)$$

At cathode,

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

Overall reaction,

$$H_2 + 1/2O_2 \rightarrow H_2O \quad (3)$$

The ions (H^+) and electrons (e^-) are produced by H_2 due to anode reaction. The H^+ moves towards cathode directly and e^-moves to cathode via load (external circuit). Finally, H^+ and e^- combines with O_2 and produces water, which is the added advantage of fuel cell [23]. Fig. 1 shows the schematic of fuel cell.

2.2. Types of fuel cell

Fuel cells are mainly classified according to the electrolyte and types of fuel used. The main categories of fuel cells available in the market are explained below.

2.2.1. Proton Exchange Membrane Fuel Cells (PEMFC)

Acid polymer is used as the electrolyte and pure hydrogen is used as fuel. The operating temperature of the PEMFC is below 100°C. Now a day, this fuel cell is popular and widely used in vehicle application.

2.2.2. Direct Methanol Fuel Cell (DMFC)

In DMFC, the polymer membrane used as an electrolyte, and the fuel used is methanol. The operating temperature of DMFC is below 60 °C and it is mainly used for portable power applications below 259 W.

2.2.3. Phosphoric Acid Fuel Cell (PAFC)

In PAFC, The liquid phosphoric acid is used as the electrolyte and pure hydrogen is used as the fuel. The operating temperature is around 180 °C. These types of fuel cell are particularly used as stationary power generators and which is not efficient electrically.

2.2.4. Alkaline Fuel Cell (AFC)

Here, alkaline solutions are used as electrolyte of fuel cell and pure

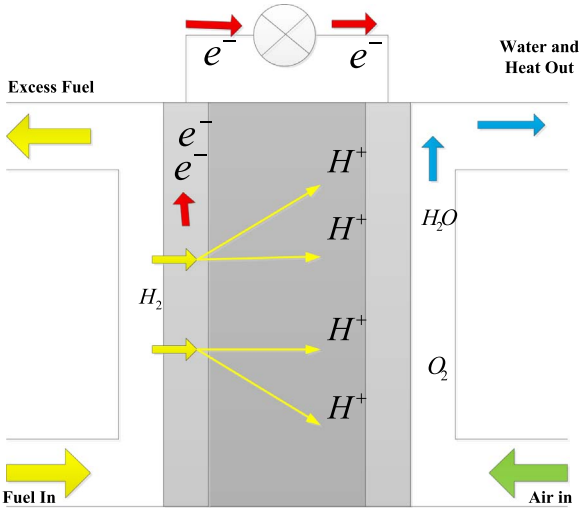

Fig. 1. Schematic of fuel cell.