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A Review Article of Solid Oxide Fuel Cell Connected To Three Phase Electrical Power System

M.Tech. Scholar Dinesh Kumar Sahu, Asst. Prof. Durgesh Vishwakarma
Dept. of Electrical and Electronics Engineering
Radharaman Engineering College (Rec) Ratibad Bhopal

Abstract – **The energy crisis is one of the most critical phenomena happening in today's world. The depletion of fossil fuels, the rise in oil prices, and the increase in power demand are the main causes of this problem. Concern over environmental conditions and human health make renewable energy one of the most viable alternative solutions to this crisis. Among various types of renewable energy, fuel cell technology shows a great potential in the electrical energy sector for several reasons, such as high efficiency, clean operation, and immunity to the adverse effects of weather conditions. Recent works prove that fuel cell technology is expected to be a better choice for distributed generation purposes. Distributed generation, which is installed near load centers, can moderate the stress of high electricity demand in the mainstream utility grid. This paper presents an overview of fuel cell technology, with emphasis on fuel cell types, characteristics, and applications. The differences among the various fuel cell types and the dynamic models of each type required for simulation are also discussed.**

Keywords– **Fuel Cell Vehicle, Hydrogen, Vehicle-to-Grid, Power Generation Plant, LCOE.**

I. INTRODUCTION

Distributed generation is referred in general to small generators, starting from a few kW up to 10 MW, whether connected to the utility grid or used as stand-alone at an isolated site. Normally small DGs, in the 5-250 kW range serve households to large buildings (either in isolated or grid-connected configuration). DG technologies can be categorized to renewable and nonrenewable DGs.

Renewable energy technologies are in general sustainable (i.e., their energy source will not run out) and cause little or no environmental damage; they include: Solar photovoltaic, Solar thermal, Wind, Geothermal, Tidal, Low-head (small) hydro, Biomass and biogas and Hydrogen fuel cells (hydrogen generated from renewable resources). Nonrenewable energy technologies are referred to those that use some type of fossil fuel such as gasoline, diesel, oil, propane, methane, natural gas, or coal as their energy source.

Fossil fuel-based DGs are not considered sustainable power generation sources as their energy source will not renew. They include: Internal combustion engine (ICE), Combustion turbine, Gas turbine, Micro turbine and Fuel cells (using some type of fossil fuel, e.g. natural gas to generate hydrogen). Both types of DGs (renewable and nonrenewable) are popular and widely used around the world. The downside of renewable resource DGs is the intermittent nature of their renewable energy source; and the disadvantage of fossil fuel-based DGs is that they generate environmentally polluting, and in some cases poisonous exhaust gases, such as SO2 and NOx, which are similar to the pollutants from conventional centralized power plants. However, considering the increasing need for electricity, the benefits of the nonrenewable DG technologies with low emission of polluting gasses exceed their disadvantages and are expected to be used in the foreseeable future[1-8].

Fuel cell technology can belong to either of the above categories. If the hydrogen fuel needed to power the fuel cell is generated from a renewable source, the fuel cell power generating unit is considered a renewable energy technology. i.e., wind and solar energy used to generate hydrogen to fuel a fuel cell stack. On the contrary, if hydrogen is produced from a fossil fuel source (e.g., natural gas or methane), the fuel cell is considered a nonrenewable energy technology. Through careful design, selected fossil fuel driven DGs can be built to oxidize some of the fossil fuel (by combining with oxygen) to produce heat.

Such operation modes, whether in electromechanical (rotational) or electrochemical (fuel cell) systems, are referred to as combined heat and power (CHP) operation mode. Most of the new DG technologies include power electronic devices to provide usable output power. These DGs are often referred to as power electronically interfaced DGs. Enormously improved power control of these generation sources has become possible by controlling their power electronic interfacing units. In a common approach the output voltage of these generation devices whether dc or ac is converted to a controlled output voltage.

II. BASIC OF FUEL CELL

The first references to hydrogen fuel cells appeared in 1838. In a letter dated October 1838 but published in the December 1838 edition of The London and Edinburgh Philosophical Magazine and Journal of Science, Welsh physicist and barrister William Grove wrote about the development of his first crude fuel cells. He used a combination of sheet iron, copper and porcelain plates, and a solution of sulphate of copper and dilute acid.[4][5] In a letter to the same publication written in December 1838 but published in June 1839, German physicist Christian discussed the first crude fuel cell that he had invented. His letter discussed current generated from hydrogen and oxygen dissolved in water.[6] Grove later sketched his design, in 1842, in the same journal. The fuel cell he made used similar materials to today's phosphoric-acid fuel cell.

In 1939, British engineer Francis Thomas Bacon successfully developed a 5 kW stationary fuel cell. In 1955, W. Thomas Grubb, a chemist working for the General Electric Company (GE), further modified the original fuel cell design by using a sulphonated polystyrene ion-exchange membrane as the electrolyte. Three years later another GE chemist, Leonard Niedrach, devised a way of depositing platinum onto the membrane, which served as catalyst for the necessary hydrogen oxidation and oxygen reduction reactions. This became known as the "Grubb-Niedrach fuel cell". GE went on to develop this technology with NASA and McDonnell Aircraft, leading to its use during Project. This was the first commercial use of a fuel cell.

In 1959, a team led by Harry Ihrig built a 15 kW fuel cell tractor for Allis-Chalmers, which was demonstrated across the U.S. at state fairs. This system used potassium hydroxide as the electrolyte and compressed hydrogen and oxygen as the reactants. Later in 1959, Bacon and his colleagues demonstrated a practical five-kilowatt unit capable of powering a welding machine. In the 1960s, Pratt and Whitney licensed Bacon's U.S. patents for use in the U.S. space program to supply electricity and drinking water (hydrogen and oxygen being readily available from the spacecraft tanks).

In 1991, the first hydrogen fuel cell automobile was developed by Roger Billings. UTC Power was the first company to manufacture and commercialize a large, stationary fuel cell system for use as a co-generation power plant in hospitals, universities and large office buildings.

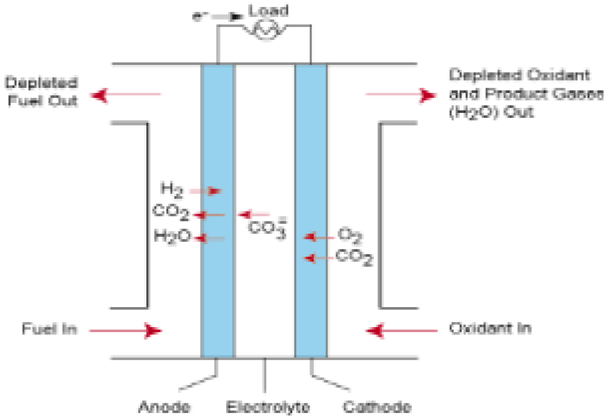

Fig.1. Fuel cell Internal Structure.

In recognition of the fuel cell industry and America’s role in fuel cell development, the US Senate recognized October 8, 2015 as National Hydrogen and Fuel Cell Day, passing S. RES 217. The date was chosen in recognition of the atomic weight of hydrogen (1.008).

III. LITERATURE REVIWE

Y. RajuBabu: Electrification of daily life causes growing electricity consumption; rising number of sensitive/critical loads demand for high-quality electricity, the energy efficiency of the grid is desired to be improved1,2. The outputs from the fuel cells are obtained by electrochemical reaction between H2 and oxygen. Generally, the fuel cell stacks are obtained by series connection of several individual fuel cells, which are equivalent to series connection of general voltage sources, with its internal impedance.

This paper compared with different types of dc–dc converters and dc–ac inverters, including voltage source and current source, e.g., a boost converter followed by a voltage source based inverter, single-stage current source based inverter, and z-source inverter. Specifically, CSI and z-source inverters provide boost and inverter functions in a only one and a wide input voltage range, while limited input voltage lower than the peak grid voltage and insufficient voltage gain are considered. In three-phase boost-inverter topology was proposed including sliding mode control technique and small signal analysis.

Inderjeet Singh: Dynamic modeling of solid-oxide fuel cell with three phase inverter has been performed to analyze its load behavior as distributed generator in a grid connected power system. The response of the system to step changes in load demand are presented along with the analysis of the simulated results. It has been observed that the fluctuations in the output voltages in the power system due to load variations are taken care of by the SOFC very closely. An efficient dynamic model of Solid Oxide Fuel Cell has also been developed which can supply active power maintaining inverter voltage as desired.

The combined system reduces the cost of power generation as well as the level of pollution reducing the fuel consumption enables comprehensive quantitative and qualitative analysis N. Prema Kumar The type and chemical properties of the electrolyte used in fuel cells determine their operating characteristics and internal operating temperature. The polarity of an ion and its transport direction can differ for different fuel cells, determining the site of water production and removal. If the working ion is positive, like, then water is produced at the cathode. On the contrary, if the working ion is negative, like in solid oxide fuel cell and molten carbonate fuel cell, water is formed at the anode. In both cases electrons pass through an external circuit and produce electric current. An individual fuel cell produces less than a volt of electric potential. A large number of cells are stacked on top of each other and connected in series (with bipolar connects) to produce higher voltages. Figure shows cell stacks which consists of repeating units, each comprising an anode, cathode, electrolyte and a bipolar separator plate. The number of cells depends on the desired power output.

Jin Woo Jung: This dissertation presents circuit models and control algorithms of fuel cell based distributed generation systems (DGS) for two DGS topologies. In the first topology, eachDGS unit utilizes a battery in parallel to the fuel cell in a standalone AC power plant and a grid-interconnection. In the second topology, a Z-source converter, which employs both the L and C passive components and shoot-through zero vectors instead of the conventional DC/DC boost power converter in order to step up the DC-link voltage, is adopted for a standalone AC power supply. In Topology 1, two applications are studied: a standalone power generation (Single DGS Unit and Two DGS Units) and a grid-interconnection. First, dynamic model of the fuel cell is given based on electrochemical process. Second, two full-bridge DC to DC converters are adopted and their controllers are designed: an unidirectional full bridge DC to DC boost converter for the fuel cell and a bidirectional full-bridge DC to DC buck/boost converter for the battery. Third, for a three-phase DC to AC inverter without or with a Δ/Y transformer, a discrete-time state space circuit model is given and two discrete-time feedback controllers are designed: voltage controller in the outer loop and current controller in the inner loop.

Professor Donald G. Kasten: This dissertation studies the circuit models and control strategies for twotopologies of the fuel cell powered distributed generation systems. In Topology 1, each DGS unit positions the battery in parallel to the fuel cell for a standalone AC power plantAnd a grid-interconnection. In Topology 2, a Z-source converter, which uses L and C components and shoot-through zero vectors without a DC to DC power converter to boost the DC-link bus voltage, is adopted for a standalone AC power generation. In the first topology, two applications are presented: a standalone power system (a single DGS unit and two DGS units) and a grid-interconnection. First, dynamic model of the fuel cell with a voltage-current polarization curve of the stack is given based on electrochemical process. Second, controllers of two full-bridge DC to DC converters are designed: a unidirectional full-bridge DC to DC boost converter for the fuel cell and a bidirectional full-bridge DC to DC boost/buck converter for the battery.

IV. METHODOLOGY OF FUEL CELL PLANT

The main objective of this paper is to propose a 3-phase FC stand-alone power supply having only single energy conversion converter along with a back-up unit is shown in Figure 1. The cost of this proposed system is reduced by making the multi stage conversion system with a single stage system, i.e. boost-inverter due to this the switching losses and conduction losses are also reduced.

Generally, the diagram shown in Figure 1 shows that boost converter is followed by the Fuel Cell and the back-up energy storage system, these two converters are connected at the same bus and output from the boost inverter is a three phase AC and it is connected to three phase balanced star connected resistive load4. The Fuel Cell system has operated in current mode controlled bidirectional converter for battery converter to support the Fuel Cell.

In this proposed concept the 3-ø boost inverter is separated to three individual converters for three phase arms and connected to three individual balanced loads, as shown in Figure 5.1. The dc-biased three phase output voltages are described by In the above equation Ao is the peak amplitude of line-to-neutral voltage and Vdc is dc voltage across each converter which is greater than Ao + Vin. In this boost converter generates ac output voltage with dc bias, so that the output voltage generated from the boost converter is greater than the input voltage from the fuel cell and have equal magnitude the dc components are canceled5.
Three-phase three-wire balanced output and the expression for line to line voltages are,

A stand-alone 3-ø Fuel Cell power supply based boost converter along with a battery energy storage system has been successfully proposed. With these Simulation results the operational characteristics of FCBI has been understand. The results of the proposed 3-ø FC supply have confirmed its satisfactory performance in delivering boosting and inversion functions in one conversion stage to generate 210 Vac at rated power. The back-up unit key function is to support the slow variations of the Fuel Cell. Finally, the efficiency of this proposed boost inverter fuel cell system is improved with its single stage conversion process and from economical point of view it is better than all other conventional converters. It is in compact size because of usage of less number of switching devices.

V. EXPECTED FUEL SYSTEM PARAMETER

Fuel cells are also well used for distributed generation applications, and can essentially be described as batteries which never become discharged as long as hydrogen and oxygen are continuously provided. The hydrogen can be supplied directly, or indirectly produced by reformer from fuels such as natural gas, alcohols, or gasoline. Each unit ranges in size from 1-250 kW or larger MW size. Even if they offer high efficiency and low emissions, today's costs are high. Phosphoric acid fuel cell is commercially available in the range of the 200 kW, while solid oxide and molten carbonate fuel cells are in a pre-commercial stage of development. The possibility of using gasoline as a fuel for cells has resulted in a major development effort by the automotive companies. The recent research work about the fuel cells is focused towards the polymer electrolyte membrane (PEM) fuel cells. Fuel cells in sizes greater than 200 kW, hold promise beyond 2005, but residential size fuel cells are unlikely to have any significant market impact any time soon.

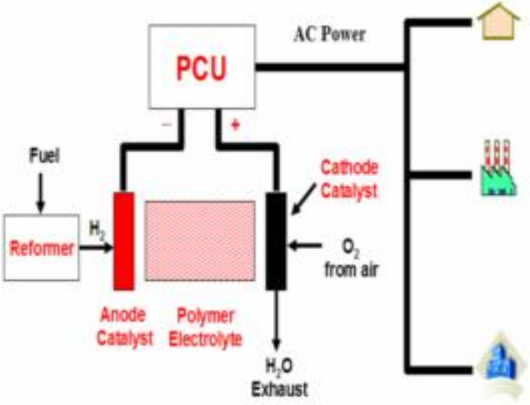

Fig.2. Block diagram of fuel cell system.

Features:

- Size: 1 kW – 10 MW
- Efficiency: electricity (30 – 60%), cogeneration (80 – 90%)
- Installed cost ($/kW): 1,000 – 5,000
- O&M cost ($/kWh): 0.0019 – 0.0153
- Fuel: natural gas, hydrogen, propane, diesel
- Emission: very low
- Cogeneration: yes (hot water, LP or HP steam)
- Commercial Status:
- PAFC: commercially available
- SOFC, MCFC, PEMFC: available in 2004

Applications:

- PAFC: medical, industrial, schools, commercial utilities, utility power plants,
- waste water treatment plants
- SOFC: residential cogeneration, small commercial buildings, industrial facilities
- MCFC: industrial, government facilities, universities, hospitals
- PEMFC:
- Automotive
- Residential (< 10kW), both with and without cogeneration
- Commercial (10 – 250kW), both with and without cogeneration
- Light industrial (< 250kW), both with and without cogeneration
- Portable power (< several kW)

Advantages:

- PAFC: quiet, low emissions, high efficiency, proven reliability
- SOFC and MCFC: quiet, low emissions, high efficiency
- PEMFC: quiet, low emissions, high efficiency, synergy with automotive.

VI. CONCLUSIONS

Hydrogen and fuel cell technology have advanced considerably over the last fifteen years. At the global level, this area continues to face significant challenges—technical, commercial and infrastructure-related—that need to be overcome before fuel cells can realize the full potential of which they are capable. Policy makers have included hydrogen and fuel cell on the map of future energy strategies and have already taken into account the fact that fuel cells have great real potential and can successfully meet the technical, social, economic and environmental objectives in the context of the multidisciplinary concept of sustainable development. In this paper, the review of literature and agencies' reports on specialized metrics in the domain of the hydrogen fuel cell technologies highlights the essential considerations regarding stationary applications, as follows:

More than 850 MW of large stationary fuel cell systems with a (> 200 kw) nominal power have been installed worldwide for power generation and CHP applications up until 2018. • Worldwide, the use of three types of fuel cell technologies is prevalent: MCFC, SOFC and PAFC.
AFC and PEMFC are relatively new technologies under development and implementation within stationary applications.
The main modalities of integrating hydrogen fuel cell technology into stationary applications are in the form of CHP units with fuel cells for small individual residential buildings, back-up power systems and large capacity electric power stations or distributed generation systems.
The key factors that influencing development include: energy and climate policies, fuel cell funding programmes, concurrent technologies, the attendance of fuel cell system producers and energy costs.

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