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A Review Article of Improvement of Solid Oxide Fuel Power Plant Efficiency Using Power System Topology

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Abstract- **Fuel cell technology is a relatively new energy-saving technology that has the potential to compete with the conventional existing generation facilities. Among the various Distributed Generation or onsite generation or localized generation technologies available, fuel cells are being considered as a potential source of electricity because they have no geographic limitations and can be placed anywhere on a distribution system. Fuel cells have numerous benefits which make them superior compared to the other technologies. The integration of the fuel cell system is to provide the continuous power supply to the load as per the demand. In this paper, design and modeling of Solid Oxide Fuel cell (SOFC) is discussed for the distributed generation applications. Modeling and simulations are carried out in MATLAB Simulink platform. Solid oxide fuel cells operate at temperatures near these are highly efficient combined heat and electric power. Modeling of SOFC is done by using by using Nernst equation. In that the output power of the fuel cell can be controlled by controlling the flow rate of the fuels used in the process.**

Keyword- Fuel Cell, SOFC, Distributed Generator, DC-DC converter, Simulink.

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.

II. SOLID OXIDE FUEL CELLS

Solid oxide fuel cells are a class of fuel cells characterized by the use of a solid oxide material as the electrolyte. SOFCs use a solid oxide electrolyte to conduct negative oxygen ions from the cathode to the anode. The electrochemical oxidation of the oxygen ions with hydrogen or carbon monoxide thus occurs on the anode side. More recently, proton-conducting SOFCs (PC-SOFC) are being developed which transport protons instead of oxygen ions through the electrolyte with the advantage of being able to be run at lower temperatures than traditional SOFCs.

They operate at very high temperatures, typically between 500 and 1,000 °C. At these temperatures, SOFCs do not require expensive platinum catalyst material, as is currently necessary for lower temperature fuel cells such as PEMFCs, and are not vulnerable to carbon monoxide catalyst poisoning. However, vulnerability to sulfur poisoning has been widely observed and the sulfur must be removed before entering the cell through the use of adsorbent beds or other means.

Solid oxide fuel cells have a wide variety of applications, from use as auxiliary power units in vehicles to stationary power generation with outputs from 100 W to 2 MW. In 2009, Australian company, Ceramic Fuel Cells successfully achieved an efficiency of an SOFC device up to the previously theoretical mark of 60%.[2][3] The higher operating temperature make SOFCs suitable candidates for application with heat engine energy recovery devices or combined heat and power, which further increases overall fuel efficiency.

III. LITERATURE REVIWE

Fuel cells based DG system is considered an alternative to centralized power plants due to their nonpolluting nature, high efficiency, flexible modular structure, safety and reliability. At present, they are under extensive research investigation as the power source of the future, due to their characteristics. A fuel cell converts chemical energy directly to electrical energy through an electrochemical process. As opposed to a conventional storage cell, it can work as long as the fuel is supplied to it. There are many motivations in developing this method of energy generation and it needs further development to have a realistic system analysis combining various subsystems and component.

Y. Raju Babu 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.

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, each DGS 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.

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 plant And 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.

O. S. Popel', A. B. Tarasenko & S. P. Filippov, "Fuel Cell Based Power-Generating Installations: State of the Art and Future Prospects"Specific features of power-generating installations constructed using different types of fuel cells are considered. Problems and trends of their development in Russia and abroad are analyzed. Fuel cell commercialization lines, their application niches, and the most well-known projects of constructing and exploiting fuel cell-based power-generating installations are described. Special attention is paid to analyzing the specific features pertinent to the domestic market of fuel cells and prospects of different lines of their application taking into account competition from other energy sources. Conclusions about the most topical development lines of the considered technologies under the conditions of Russia are drawn with due regard to the available groundwork as well as technical and economic aspects. It is pointed out that the main application field of fuel cells in Russia may be distributed generation of electricity, including off-grid supply of power to consumers on the basis of network and liquefied natural gas, liquefied hydrocarbon gases, and also renewable energy sources. In this regard, installations involving combined generation of electricity and heat, including small ones with a capacity of a few tens or hundreds of kilowatts, are of special interest. Prospective market niches for using fuel cells may include pipeline cathodic protection stations, utilization of biogas obtained, e.g., in reprocessing domestic waste, emergency and uninterruptible power supply systems, propulsion power installations of air drones, auxiliary power installations with a capacity of 1–3 kW, and utilization of hydrogen rejected from chemical production facilities.

R.J.Braun, S.A.Klein, D.T.Reindl, "Evaluation of system configurations for solid oxide fuel cell-based micro-combined heat and power generators in residential applications"The evaluation of solid oxide fuel cell (SOFC) combined heat and power (CHP) system configurations for application in residential dwellings is explored through modeling and simulation of cell-stacks including the balance-of-plant equipment. Five different SOFC system designs are evaluated in terms of their energetic performance and suitability for meeting residential thermal-to-electric ratios. Effective system concepts and key performance parameters are identified. The SOFC stack performance is based on anode-supported planar geometry. A cell model is scaled-up to predict voltage–current performance characteristics when served with either hydrogen or methane fuel gas sources. System comparisons for both fuel types are made in terms of first and second law efficiencies.

Verda Vittorio, Michele Calì, "Solid oxide fuel cell systems for distributed power generation and cogeneration"Solid oxide fuel cell (SOFC) is a promising technology for decentralized power generation and cogeneration. This technology has several advantages: the high electric efficiency, which can be theoretically improved through integration in power cycles; the low emissions; and the possibility of using a large variety of gaseous fuels. The analysis of some possible improvements of a 100 kW SOFC system as well as possible applications is conducted. Both technical and economic aspects are considered.

Katsuya Hayashi†, Masayuki Yokoo, Yoshiteru Yoshida, and Hajime Arai, "Solid Oxide Fuel Cell Stack with High Electrical Efficiency"This article introduces the development of a solid oxide fuel cell (SOFC) stack with anode-supported cells. The SOFC can provide the highest electrical efficiency among all fuel cell types, and high electric efficiency leads to less CO2 produced during power generation.

Gamze Genç &Selçuk Sarikoç, "Energy and exergy analysis of a solid-oxide fuel cell power generation system for an aerial vehicle (ISSA- 2015–139)" This paper presents the performance of the solid-oxide fuel cell/gas turbine hybrid power generation system with heat recovery waste unit based on the energy and exergy analyses. The effect of air inlet temperature and air/fuel ratio on exergy destruction and network output is determined. For the numerical calculations, air inlet temperature and air fuel ratio are increased from 273 to 373 K and from 40 to 60, respectively. The results of the numerical calculations bring out that total exergy destruction quantity increases with the increase of air inlet temperature and air/fuel ratio. Furthermore, the maximum system overall first and second law efficiencies are obtained in the cases of air inlet temperature and air/fuel ratio equal to 273 K and 60, respectively, and these values are 62.09% and 54.91%.

Eric D. Wachsman,*[a] Craig A. Marlowe[a] and Kang Taek Lee[a] , "Role of solid oxidefuel cells in a balanced energy strategy"The 2012 Department of Energy (DOE) budget request significantly reduces fuel cell RD&D funding and would cease to support the Solid State Energy Conversion Alliance (SECA), DOE's solid oxide fuel cell (SOFC) program. This would be a grave mistake considering the US's historic dominance in fuel cell RD&D, exciting recent technological advancements in fuel cells, and clear positive market signals around the globe. In this paper we discuss DOE's energy RD&D policy, how SOFCs address every key DOE strategy, and why recent advances should make SOFCs an integral part of our energy RD&D policy. Moreover, we compare the prospects of low temperature SOFCs with the more common proton exchange membrane fuel cell (PEMFC) in the absence of a hydrogen infrastructure.

Sangeeta Das* , Debapriya Das, Amit Patra, "Operation of Solid Oxide Fuel Cell based Distributed Generation" This paper presents the operation of a Solid Oxide Fuel Cell (SOFC) stack model based distributed generation (DG) by taking into consideration its dynamics. The SOFC modeling is carried out in state space form. The operation of this model in islanding as well as in grid connecting mode is discussed. The variations in the grid frequency and the output power delivered by the grid is presented for the both the modes. Effectiveness of the SOFC model has been demonstrated by connecting it to an infinite bus and to a 10 node distribution network. Voltage profile improvement and power loss reduction play a key role in distribution network. Results confirm the usefulness of this model in improving the voltage profile and in maintaining the grid frequency.

Sidra Mumtaz , Laiq Khan, "Adaptive control paradigm for photovoltaic and solid oxide fuel cell in a grid-integrated hybrid renewable energy system"The hybrid power system (HPS) is an emerging power generation scheme due to the plentiful availability of renewable energy sources. Renewable energy sources are characterized as highly intermittent in nature due to meteorological conditions, while the domestic load also behaves in a quite uncertain manner. In this scenario, to maintain the balance between generation and load, the development of an intelligent and adaptive control algorithm has preoccupied power engineers and researchers.

Palsson et al. [8] proposed an SOFC–GT system with 30% fuel reforming in an external pre-reformer with anode gas re-circulation where the effluent from the anode was partially recycled to supply steam and heat to the external reformer. The rest of the anode effluent was burnt in the combustor with the cathode effluent. The hot gases were then sent to the GT for generating additional electrical power, whereas the exhaust gas from the GT was utilized for fuel preheating.

Cunnel et al. analyzed six different hybrid cycles in order to have clear understanding of the various integration schemes and to determine the theoretical optimum configuration thereof. These were namely (i) the FC schematic where the fuel cell replaces the combustor of a simple gas turbine (SGT) schematic, (ii) the SGT–FC cycle with both fuel cell and combustor in the cycle (iii) the recuperated gas turbine (RGT)–FC schematic with a recuperator between the compressor and the fuel cell (iv) intercooled recuperated gas turbine (IRGT)–FC schematic with an intercooler between the compressors (v) IRGT–reheat FC schematic with one reheat fuel cell between the high and low pressure GT (vi) IRGT–FC–reheat FC cycle with one primary fuel cell between the recuperator and the combustor and one reheat fuel cell. Variation of thermal efficiency and net specific power variation with compression ratio was reported for all these cycles for the purpose of comparison with the corresponding cycle without the fuel cell. It was shown that both the thermal efficiency and the net specific power were higher for the hybrid schemes compared to their corresponding without the fuel cell.

IV. FUEL CELLS FEATURES

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.

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

Many different materials can be used for the realization of a traditional bipolar plate however some requirements must always be guaranteed:

- Functionality of the electrical connection between two consecutive cells;
- a constant and homogeneous supply of hydrogen and oxygen to the electrodes of the different cells;
- An efficient thermal dissipation;
- The removal of the water produced by the reactions.

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

V. CONCLUSION

The proposed scheme is implemented by harmonic sharing control loop as well as combined droop method and average power control method, and power information exchange between each DGS unit is needed to ensure good load sharing. We improvement of total efficiency 95% Using proposed modelling.

In particular, the theory of the average power control method can significantly reduce the sensitivity about voltage and current measurement errors, and the harmonic control loop is also added to guarantee harmonic power sharing under nonlinear loads With reference to the simulation results (Figures, it is shown that the proposed control method is very effective for each DGS unit to properly share the loads such as the real, reactive, harmonic powers in a standalone AC power system. Last, for power flow control of the DGS connected in parallel to the grid, real and reactive power controllers are proposed.

Particularly, a synchronization issue between an islanding mode and a paralleling mode to the grid is investigated, and two case studies are performed. Simulation test-beds using Matlab/Simulink are constructed for each configuration of the fuel cell based DGS with a three-phase AC 120 V/60 Hz/50 kVA and the proposed circuit models and control strategies are verified by various results. In the second topology, this dissertation presents system modeling, modified space vector PWM (MSVPWM) implementation and design of a closed-loop controllerof the Z-source converter that employs L and C components and shoot-through zero vectors for the standalone AC power generation.

The Z-source converter does not need .Consequently, this research can be a reference to those who want to demonstrate the fuel cell based DGS discussed in the previous chapters for industrial applications such as stationary and distributed power generation systems that require a three-phase AC voltage output. In the future, experimental results about all configurations will be presented using a prototype test-bed with a real fuel cell to verify the proposed circuit models and control algorithms.

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