**Literature Review**

1. **Mathematical Modelling of Planar Solid Oxide Fuel Cells.**

Jamie Ian Sandells **-**  School of Chemical Engineering The University of Birmingham August 2013

**Importantant Outcome from Paper –**

1. Clear Idea of SOFC, its structure and function – Generally, fuel cells consist of three layers which are two electrodes (the anode and cathode) on the outside of an electrolyte. The electrodes consist of a porous material which allows the fuel and oxidant to diffuse into the electrode. The electrolyte is made of a non-porous material to stop the fuel and oxidant mixing during the operation of the cell and to also conduct the charge carrier. Connecting the two electrodes is an interconnect which the produced electrons pass through to generate an electric current
2. Types of Fuel Cells and their differences -Fuel cell Abbreviation Mobile ion Operating Temperature

1. Polymer Electrolyte Fuel Cell PEMFC - H+ - 60-80◦C

2. Alkaline Fuel Cell AFC - OH - 50-200◦C

3. Phosphoric Acid Fuel Cell PAFC - H+ - 200◦C

4. Molten Carbonate Fuel Cell MCFC - CO−2 - 650◦C

5. Solid Oxide Fuel Cells SOFC - O−2 - 600-1000◦C

1. Reactions of SOFC –

Anode reaction within an SOFC is given by

H2 + O 2− → H2O + 2e –

Cathode reaction is

1/2 O2 + 2e − → O 2−

Full cell reaction

H2 + 1 2 O2 → H2O

1. **Mathematical modelling of solid oxide fuel cell using MATLAB/Simulink –**

By - TVVS Lakshmi, P Geethanjali and Krishna Prasad S School of Electrical

Engineering, VIT University, Vellore, Tamil Nadu, India

Published at - International Conference on Microelectronics, Communication and Renewable Energy (ICMiCR-2013)

**Important Outcome from Paper –**

1. In this paper transfer function model of Nernst reversible voltage and all the losses are included for modelling. Steady state response of single cell fuel cell is obtained at different flow rates and temperatures. It is observed that as the flow rate is increased, the limiting current value has also increased. The maximum limiting current is observed at fuel flow rate 51ml/sec. Results are validated from the experimental results in the reference paper
2. Formulae’s for following are Derived which can be used directly to find out and study the various parameters for solid oxide fuel cells- Net Voltage Output,Activation Loss, Ohmic Loss, Concentration Loss, Nernst Potentials, Partial Pressures for Hydrogen, Oxygen and Water, Exchange Current Density.
3. We also get Importantant values for some of the important constants that we use to solve the formulaes like – Molar gas valves for hydrogen, oxygen and water, Respnose time for hydrogen,oxygen and water etc.
4. **Solid Oxide Fuel Cell Modeling –**

**By -** Abraham Gebregergis, Member, IEEE, Pragasen Pillay, Fellow, IEEE, Debangsu Bhattacharyya, and Raghunathan Rengaswemy

**Presented at -** IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 56, NO. 1, JANUARY 2009

**Important Outcomes from Paper –**

1. A lumped model was discussed that can be extended to model fuel cell stacks for real-time applications. The basic governing equations of the fuel cell were modeled with equivalent electrical circuits in order to simplify the system and achieve flexibility and easy tuning. The steady-state simulation results of the lumped model agree with the experimental data and results of the distributed model. The capacitance in the simplified equivalent RC circuit can be changed to give the exact dynamic time response of the physical fuel cell. This SOFC model can be easily implemented in Matlab/Simulink and then programmed for real-time testing, which will help to study the performance of the fuel cell when subjected to external control.

2. Distributed Model The distributed- modeling approach is introduced here before discussing the lumped SOFC modeling. We also acknowledges with the Conservation equations in the channels for Distributed SOFC Models like Hydrogen conservation, Water conservation, Oxygen conservation also, The momentum conservation equations for the distributed SOFC model like Anode, Cathode momentum conservation equation

1. **Modeling of Solid Oxide Fuel Cell/Gas Turbine Hybrid Systems –**

By - Nischal Srivastava

Presented at - THE FLORIDA STATE UNIVERSITY FAMU-FSU COLLEGE OF ENGINEERING

**Important outcomes from paper –**

This thesis deals with solid oxide fuel cell and gas turbine hybrid systems.

Hybrid systems combine two or more power generating devices and make use of the synergism to generate maximum power and offer higher efficiencies. Hybrid systems typically present low combustion temperature resulting in low exhaust temperature and zero or low level of nitrogen oxides. The exhaust of a high temperature fuel cell can be expanded in a gas turbine to drive a compressor, which in turn provides pressurized streams to the fuel cell. The residual enthalpy can be used in other turbine stages resulting in additional power. There are several configurations in which a fuel cell and a gas turbine can be arranged as a cycle. shows a particular configuration of a micro GT/SOFC hybrid system. The air stream is pressurized in a compressor and passes through a recuperator where it is preheated. The fuel stream from the pump and the air stream from the recuperator enter the SOFC. Within the fuel cell, fuel and air react electrochemically to generate electricity and a high enthalpy exhaust. This high enthalpy exhaust is mixed with bypassed air stream from the recuperator and combusted in an oxidizer. This high temperature and high pressure effluent is now expanded in the turbine to provide work to drive the compressor and an electrical generator. In this way, the waste heat from the fuel cell is utilized to increase the system efficiency.

1. **Modeling and Simulation of Solid Oxide Fuel Cell Based Distributed Generation System –**

By - Mukesh Kumar Baliwal, Dr.A.Bhargava, Mr. S.N. Joshi,Sunil kumar M.Tech Scholar (Power Systems), Dept. of Electrical Engineering, UCE-RTU Kota (Rajasthan). Associate Professor, Dept. of Electrical Engineering, UCE-RTU Kota (Rajasthan),Assistant Professor& HOD, Dept. of Electrical Engineering, -GWEC, Ajmer (Rajasthan)

Presented at - International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 8, August - 2013 IJERT ISSN: 2278-0181

**Important outcomes from Paper –**

This paper shows the impact of fuel cell power system on the stability of power system. The dynamic modeling and simulation results of a fuel cell based power system which consists of solid oxide fuel cell (SOFC) for power generation. The SOFC modeled individually and latterly integrate in Matlab/Simulink software. The developed Simulink model of fuel cell system is then connected to 11Kv grid through an AC bus. . Simulation studies have been carried out to verify the system performance under faulty condition.

1. **Computational modeling of the transport and electrochemical phenomena in solid oxide fuel cells**

**By -** Hocine. Mahcenea , Hocine Ben Moussab , Hamza. Bouguettaiaa , Djamel. Bechkia , Mostefa Zeroualc

**Presented at -** Laboratory of New and Renewable Energy (LENREZA), P.O.Box 511, Ouargla University 30000 Algeria, Department macaque, University Batna, Algeria Department physics, University Algeria

**Important outcomes from Paper –**

This paper has presented a computational simulation of the transport and electrochemical phenomena in a planar SOFC. Significant results about the local transport characteristics inside the planar SOFC, such as the steam water, hydrogen and the temperature distributions, under various losses, operating conditions and different values of thickness have been presented. The unique features of this model are the implementation of the voltage-to-current algorithm and the coupling of the potential field with the reactant species concentration field, which allows for a more realistic spatial variation of the electrochemical kinetics. The results of this numerical thermodynamic–electrical model, solved by finite volume method and resolved by self-programming , show the effect of the heat sources as the temperature changes. Furthermore, hydrogen mass transfer is function of the anode thickness

We observe the study of following factors in this paper

1. Effect of anode thickness
2. Effect of various losses on the cell performance
3. Effect of fuel flow rate on the cell performance
4. Effect of operating pressure on SOFC performance
5. **Modelling of a High Temperature Solid Oxide Fuel Cell –**

By - Pankaj Kalra, Rajeev Garg, Ajay Kumar Dept. of Chem. Engg., Shaheed Bhagat Singh State Technical Campus, Ferozepur, Punjab, India, Dept. of App. Sci. & Hum.,Shaheed Bhagat Singh State Technical Campus, Ferozepur, Punjab, India

Presented at - Journal of Energy Technologies and Policy www.iiste.org ISSN 2224-3232 (Paper) ISSN 2225-0573 (Online) Vol.5

**Important outcomes from Paper –**

A one - dimensional model was developed to comprehensively describe the electrochemistry, hydrodynamics and multi-component transport of SOFC. The model would be implemented into the commercial CFD software Ansys Fluent. The CFD model would to be able to predict the current-voltage characteristics of SOFC, in addition to the detailed reactant and product distributions in the cell. This data makes it possible to analyze SOFC operation in detail.The CFD model described in this study is intended to present a tool for design optimization of SOFCs. To achieve this and fully utilize this tool, the model can be used to perform parametric and sensitivity studies of varying operating conditions and cell designs.

The present CFD model also has the energy equation built in to resolve the temperature distribution. However, a detailed account of various heat generating sources such as irreversible and reversible (entropic) heat as well as ohmic heating has not been accounted in the equations. The temperature distribution can be used to couple to stress analyses, thereby providing a comprehensive computer-aided engineering (CAE) tool for SOFC design and operation. The present model can be easily extended to include multiple fuels such as H2 and CO. Finally, the present model would serves as a building block to build a comprehensive CFD-based model for 3- dimensional SOFC with internal reforming on the anode. In such a situation, convectional & diffusional transport of various chemical species in all the three dimensional have to be taken into account

1. **STEADY STATE MATHEMATICAL MODELING OF SOLID OXIDE FUEL CELL FOR HYBRID SYSTEM OF FUEL CELL AND GAS TURBINE (FC-GT)**

By - Dhananjay Sahu , Brijesh Patel

Presented at - Volume 6, Issue 6, June (2015), Pp. 12-17 Article ID: 20120150606003 International Journal of Advanced Research in Engineering and Technology (IJARET) © IAEME: www.iaeme.com/ ijaret.asp ISSN 0976 - 6480 (Print) ISSN 0976 - 6499 (Online)

**Important outcomes from Paper –**

The modeling of Solid Oxide Fuel Cell is done with consideration of almost all factor losses like activation losses, Ohmic losses, and concentration (diffusion) losses. And the equation for power output and the system efficiency is mathematically developed. Still modeling for fuel reformer and other component like compressor, recuperator, and combustor of hybrid system is to be carried out. This is supposed have huge area of modeling and other consideration with need of some practical assumptions

1. **Mathematical modeling of solid oxide fuel cells: A review**

**By -** S.Ahmad, A.shamiri

**Important outcomes from Paper –**

This paper presents a review of studies on mathematical modeling of solid oxide fuel cells (SOFCs) with respect to the tubular and planar configurations. In this work, both configurations are divided into five subsystem and the factors

1. **Simulation of Solid Oxide Fuel Cell Anode in Aspen HYSYS—A Study on the Effect of Reforming Activity on Distributed Performance Profiles, Carbon Formation, and Anode Oxidation Risk**

**By** Khaliq Ahmed Amirpiran Amiri

**Important outcomes from Paper –**

A distributed variable model for solid oxide fuel cell (SOFC), with internal fuel reforming on the anode, has been developed in Aspen HYSYS. The proposed model accounts for the complex and interactive mechanisms involved in the SOFC operation through a mathematically viable and numerically fast modeling framework. Distributed variables including temperature, current density, and concentration profiles along the cell length, have been discussed for various reforming activity rates.

1. **Modeling and simulation of grid connected solid oxide fuel cell using PSCAD**

**By -** S.Fedakar , S.Bahceci, and  T.Yalcinoz

**Important outcomes from Paper –**

In this paper, a grid connected SOFC system is presented by using PSCAD software. The power conditioning unit (PCU) is used for simulation studies and also the transformer is used for electrical isolation. The simulation studies of the SOFC dynamic model are investigated for three case studies.The results show the fast response capabilities of the grid connected SOFC system in different case studies and various load types.

1. **Dynamic modeling and simulation of Solid Oxide Fuel Cell system**

**By -** A.A.Salam; M.A.Hannan ; A.Mohamed

**Important outcomes from Paper –**

This paper deals with the modeling and analysis of dynamic model of solid oxide fuel cell (SOFC) system in response to the grid connection using PSCAD/EMTDC simulation software. The designed controller is also implemented to analyzed the output response of the developed fuel cell that can be used in distributed generation applications.

1. **Modelling and Simulation of Solid Oxide Fuel Cell**

**By -** Ruchi Yadav Gauri Shankar

**Important outcomes from Paper –**

This paper focuses on the study of fuel cells as a renewable source of energy which is environment friendly and much more consistent in performance as compared to solar and wind energy. This paper deals with the study of dynamic model of solid oxide fuel cell (SOFC) based on transfer function. The studied model includes the effect of activation, ohmic and concentration losses on the dynamic performances of SOFC