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Simulation Analysis Of Doubly-Fed Induction Generator With Solid Oxide Fuel Cell

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Abstract: In current few years the statistical data expresses that Doubly-fed Induction Generator (DFIG) based wind turbine with variable pitch control and variable speed is mainly regular wind turbine in the growing wind souk. Because of the fluctuating behavior of wind power, a dynamic model of Solid Oxide Fuel Cell (SOFC) energy source is integrated with wind turbine for abrupt load changes to make sure reliable and competent operation of the power system. This research study deals with simulation of a wind turbine rooted in a doubly-fed induction machine hybrid with fuel cell energy system employed in generating mode to generate or produce electrical energy on a power network. In the middle of, a variety of renewable energy sources, fuel cell is getting more popularity because of their cleanliness, higher efficiency and cost-effective supply of power demanded by the customers.

Keywords- Solid Oxide Fuel Cell (SOFC), Doubly-fed Induction Generator (DFIG), Wind Energy Conversion System (WECS), Induction Machine (IM)

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I. INTRODUCTION

Ever growing energy utilization, rising public consciousness for environmental safety and existing nature of fossil fuels, outcomes much of the research study to focus on renewable/alternative energy sources. The small-scale production or generation system for example fuel cells, wind turbine, micro-turbines, photovoltaic, etc. plays a significant role to meet the customers demand using the ideas of distributed generation. The word distribution generation means a few small-scale generations is sited near to the consumers rather than central or distant locations. Investigation shows that at the end of the year 2005, entire loss over the distribution, transmission and transformers in India is about 32.15 percent. The most important advantages of distributed generation systems (DGs) are reduction in losses over the long transmission and distribution lines, local voltage regulation, installation charge, and capability to insert a small unit in its place of a larger one during peak load conditions. In the middle of the unusual distributed generation more desirability is going on fuel cells for the reason that it has the potential ability of providing both power and heat.

1.1 FUEL CELL TECHNOLOGY

A fuel cell is an electro-chemical contrivance that converts the chemical energy of the hydrogen fuel into electrical energy. It is centered on a chemical reaction between fuel and the oxidant (generally oxygen) to produce electricity where water and heat are by products. This alteration of the fuel into energy takes place devoid of combustion. The effectiveness of the fuel cells ranges from 40-60 percent and can be get better to 80-90 percent in cogeneration applications. Fuel cell expertise is a moderately new energy saving technology that has the potential to contend with the conventional existing generation amenities. In the middle of the variety of DG technologies existing, fuel cells are being well thought-out as a potential source of electricity for the reason that they have no geographic restrictions and can be sited anyplace on a distribution system. Fuel cells have several advantages which make them better as compared to the further technologies. Advantages include high power quality, high efficiency and service trustworthiness, hardly any or no moving parts which lead to low noise, modularity, low maintenance and fuel flexibility.

II. OPERATING PRINCIPLE

The arrangement and the working of a fuel cell are alike to that of a battery excluding that the fuel can be incessantly fed into the cell. The cell consists of two electrodes, positive electrode (cathode) and negative electrode (anode) separated by an electrolyte. Fuel is fed keen on the anode where electro-chemical oxidation takes place and the oxidant is fed keen on the cathode where electro-chemical diminution takes place to produce or generate electric current and water is primary product of cell reaction.

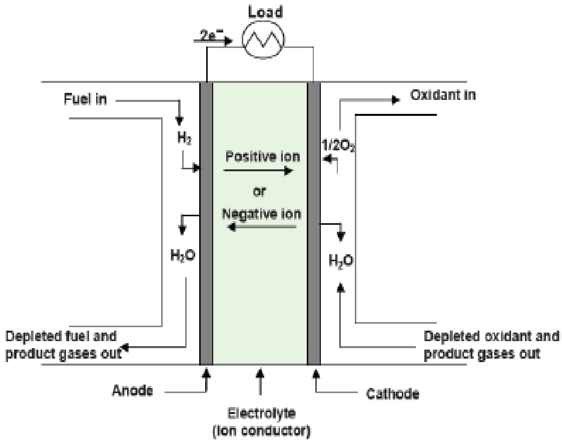

Fig.2.1 Schematic of an Individual Fuel Cell [6]

The archetypal cathode and anode reactions for a fuel (Hydrogen) cell are given by Equations;

$$H_2 \text{----------------} 2H^+ + 2e^- \qquad (2.1)$$

$$\tfrac{1}{2} O_2 + 2H^+ + 2e^- \text{------} H_2O \qquad (2.2)$$

An entity fuel cell produces a lesser amount 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 demonstrates cell stacks which consist of repeating units, each comprising a cathode, anode, electrolyte and a bipolar separator plate. Many of cells depend on the preferred power output.

III. SOLID OXIDE FUEL CELL

The Solid Oxide Fuel Cell is a high-temperature working fuel cell which has high potential in motionless applications. The effectiveness of Solid Oxide Fuel Cell is in the range of 45-50 percent and when incorporated with a gas turbine, it attains a high effectiveness of 70-75 percent. It is a solid-state contrivance that employs an oxide ion carry out non-porous ceramic material as an electrolyte. While the solid electrolyte, the cells do not have to be built in the plate-like configuration archetypal of other fuel cell types. Rust is less compared to molten carbonate fuel cell and no water management problems as in Proton-exchange membrane fuel cells due to the solid electrolyte. High temperature operation eliminates the want for a precious-metal catalyst, thus reducing the cost. It also allows Solid Oxide Fuel Cells to reform fuels internally, which permits the use of various or a variety of fuels and diminishes the cost linked with adding a reformer to system.

The electrolyte used is a ceramic oxide (yttria stabilized zirconia). The cathode is a strontium doped lanthanum magnetite and the anode employed is nickel-zirconia cermets. The employ of ceramic matters increases the cost of Solid Oxide Fuel Cells. High operating temperature needs rigorous materials to be employed which further makes up the cost. Research or investigation is being carried out to diminish the operating temperature and employ less rigorous materials. Diminution of temperature get betters the starting time, cheaper materials can be used, and durability and robustness can be increased. Intermediate-temperature Solid Oxide Fuel Cells cannot be used for all applications. Higher temperature is requisite for fuel cell micro turbine hybrid systems. Though, for smaller systems intermediate temperature Solid Oxide Fuel Cells would be ideal.

As Solid Oxide Fuel Cells have fuel-litheness, the input to the anode can be hydrogen, methane or carbon monoxide. Carbon monoxide or hydrogen may go into the anode. At the cathode, electro-chemical diminution takes place to get oxide ions. These ions lead through the electrolyte layer to anode where hydrogen is oxidized to get water. In case of carbon monoxide (CO), it is oxidized to carbon dioxide (CO_2). In general, it is mostly caused by the electrolyte.

IV. MODELLING OF SOLID OXIDE FUEL CELL

The modeling of solid oxide fuel cell (SOFC) is based on the following assumptions;

- The fuel cell temperature is presumed to be constant.
- The fuel cell gasses are ideal.
- Nernst's equation applicable.

By Nernst's equation dc voltage fc V across stack of the fuel cell at current I is given by the following equation. [6]

$$V_{fc} = N_o\left[E_O + \frac{RT}{2Fln\left(\frac{pH_2pO_2^{0.5}}{pH_2O}\right)}\right] - rI_{fc} \quad (4.1)$$

Where,
V_{fc} – Operating dc voltage (V)
E_0 – Standard reversible cell potential (V)
Pi – Partial pressure of species i (Pa)
r – Internal resistance of stack (S)
I – Stack current (A)
N_0 – Number of cells in stack
R – Universal gas constant (J/ mol K)
T – Stack temperature (K)
F – Faraday's constant (C/mol)

The main equations describing the slow dynamics of a solid oxide fuel cell can be written as follows;-

$$P_{ref} = V_{fc} * I_{ref} \quad (4.2)$$

$$\frac{dI_{fc}}{dt} = \frac{1}{Te}\left[-I_{fc} + I_{ref}\right] \quad (4.3)$$

$$\frac{dqH_2^{in}}{dt} = \frac{1}{Te}\left[-qH_2^{in} + 2\frac{K_r}{U_{opt}} * \frac{1}{I_{fc}}\right] \quad (4.4)$$

$$\frac{dP_{H2}}{dt} = \frac{1}{\tau_{H2}}\left[-P_{H2} + \frac{1}{K_{H2}}\left(q_{H2}^{in} - 2K_r I_{fc}\right)\right] \quad (4.5)$$

$$\frac{dP_{O2}}{dt} = \frac{1}{\tau_{O2}}\left[-P_{O2} + \frac{1}{K_{O2}}\left[\frac{1}{r_{HO}\, q_{H2}} - 2K_r I_{fc}\right]\right] \quad (4.6)$$

$$\frac{dP_{H2O}}{dt} = \frac{1}{\tau_{H2O}}\left[-P_{H2O} + 2\frac{K_r}{K_{H2O} I_{fc}}\right] \quad (4.7)$$

Where,
q_{H2} – Fuel flow (mol/s)
q_{O2} – Oxygen flow (mol/s)
K_{H2} –Hydrogen Valve molar constant (kmol/s atm)
K_{O2} –Oxygen Valve molar constant (kmol/s atm)
K_{H2O} –Water Valve molar constant (kmol/s atm)
τ_{H2} – Response time for hydrogen (s)
τ_{O2} – Response time for oxygen (s)
τ_{H2O} – Response time for water (s)
τ_e – Electrical response time (s)
τ_f– Fuel response time (s)
Uopt – Optimum fuel utilization
r_{HO} – Ratio of hydrogen to oxygen
K_r – Constant (kmol/s A)
P_{ref} – Reference power (kW)

The block diagram illustration of the solid oxide fuel cell dynamic model is revealed in the Figure 4.1.

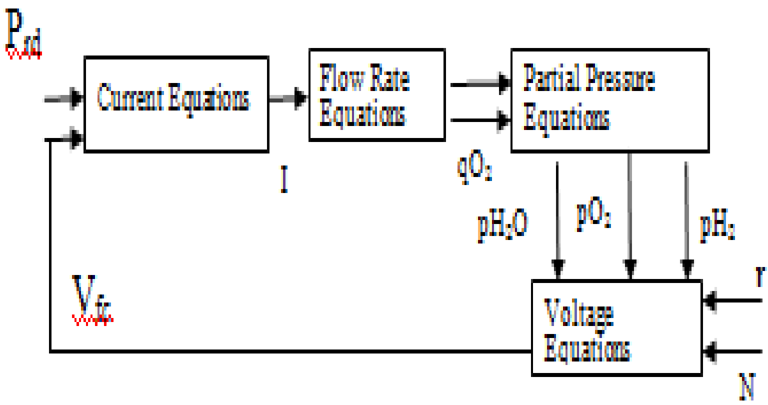

Fig.4.1 Block Diagram for Dynamic Model of solid oxide fuel cell

V. MODELING AND SIMULATIONS

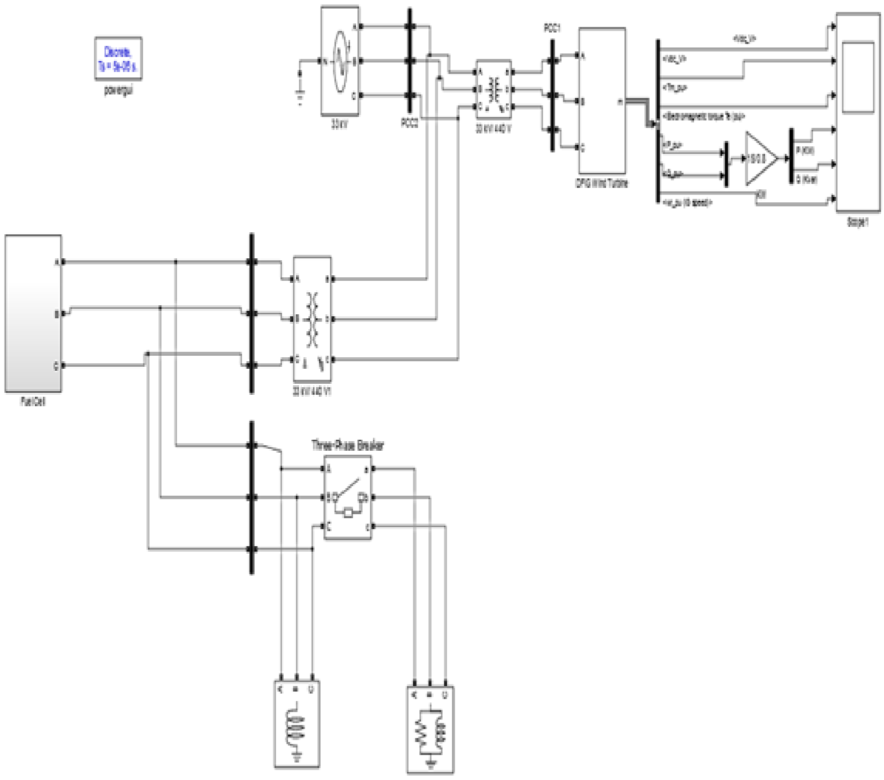

Fig.5.1 Grid Connected DFIG with Fuel Cell

(I) WHEN LOAD IS 70KW

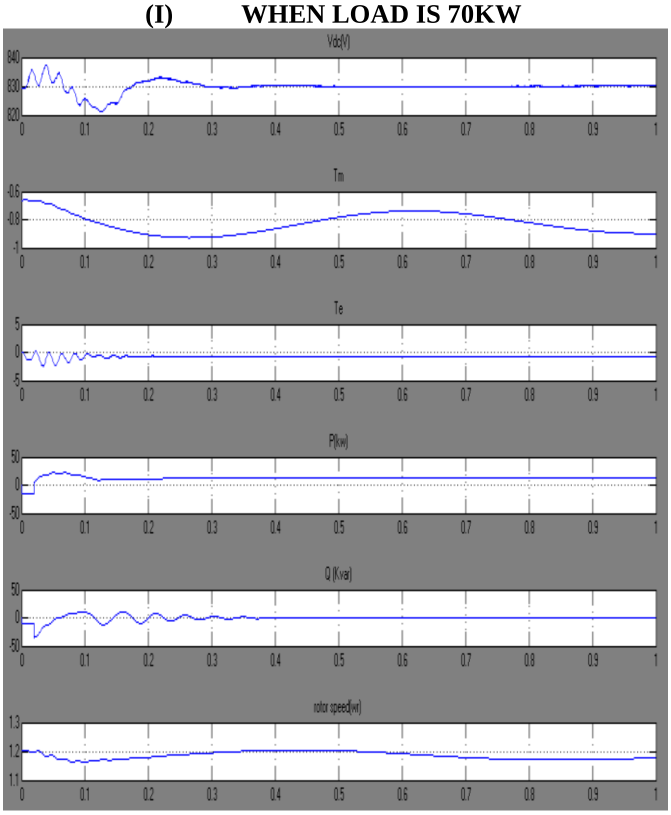

Fig.5.2 Simulation Result (DC Voltage, Mechanical Torque, Electrical Torque, Active Power, Reactive Power and Rotor Speed)

(II) WHEN LOAD IS 7000W

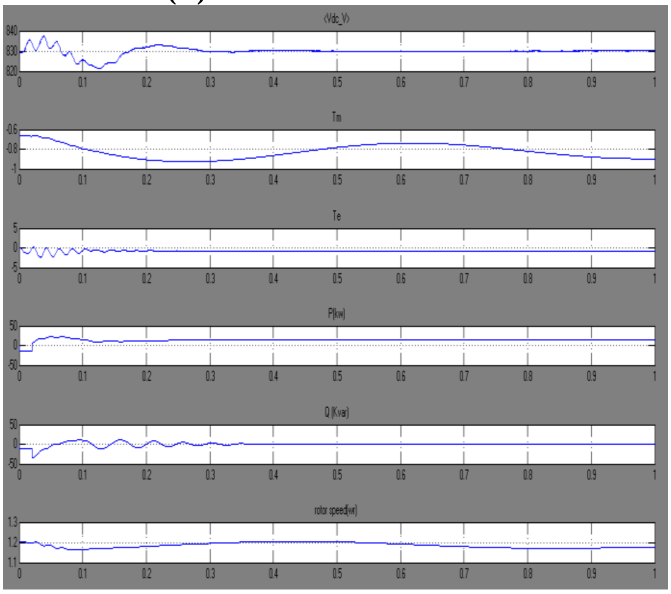

Fig.5.3 Simulation Result (DC Voltage, Mechanical Torque, Electrical Torque, Active Power, Reactive Power and Rotor Speed)

VI. CONCLUSION

Distributed generation of the hybrid renewable energy systems linked to the electrical grid is a superior balance to conventional energy production, which is polluting and finite. This research paper has revealed with its simulation outcomes how a hybrid system composed by a fuel cell and a wind turbine satisfy such challenge.

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