Scientific Journal of Impact Factor (SJIF): 4.72
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 4, Issue 5, May -2017

An alternative to standard sources of energy-SOFC fed DC-DC Boost Converter

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Abstract- *In this paper comprehensive dynamic modeling of Solid Oxide Fuel Cell has been developed which can be used for transient and dynamic stability studies. Hybrid Electric Vehicles Powered by fuel cell are being used by many automobile companies as the offer reduced emission and improve fuel economy. The key technology for such development of fuel cell for propulsion is the power electronics. Mathematical Modeling has been done and Nernst Equation is obtained for temperature 1273ºC, represent physic-chemical processes occurring in SOFC This is one of the benefit of Solid Oxide Fuel Cell. Fuel cells operate at low voltages and hence fuel cells need to be boosted and inverted in order to connect to the utility grid. The model is built in MATLAB/SIMULINK.*

Keywords- *SOLID OXIDE FUEL CELL (SOFC), DC to DC Boost Converter, Pulse Generator, MATLAB, Distributed Generation*

I. INTRODUCTION

In future role of distributed generation in electrical power generation is major .Attraction toward fuel cell is because of its efficiency and friendly towards environment. Power system dynamic behavior will be affected as fuels are dynamic. Chemical energy of fuel is directly converted to electricity in a fuel cell. Due to solid Oxide electrolyte in SOFC it has high efficiency with less emission and allows direct use of hydrogen and natural gas as fuels. SOFCs are simple, reliable and highly efficient (up to *85% energy efficiency when combined with gas turbine) compared to engines and modern thermal power plants (*30%).They are attractive as it reduces vehicle emission and also reduces large consumption of fuel in less time [1] .IC engines in vans, buses etc can be replaced by fuel cell in less time.High-temperature fuel cells such as solid oxide fuel cells (SOFC) have potential for centralized power generation as well as combined heat and power. Compared to other fuel cells, SOFC's are capable of handling more convenient forms of hydro carbons fuels where they are highly efficient and tolerant to impurities and its high temperature enables internal reforming [1]. DC voltage output of SOFC is low around 60 volts so its voltage is needed to be boosted so a DC to DC boost converter is required The DC-DC converter boosts the low voltage of the fuel cell as well as regulates the voltage. The DC-AC inverter plays a key role in making the fuel cell DC power available for standalone applications as well as grid connected applications.

To get the desired boosted DC voltage in DC to DC boost converter, average voltage obtained across output needs to be constant even though input to converter is varying. In these converters the average

DC output voltage must be controlled to be equated to the desired value although the input voltage is changing. In the DC/DC converter from view point of energy, voltage regulation of output is achieved by constantly adjusting energy injected into the load and absorbed from the source and it can be controlled by controlling relative injection and absorption durations intervals. Energy absorption and injection the two basic process constitute switching cycle. Converter with too small energy storage capacity or too long switching period, then before the next cycle begins all energy that was stored would have transmitted to load. This introduces an idling period immediately following the injection interval, during which the converter is not performing any specific task [4]. The converter can therefore operate in two different modes depending upon its energy storage capacity and the relative length of the switching period. These two modes are know as the discontinues conduction and continuous modes. Graphically model of the boost converter is shown in Figure 1.The full details of the boost converter topology have been already discussed in [5,6,7]. The DC/DC boost converter only needs four external components: Inductor, Electronic switch, Diode and output capacitor. The converter can therefore operate in the two different modes depending on its energy storage capacity and the relative length of the switching period. These two operating modes are known as the discontinuous conduction mode, DCM, and continuous conduction mode, CCM, corresponding to the cases with and without an idling interval respectively [6,7].

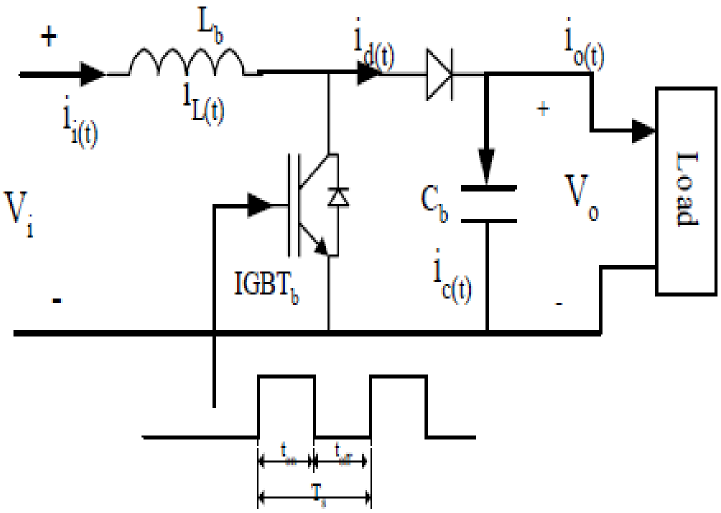

Figure 1. Circuit of step up DC to DC Boost Converter

II. METHODOLOGY

The basic block diagram of the Work done in MATLAB is shown below:

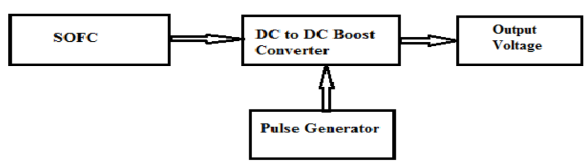

Figure 2. Block Diagram for System

2.1 Mathematical modeling of SOFC:

The modeling of SOFC is based on the following assumptions. The fuel cell temperature is assumed to be constant. The fuel cell gasses are ideal. Nernst's equation applicable. By Nernst's equation dc voltage across stack of the fuel cell at current I is given by the following equation [].

$V_{fc}= N_0\ [E_0+ (RT/2f)\ln(P_{H2}(P_{02})^{0.5}/P_{H20})] - rI_{fc}$ … (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 SOFC can be written as follows:

$P^{ref}=V_{fc}*I_{ref}$ … (2)
$dI_{fc}/dt=(1/\tau_e)[-I_{fc}+I_{ref}]$ … (3)
$d(q_{H2})^{in}/dt=(1/\tau_f)[-q_{H2}^{in}+(2K_r/U_{opt})*I_{fc}]$ … (4)
$dp_{H2}/dt=(1/\tau_{H2})[-P_{H2}+(1/K_{H2})(q_{H2}^{in}-2K_rI_{fc})]$ … (5)
$dP_{O2}/dt=(1/\tau_{O2})[-P_{O2}+(1/K_{O2})[(1/r_{H0})*q_{H2}^{in}-2K_rI_{fc}]$ … (6)
$dP_{H2O}/dt=(1/\tau_{H2O})[(2K_r/K_{H2O})*I_{fc}]$ … (7)

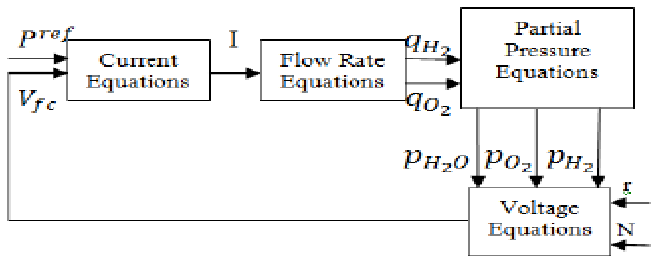

Figure 3. SOFC block diagram for dynamic model

Given below are the parameters taken for modeling of SOFC:
$U_{opt,}$ Optimum fuel utilization =0.85
$r_{HO,}$ Ratio of hydrogen to oxygen=1.145
$E_{0,}$ Standard reversible cell potential (V) =1.184
R, internal resistance of stack=3.2813×10^{-4} Ω
F, Faradays Constant=96.487×10^{8}
T, Stack Temperature=1273ºC
$N_{0,}$ Number of fuel cell stacks =105
$\tau_{f,}$ Fuel response Time=5 sec
$K_{H2,}$ Valve molar constant for hydrogen (kmol/s atm) =8.43×10^{-4}
$K_{O2,}$ Valve molar constant for oxygen (kmol/s atm) =2.5×10^{-2}

2.2 DC to DC Boost Converter

The DC/DC converter has two modes, a Continuous Conduction Mode for efficient power conversion and Discontinuous Conduction Mode for low power or Stand-by operation,

2.2.1 Continuous Conduction Mode:

- **Mode 1 (0<t≤ton)**

Mode 1 begins when IGBT's is switched on at t=0 and terminates at t=ton.The inductor current iL(t) greater than zero and ramp up linearly. The inductor voltage is Vi.

- **Mode 2 (ton<t≤Ts)**

Mode 2 begins when IGBT's is switched off at t=ton and terminates at t=Ts.The inductor current decrease until the IGBT's is turned on again during the next cycle. The voltage across the inductor in this period is Vi-Vo.
Since in steady state time integral of the inductor voltage over one time period must be zero.

$V_i\, t_{on}+ (V_i-V_0)\, t_{off}=0$ [4]

Where;

Vi : The input voltage, V ;Vo : The average output voltage, V. ; ton : The switching on of the IGBT's, s ;toff : The switching off of the IGBT's

2.2.2 Discontinuous Conduction Mode

If the current following through the inductor falls to zero before the next turn-on of the switching IGBT's, then the boost converter is said to be operating in the discontinuous conduction mode.

III. SIMULATION RESULT AND DISCUSSION OF SOFC :

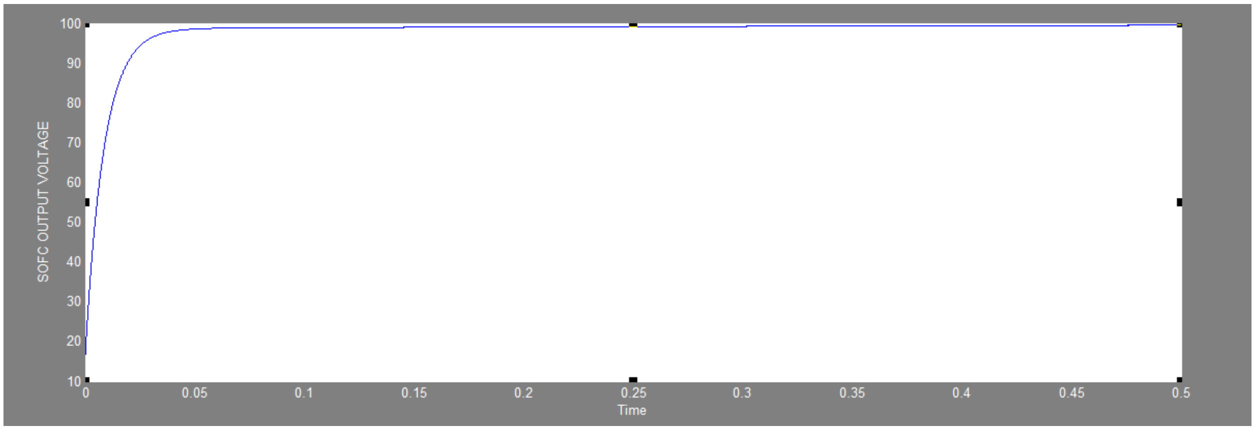

Figure 4. SOFC output voltage in Volts

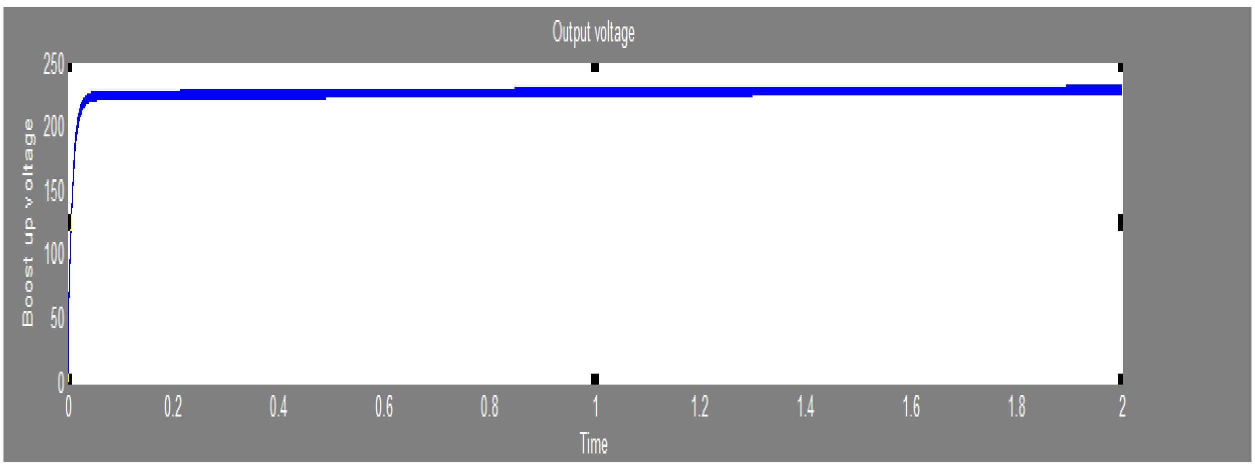

Figure 5. Voltage across DC to Dc boost converter in volts

IV. CONCLUSION

This paper describes a detailed dynamic model of a Solid Oxide fuel Cell (SOFC).This has been done using Nernst Equation for temperature of 1273ºC.It is designed for a single stack with 105 cells connected in series. The output voltage obtained across SOFC terminals is 101V.This voltage is required to be boosted so a DC to DC boost converter is connected. Pulse generator is used for the triggering MOSFET in converter. The values of inductor and capacitor taken are 400µH and 25µF The voltage across converter obtained is 230 V.

V. REFERENCES:

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