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The Design and Replication of a 6kw Fuel Cell Power Plant

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ABSTRACT

Fuel cell technology is among the most promising choices for distributed generation system either as standalone, isolated or grid connected mode. It can also be utilized both in single and hybrid systems for power generation. In this paper, a Standalone Solid Oxide fuel cell (SOFC) power plant is developed using MATLAB/Simulink algorithm for Bodo city Strengthening Transparency and Accountability in Niger Delta (STAND) computer center to generate electricity to a load demand of 6 kW 220Vac at 50 Hz. The Solid Oxide fuel cell (SOFC) stack is modeled based on the mathematical equations and executed using the Simulink power system blocks. The SOFC low output DC voltage is stepped-up using a boost DC-DC converter then fed to a pulse width modulation (PWM) based inverter (DC-AC converter). Simulation results shows that the Solid Oxide fuel cell (SOFC) power plant is capable of delivering the maximum output power with voltage and current within tolerable range.

Keywords: *Fuel Cell, Renewable, Standalone, Solid Oxide, Power plant, Converter, Power Conditioners*

Introduction

Fuel cells are fast becoming the next power home yet to come. The interest in fuel cell systems as a substitute to a central power plant has been growing during the past decades owing to their non-pollutant nature, great efficiency, high reliability and safety, flexible configuration, environmentally friendly and use-able by product. For a long time, fuel cells are under thorough research as future sources of electric power generation based on their characteristics. The fuel cells are systems or devices which converts chemical energy straight into electrical energy by means of an electro-chemical process called electrolysis. As different to a usual storing cell, it can function as long as there's a continuous supply of fuel to it (Devender, S, Sushil, K, Shiba, A., 2015). Amid the different fuel cell types briefly deliberated upon, Proton Exchange Membrane Fuel cell (PEMFC) with Solid oxide fuel cell (SOFC) are widely used and commercialized (Prema. N. K, Nirmala. K. K, and Rosalina. K. M., 2014). Also, a handful of research is ongoing in the design, process and operation of the Proton Exchange Membrane Fuel Cell (PEMFC), best suitable for mobile and residential uses. Due to their low efficiency and reliance on clean hydrogen as fuel, they have not been used widely in stationary power purposes (Huang. X, Zhang. Z, and Jiang. J., 2016). Solid oxide fuel cell (SOFC), which operate at great temperatures, however, remain suitable for Distributed Generation applications, where power can also be produced at the load location itself.

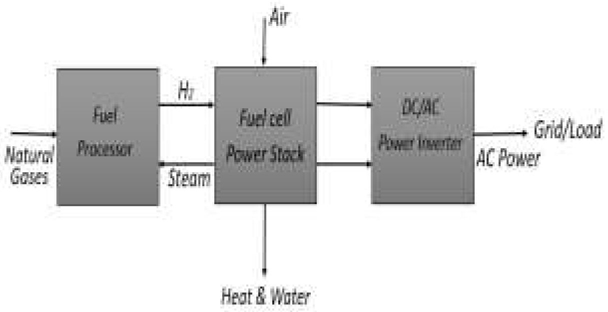

Fig 1. Diagram of a Fuel cell system (Huang. X, Zhang. Z, and Jiang. J.,2016).

In view of the known point that Fuel cells generate DC power, they are essentially tied to the AC power distribution system via DC/AC inverters which can control the tracking of actual and reactive power set points and to regulate the power factor (Miao, Z, etal, 2013). An appropriate dynamic prototype of fuel cells bearing in mind the electro-chemical thermodynamic practice and electrical operation, is essential with regards to distributed generation know-how application of this Solid oxide fuel cell (SOFC) (Hosseinzadeh et al., 2016).

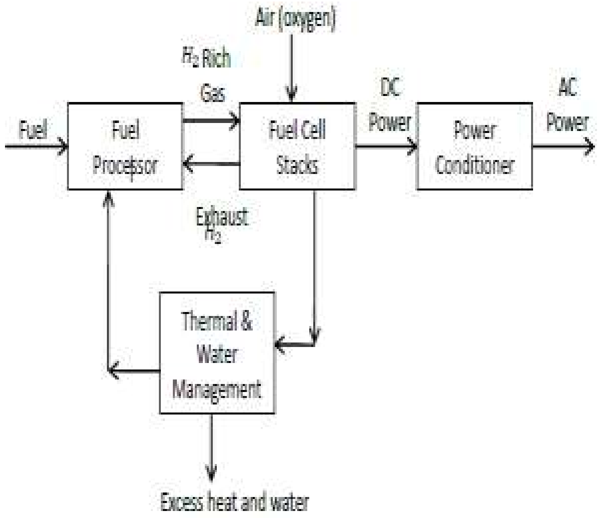

Fig 2. Fuel Cell Power Plant (Prabha R, A., 2014).

The fundamental features of a fuel cell as shown in figure 2 above, are composed of six basic subsystems: a fuel processor, fuel cell stack, an air, water, thermal management, and Power Conditioning System (PCS) (Tae-Won., et al.,2014). Much effort has been put in to make it an inevitable choice for power generation. They are commercially available more than ever, and have the tendencies to fulfilling global power needs while meeting the environmental expectations.

Design of Solid Oxide Fuel Cell

Fuel are conveyed through this cells by regulating the valves. Been the central unit or heart of the system is made up of the anode, cathode, electrolyte, cell stacks, H_2 and O_2 gases, cooling system to maintain temperature, water management to maintain the humidity in the cell system and cell resistance is left constant at any condition of operation (Khan. M. J, Iqba. M. T., 2015).

They utilize hydrogen as fuel and oxygen (usually from air) as the oxidant in the electrochemical reaction. This reaction that takes place are given in equations 1, 2 and 3 respectively.

In the anode:

$$H_2 + O^2 \rightarrow H_2O + 2e^- \qquad (1)$$

In the cathode:

$$\frac{1}{2}O_2 + 2_e \rightarrow O^{2-} \qquad (2)$$

Overall reaction is given as;

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O \qquad (3)$$

The stoichiometric ratio of hydrogen to oxygen is 2:1.

Nernst equation defines the average voltage degree of the fuel cell stack (Huang. X, Zhang. Z, and Jiang. J.,2016) The output fuel cell dc voltage (V_{fc}) across the stack of the fuel cell at current (I) is given as:

$$V_{fc} = N_o \left(E^o + \frac{RT}{2F} \mathrm{In}\left(\frac{pH_2.pO_2}{pH_2O}\right)\right) - rIfo \qquad (4)$$

Where:
V_{fc} - is the operating dc voltages (V);
N_o - is the number of cells;
E^o - is standard cell reversible potential (V);
R - is the universal gas constant (J/mol K);
T - is the stack temperature (K);
Ifo-is the fuel cell stack current (A);
r - is the internal resistance of stack (S);
F - is the Faraday's constant (C/mol);

The main equation describing the slow dynamics of the SOFC is given where pH_2, pH_2O, and $p0_2$ are determined by the following differential equations:

$$\frac{dI_{fc}}{dt} = \frac{1}{t_e}(I_{fc} + I_{ref}) \qquad (5)$$

$$\frac{dq_{H_2}^{In}}{dt} = \frac{1}{t_f}\left(q_{H_2}^{In} + \frac{2Kr}{U_{opt}} I_{fc}\right) \qquad (6)$$

$$\frac{dpH_2}{dt} = \frac{1}{tH_2}\left(pH_2 + \frac{1}{KH_2}\left(q_{H_2}^{In} - 2Kr\, I_{fc}\right)\right) \qquad (7)$$

$$\frac{dp0_2}{dt} = \frac{1}{t0_2}\left(p0_2 + \frac{1}{KO_2}\left(\frac{1}{rH_20} q_{O_2}^{In} - 2KrI_{fc}\right)\right) \qquad (8)$$

$$\frac{dpH_2O}{dt} = \frac{1}{tH_2O}\left(pH_2O + \frac{2}{KH_2O}(Kr\, I_{fc})\right) \qquad (9)$$

$q_{\mathrm{H_2}}^{In}$ and $q_{\mathrm{O_2}}^{In}$ are the molar flow of Hydrogen and Oxygen and Kr = $\frac{No}{2F}$ is Constant (kmol/s A).

where:
qH_2 is the fuel flow in (mol/s)
qO_2 is the oxygen flow in (mol/s)
kH_2 is the valve molar constant for hydrogen (kmol/s atm)
kO_2 is the valve molar constant for oxygen (kmol/s atm)
kH_2O – is the valve molar constant for water (kmol/s atm)

τ_{H2}, τ_{H2O}, τ_{O2} is the response time for hydrogen, water and oxygen (s)

τ_e – Electrical response time (s)
τ_f– Fuel response time (s)
I_{ref} - Reference current (A)
P_{ref} – Reference power (kW)
Uopt – optimum fuel utilization
Kr – constant (kmol/s A)
The partial pressures of the gas can be calculated as:

$$\mathrm{pH_2} = \left(1 - \mathrm{U_{f_{H_2}}}\right) x\%\mathrm{P_{fuel}} \qquad (10)$$

$$\mathrm{pO_2} = \left(1 - \mathrm{U_{f_{O_2}}}\right) \mathrm{y\%P_{air}} \qquad (11)$$

where $\mathrm{U_{f_{H_2}}}$ and $\mathrm{U_{f_{O_2}}}$ are the hydrogen and oxygen conversion rate, $x\%$ and y% are the percentage of hydrogen and oxygen in the fuel and oxidant, also $\mathrm{P_{fuel}}$ and $\mathrm{P_{air}}$ are supply pressure of hydrogen and oxygen.

The rate of conversion of hydrogen and oxygen are determined as follows:

$$\mathrm{U_{f_{H_2}}} = \frac{\mathrm{n^r H_2}}{\mathrm{n^{In} H_2}} = \frac{60{,}000RTNi_{fc}}{2F\mathrm{P_{fuel}}V_{lpmf}\, x\%} \qquad (12)$$

$$\mathrm{U_{f_{O_2}}} = \frac{\mathrm{n^r O_2}}{\mathrm{n^{In} O_2}} = \frac{60{,}000RTNi_{fc}}{4F\mathrm{P_{air}}V_{lpma}\, \mathrm{y\%}} \qquad (13)$$

where V_{lpmf} and V_{lpma} are flow rates of hydrogen and air in (L/min), 60,000 is a constant that comes from the conversion in the (litre/min) flow rate model (m^3/s) given as (1litre/min = 1/60,000m^3/s).

Design of the Fuel Cell Block

The designing of the fuel cell plant is achieved based on the mathematical equations derived from [9]. This comprises of a steady and dynamic state features.

Steady State Model

According to (Lee. C. H, and Yang. J. T, 2015), this model consists of a reversible potential (E_{nernst}), activation voltage loss (V_{act}), ohmic voltage loss (V_{ohm}), and concentration voltage loss (V_{conc}). The Nernst potential equation is expressed in equation (14).

$$V_{cell} = E_{nernst} - V_{loss} \qquad (14)$$

where

$$\begin{aligned} E_{nernst} &= 1.229 + 0.85 \mathrm{x}\, 10^{-3}(\mathrm{T} - 298.15) + 4.31 \\ &\mathrm{x}\, 10^{-5}\ \mathrm{x\ T\ x} \left[\mathrm{In}(\mathrm{pH_2} + \frac{1}{2}\ln(\mathrm{p0_2})) \right] \end{aligned} \qquad (15)$$

$$V_{loss} = (V_{act} - V_{ohmic} - V_{conc}) \qquad (16)$$

$$V_{cell} = E_{nernst} - (V_{act} - V_{ohmic} - V_{conc}) \qquad (17)$$

where pH_2 and pO_2 denotes partial pressures of hydrogen and oxygen in (atm), T is the temperature stated in Kelvin.

The Nernst reversible voltage is an open circuit voltage (OCV) of the SOFC when the current density $(\mathrm{I_{fc}})$ is zero. The activation voltage loss is given by the Butler-Volmer expression according to (Chen. H. C, Tzeng. S Y, and Chen. P. H.,2010) in equation (18).

$$\mathrm{I_{fc}} = \mathrm{I_o}\left(\mathrm{e}^{\frac{(\propto_1 \mathrm{nF})}{\mathrm{RT}}\mathrm{V_{act}}} - \mathrm{e}\left(\frac{-\propto_2 \mathrm{nF}}{\mathrm{RT}}\right)\mathrm{V_{act}}\right) \quad (18)$$

where Io is the exchange current, $\propto$is the coefficient of charge transfer n = 2 is the number of moles of electrons transferred. More so, the concentration voltage loss can be calculated from (Abraham. G, Debangsu. B, and Reghunathan. R., 2012) in equation (19).

$$\mathrm{V_{conc}} = \frac{\mathrm{RT}}{\mathrm{nf}}\,\mathrm{In}\left(\frac{\mathrm{C_b}}{\mathrm{C_\propto}}\right) \qquad (19)$$

where C_b is the concentration at the three-phase boundary (tpb) of gas, electrolyte and electrode meeting, $C_\propto$is the bulk concentration reactant.

The ohmic voltage loss is generated by charge in cell temperature described by (Abraham. G, Debangsu. B, and Reghunathan. R.,2012) in equation (20).

$$\mathrm{V_{ohmic}} = \left(\gamma \exp\left[\beta\left(\frac{1}{\mathrm{T_o}} - \frac{1}{\mathrm{T}}\right)\right]\right)\mathrm{I_{fc}} = \mathrm{rI_{fc}} \quad (20)$$

where T is the fuel cell temperature (T_o = 323 K), $\gamma = 0.2$ ohms and $\beta =$ -2870 K are constant coefficients of the fuel cell and r is the internal resistance of the SOFC.

Dynamic State Design

The dynamic state characteristic design on the operation of a fuel cell is hinged to the double layer charging effect. Thus, this relationship is expressed in the following equation (Xiao. Y, and Agbossou., 2015).

$$\frac{dV_d}{dt} = \frac{1}{C_{d1}} - \frac{V_d}{R_a \times C_{dc}} \qquad (21)$$

where Cd_1 is the double layer charge with V_d and Ra expressed in equation (22-a) and (22-b)

$$V_d = Vact + Vconc \qquad (22\text{-a})$$

where Ra is

$$R_a = \left(\frac{V_{act}+V_{conc}}{i}\right) \qquad (22\text{-b})$$

Based on the load requirement of the computer center, the design specifications for the fuel cell is given in Table 1.

Table 1. Fuel cell design specifications (Himadry, S, D.et al.,2013)

Descriptions	**Values**	**Units**
Rated Power	6000	W
Voltage at Max. power	100-200	V
No of Cells	170	-
Unit cell output voltage	1.18	V
Current (I)	0 – 100A	A
Operating Temperature	323.5	K
Pressure at Anode (Pa)	2.3816	Atm
Pressure at Cathode (Pc)	2.3816	Atm
Thickness, L	178e-4	Cm
Fuel Cell area	232	cm^2

Design of Power Conditioning Units

The Solid Oxide Fuel Cell (SOFC) is connected to the Power Conditioning Units (PCU) due to its main function of adjusting power factor and stabilizing unregulated DC voltages (Krykunov. O.,2017). This provides the connection between the fuel cell output voltage and the load which thus regulates and converts the DC power to a usable AC "load/grid" power electric current.

DC – DC Converter Design

The DC-DC boost converter is a unidirectional converter which converts the low output voltage of a system into a high voltage DC. Using the Faraday's law for the boost inductor, (Senthil K.A., et al., 2015) shows the following equation.

$V_s.\alpha T = (V_o - V_s)(1 - \alpha)$ (23)

where V_s is the voltage source (input voltage), V_o is the output voltage, α is the duty ratio and T is the time in (s).

The direct current transfer function is the ratio of the output voltage to the input voltage as shown in equation (24).

$$B_v = \left(\frac{V_o}{V_s}\right) = \left(\frac{1}{1-\alpha}\right) \qquad (24)$$

Since output is greater than input voltage, it operates in continuous condition mode for $L > L_b$ as shown in equation (25).

$$L_b = \left((1-\alpha)^2 D \left(\frac{R}{2f_s}\right)\right) \qquad (25)$$

where L_b is boundary value for inductor (Henry), f_s is the switching frequency, D is the duty cycle, R is the load resistance (ohms), and L is the circuit inductor.

Therefore, $D = \frac{(1-\alpha)^2 R}{f_s L} \geq 5\%$ (26)

Design of the Boost Converter

In this work, equations 3.31 is employed for the design of the boost converter using an inductor, a capacitor and other components.

Calculation of Duty cycle (D):

Duty Cycle (D) $= \frac{V_{output}}{V_{input}} = \frac{1}{(1-\alpha)}$ (27)

According to (Aminu, 2015), using smaller values for current ripple factor (CRF) and voltage ripple factor (VRF) less than 30% will generate less ripples at the boost converter output current and voltage. Hence no need to include a filter to the converter circuit design and the output voltage can be connected to the inverter without filtering.

CRF is selected as 15% $\left(\frac{\Delta I_1}{I_1}\right)$ and VRF is selected as 5% $\left(\frac{V_o}{V_i}\right)$ with switching frequency (f_s) as 25 kHz.

Inductor value calculation is given by:

$$L = \frac{V_o D}{f_s(\Delta I)} \qquad (28)$$

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$$L = \frac{V_o D}{f_s(\Delta I)} \qquad (28)$$

Output resistance (R_{out}) is shown in equation 3.33.

$$R_{out} = \frac{V_{input}}{I_{output}} \qquad (29)$$

Capacitor (C) value is expressed as:

$$\frac{\Delta V_{in}}{V_{out}} = \frac{DT_s}{R_{out}C} \qquad (30)$$

$$C = \frac{D}{R_{out}f_s} \times \frac{1}{\Delta V_{output}/V_{output}} \qquad (31)$$

The specification parameters of the DC/DC boost converter are shown in Table 2.

Table 2. DC – DC Boost Converter Parameters (Himadry, S, D., et al.,2013).

Descriptions	Values	Units
Input Voltage	100-200	V
Rated output Voltage	250	V
Rated power	6000	W
Switching Frequency	25	kHz
Inductor (L)	1e-3	mH
Capacitor (C)	2e4	µf
Equivalent Load (R)	100	Ω
Duty Cycle (D)	1.25	-
Integral gain (Ki)	0.1	-
Proportional gain (Kp)	1	kHz

DC – AC Converter Model

The DC/AC converter produces an AC output from the DC voltage by converting the DC voltage into a Vrms sinusoidal AC voltage. The average value inverter model is a voltage source (VS) type with an AC voltage/current reference signal (Erickson. R, W, and Maksimovic. D., 2014). This generates a three phase current and voltage at the inverter output. When saturated, it operates in square wave mode and the current source (IS) are replaced with the voltage sources (VS). A model description is shown in figure 3.

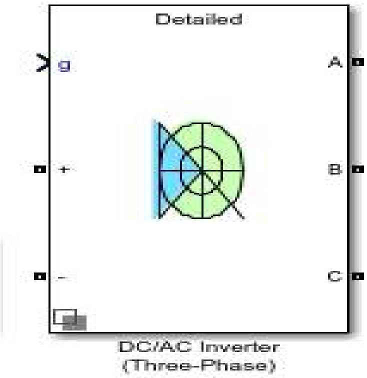

Fig 3. DC-AC Three Phase Inverter Model

Design of the Inverter

A three-phase pulse width modulation (PWM) with modulating index set as 0.8 is applied. The main components of the inverter system are the input capacitor, IGBT/diodes for switching frequency and the output filter. The inverter circuit parameters are given in the Table 3.

Table 3. DC – AC Converter Parameters (Himadry, S, D. et al.,2013)

Descriptions	Value	Units
Rated input voltage	400	V
Rated output voltage	220Vrms	Vac
Rated Power	6000	W
Career frequency, fs	1.950	kHz
DC link Capacitor, Cdc	12e3	µf
Integral gain (Ki)	1.15	-
Filter inductance, (Lf)	2	mH
Filter Capacitance,(Cf)	100	µF
Proportional gain (Kp)	0.15	-

The proportional integral (PI) and frequency controller is designed for the inverter system. Where the actual load voltage rated in per unit signal is converted to root mean square (rms) value and then compared with reference voltage (Trigg. M, and Nayar, 2016). The resultant error signal is now fed to the PI controller which provides the duty ratio in the range of 0V to 0.85V and it is then multiplied with a sinusoidal reference signal of fundamental frequency of 50 Hz to provide the main command signal for the inverter PWM.

Overall SOFC System Connected

The system entails a solid oxide fuel cell SOFC plant connected to a three-phase 6 kW load over an integrated bipolar transistor inverter. The inverter makes use of hysteresis in switching and regulating the active power by manipulation of direct current however stationing the reactive power at 0VAr. The voltage and current signals from the fuel cell are measured by the voltage and current measurement block. The overall system connected to the load block is shown below in fig. 4.

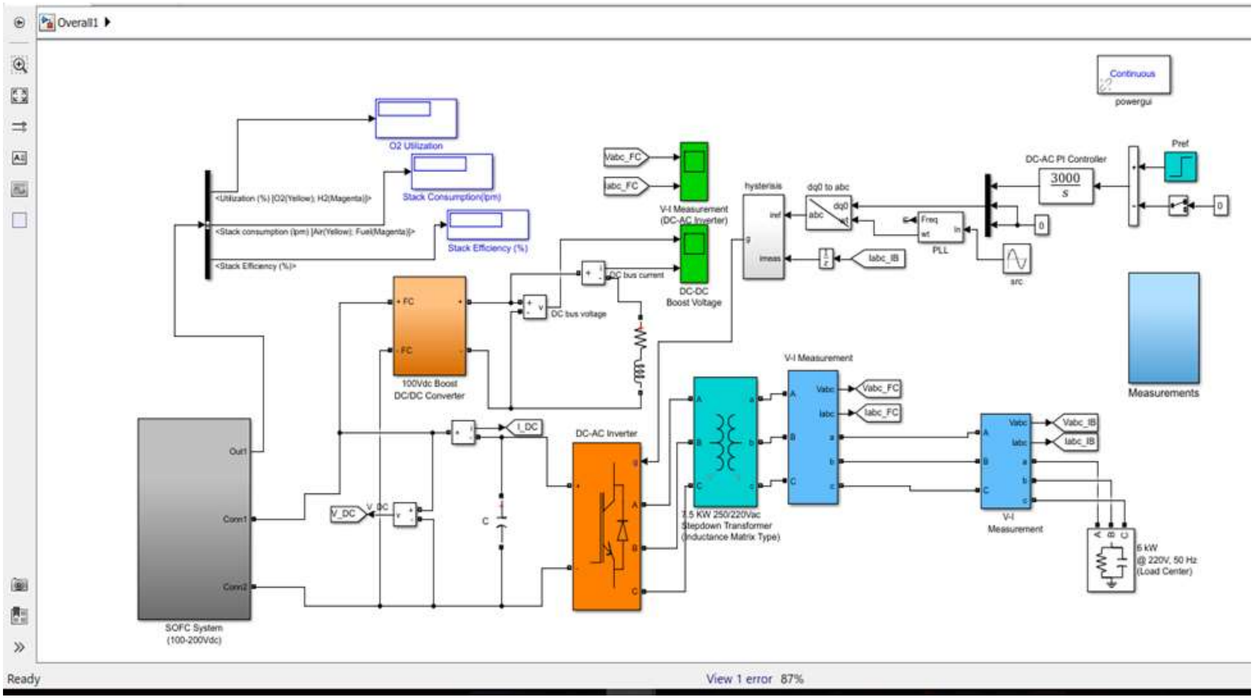

Fig 4. Overall SOFC system Connected to the Load Block

The measured signal from the fuel cell is fed to the integrated bipolar transistor (IGBT) inverter and stepped down by a transformer from inverter voltage of 250/220Vac. The voltage and current from the transformer are measured by a Three-Phase V-I measurement block. The inverted signal passes through an LC filter in order to remove any trace of DC signal, ripples or distortions and then fed into the 6 kW load block. A simplified model of the system is depicted below to reduce complexity.

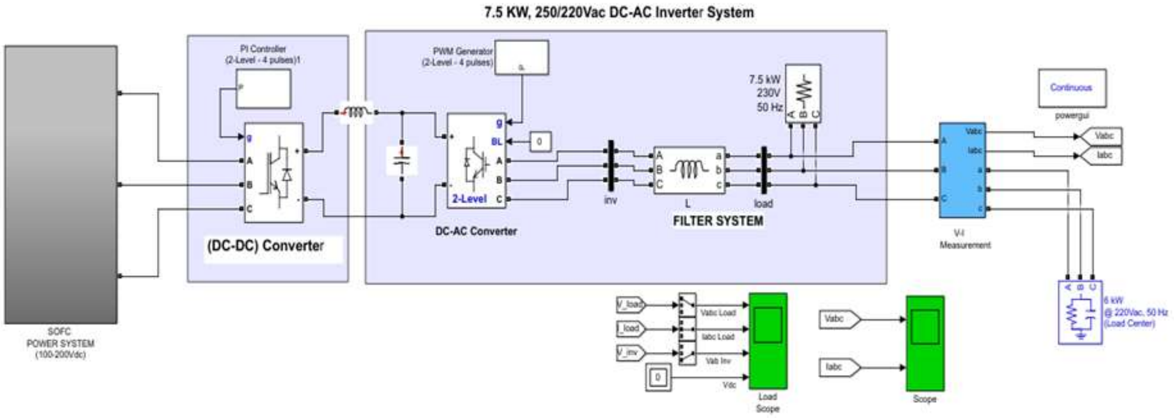

Fig 5. Simplified Overall SOFC system Connected to the Load Block

Given the above simulation block diagram, the simplified system is presented which shows the fuel cell power plant interfaced to the power conditioners via a filter circuit to the load block. It can be noticed that the load changes in the power system can be effectively controlled by controlling the internal parameters of the fuel cell.

Results and Discussion

In this work, the discrete time simulation was carried out at a simulation time of 1 second and sampling time of 5.144e-6 sec. The result shows that the percentage utilization of oxygen and hydrogen by the fuel cell is in the ratio (59.3%: 99.56%). The stack consumption (Air and Fuel) is in the ratio (248: 69.48). The stack efficiency is 54.93%. This evaluation demonstrates that the fuel cell system runs efficiently and proficiently.

DC-DC Converter Characteristics

Figure 6: shows the DC-DC boost converter system of a DC output voltage. The output voltage starts from zero point after been fed with a voltage ranging from 100-200V at start uptime of 0.1sec and gradually rises to a stable voltage of about 250V at same simulation time. It was observed that the DC-DC boost converter was used to enhance the voltage level from the fuel cell power plant.

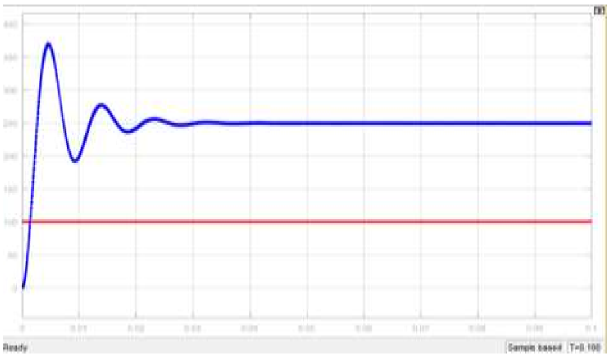

Fig 6. DC-DC Boost Output Voltage

DC-AC Converter Characteristics

The DC-AC inverter uses the pulse width modulation (PWM) signals from the duty ratio already set up to convert the DC into an AC power (Vac). During this conversion, both the voltage and frequency of the fuel cell system was regulated. Figure 7 and 8 shows the plot of the inverter system AC voltage and current signals. Note that a three-phase inverter system was used because most of the loads are in three phases and for the purpose of grid connection too.

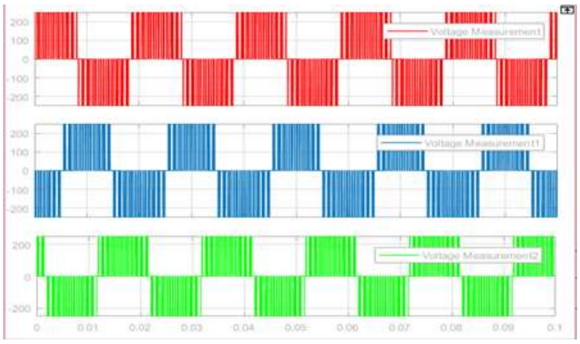

Fig 7. DC-AC Output Voltage Measurement

Figure 8. shows the AC voltage measurement plot of the inverter system. This validates the inverter output voltage waveform which is in square wave form, before been passed through the filter circuit block connection.

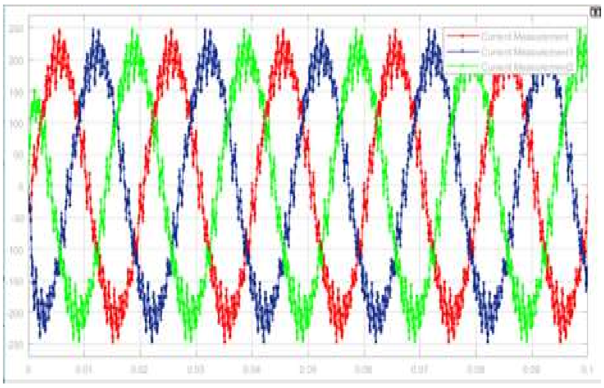

Fig 8. Output Current Measurement

From figure 4.6, the inverter output current is plotted. Although the waveform shows less distortion but sinusoidal in nature. Connecting the filter will make it a pure sine wave to be fed to the AC load block.

Overall System Connected to Electrical Load

Connecting to the load, the SOFC power plant was interfaced through the power conditioning units. The LC filter circuit block in parallel with the power conditioners, to filter off ripples and distortions. The generated power must be the same with the load demand.

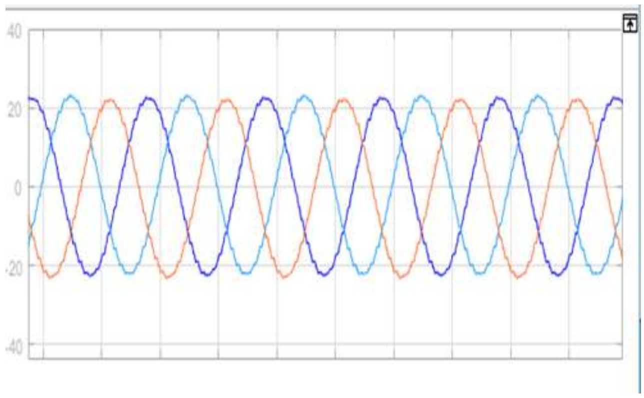

Fig 9. Output AC Pure Sinusoidal wave Vac_load

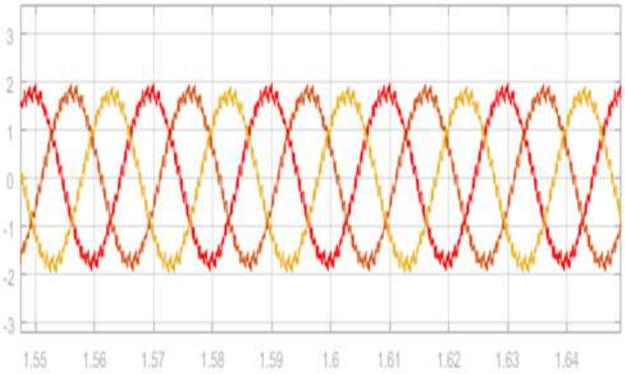

Fig 10. Load Current AC Output signals

Figure 4.8 and 4.9 shows the output pure sinusoidal wave Vab and load current for the demanded load. It clearly shows that it is within acceptable limit of the generated power from the fuel cell power plant to conveniently handle the load.

Conclusion and Recommendations

Studies have been undertaken with the Solid Oxide fuel cell (SOFC) power plant which was able to generate 6 kW of power with the electrical and physical parameters been discovered to be within the desired limits. The Solid Oxide fuel cell coupled with suitable power conditioning devices and controllers, have also demonstrated outstanding potential for standalone generation.

Furthermore, with the presence of this power electronic devices, the fuel cell slow dynamic issue was taken care of. To handle this situation, various alternative energy sources and storage devices can be joined. It will not only increase the reliability of the system applicability, but also improve the performance of the integrated system as the energy is clean and environmentally friendly.

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References

Abraham.G, Debangsu. B, & Reghunathan. R. (2012). Solid Oxide Fuel Cell Modelling. *IEEE Transactions on Industrial Electronics*, 56, (1), 141-144, January 2012.

Aminu Jibril. 2015.Modelling and Simulation of a Grid Connected Hydro-Hybrid System To Supplement Power Supply in Kaduna North. A Masters Dissertation, Department of Electrical and Computer Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria, November, 2015

Bolumil.M. H. (2015). Modeling and Simulation for 1.2kW PEM Fuel Cell Power Generation of Isolated Load Conditions. *International Conference on Electrical Drives and*

Chen. H. C, Tzeng. S Y, &Chen. P. H. (2010). Optimization design of PID controllers for PEMFC with reformer using genetic algorithm. in *Machine Learning and Cybernetics (ICMLC), 2010International Conference on*, 2010, 2990-2995.

Devender, S, Sushil, K, & Shiba, A. (2015) Oxide Fuel Cell for Distributed Generation using Simulink. *International Journal for Research in Applied Science and Engineering Technology (IJRASET),* .3, 675-681, June 2015, ISSN 2321-9653,

Erickson. R, W, & Maksimovic. D. (2014). Edition, NY, Kluwer Academic Publishers.

Trigg. M, & Nayar. C. (2016). Matlab Simulink modelling of a single-phase voltage-controlled voltage source inverter. *Electrical Engineering,* 1-6.

Hosseinzadeh, S, Golkar, M.A, Shokri, S, & Hajizadeh, A. (2016) Reliability Improvement and Loss Reduction of Distribution System with Distributed Generation. International *Power System Conference (PSC2006),* 13-15 Nov. 2016, Tehran-Iran.

Himadry, S, D, Chee Wei, T, A. H. M. Yatun, Nik Din, B. M. (2013). Modeling and Simulation of Stand-Alone Fuel Cell System for Distributed Generation Application. Department of Electrical Power Engineering, Faculty of Electrical Engineering, Universiti Teknologi, Malaysia, Johor, Malaysia.

Huang. X, Zhang. Z, & Jiang. J. (2016). Fuel Cell Technology for Distributed Generation: An Overview. *IEEE Symposium on Industrial Electron*, 1618-18.

Khan. M. J & Iqba. M. T. (2015). A Fuel Cell Generator. Modeling of Fuel Cell System, Faculty of Engineering and Applied Science, Memorial University of Newfound Land, St. John's, NL, Canada A1B, August 24.

Krykunov. O,. (2017). Comparison of the DC/DC Converters for Fuel Cell Applications. *International Journal of Electrical, Computer and Systems Engineering,* 71-79.

Senthil K.A, &Thomas. C, (2015) Stanislav. *Power Electronics (EDPE),* 1(3), 236 – 238.

Lee. C. H, & Yang. J. T. (2011). Modeling of the Ballard- Mark-V proton exchange membrane fuel cell with power converters for applications in autonomous underwater vehicles. *Journal of Power Sources,* 196, 3810-3823.

Miao, Z, Choudlry, M, A, Klien & R, L, Fan, L. (2013). Study of A Fuel Cell Power Plant in Power Distribution System – Part 1: Dynamic Model. Lane Department of Computer Science and Electrical engineering, WV, 26506 – 6109, USA, *IEEE – PES, General Meeting,* 2. 2220 – 2225, June 2013.

Prabha R, A. (20140). An Advanced Fuel Cell Simulation. Thesis, Master of Science, College of Engineering Pune, India. August 2014.

Prema. N. K, Nirmala. K. K, & Rosalina. K.M. (2012) Modelling Design Solid Oxide fuel Cell Power System for Distributed Generation Applications. *International Journal of Advanced Research in Computer Engineering and Technology, (IJARCET)*, 1(9), November, 2012.

Tae-Won, L, Byoung-Kuk, L, Su-Jin, J, Sung-Ho, K & Chung-Yuen, W (2014). Development of A 3kW Fuel Cell Generation System with An Active Fuel Cell Simulator:Topology, Control, and Design. *Korea Electro-technology Reserch Institute (KEN), P.O. Box 20, Changwon, 641-600, Korea, 35th Annul IEEE Power*

Electronics Specialists Conference, Dept. of Information & Communication Engineering, Sung Kyun Kwan University, Suwon, 440-746, Korea, 2014.

Xiao. Y, & Agbossou. K. (2015). Interface design and software development for PEM fuel cell modeling based on Matlab/Simulink environment.in *Software Engineering, 2009. WCSE'09. WRI World Congresson*, 318-322