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Grid Connected Fuel Cell Based Boost Inverter for Standalone Applications

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ABSTRACT

This paper presents a MATLAB based simulation results of a fuel cell based boost inverter for standalone grid applications. In this paper, boost inverter is uses to increases the input level of the d.c voltage from the designed fuel cell. In addition, the proposed system incorporates battery-based energy storage and a dc–dc bidirectional converter to support the slow dynamics of the FC. The proposed boost inverter can regulate the active power (P) and reactive power (Q) for the grid. The proposed fuel cell, boost inverter and its integration for standalone grid application was modelled and simulated in MATLAB 2009a GUI environment using Simulink and Sim Power System set tool boxes by using ode23tb solver.

I. Introduction

Advancement in the research of Power electronic inverters is still increasing with the rapid demands in electrical systems. In the case of grid-connected systems using renewable energy sources, the total active power can be fed to the grid. For standalone systems supplying local loads, if the extracted power is more than the local loads (and losses), the excess power from the wind turbine is required to be diverted to a dump load or stored in the battery bank. Moreover, when the extracted power is less than the consumer load, the deficit power needs to be supplied from a storage element, e.g., a battery bank [1]. In the case of stand-alone or autonomous systems, the issues of voltage and frequency control (VFC) are very important [2].

Modelling and simulation are important for electrical system capacity determination and optimum component selection. The battery sub-model is a very important part of an electrical system simulation, and the battery model needs to be high-fidelity to achieve meaningful simulation results. Current lead-acid battery models can be expensive, difficult to parameterize, and time consuming to set up. In this paper, an alternative lead acid battery system model has been proposed, which provided drive cycle simulation accuracy of battery voltage within 3.2%, and simulation speed of up to 10,000 times real-time on a typical PC. In Fig.1, a conventional design process is contrasted with Model-Based Design for electrical system component selection.

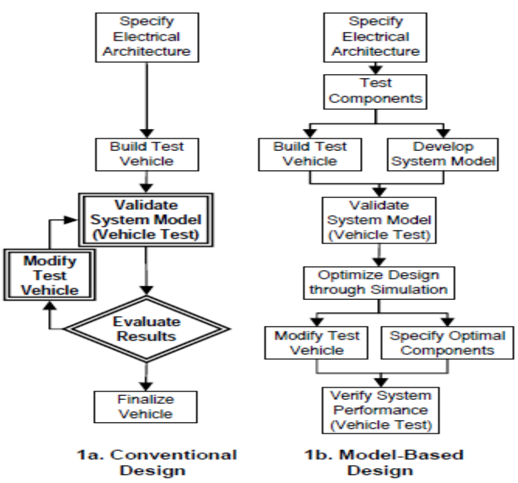

Fig. 1. Component selection processes

A single-stage FC system based on a boost inverter has been proposed in [17]. The single-stage system is able to minimize the problems with the two-stage FC power conditioning system [17]. The paper reported overall efficiency dealing with the single-stage and conventional two-stage FC systems. The total efficiency of the single-stage system has been improved around 10% over the range of the power rating and [17]. The paper illustrated the performance of a stand-alone FC system using the boost inverter with a bidirectional backup storage unit to support the slow dynamics of the FC and to cancel the ripple current that causes reduction of the lifetime and efficiency of the FC [17]–[19]. However, the performance and operating characteristics of such a system for grid applications is an important step forward that is yet to be reported in the technical literature.

The objective of this paper is to propose and report full experimental results of a grid-connected single-phase FC system using a single energy conversion stage only. In particular, the proposed system, based on the boost inverter with a backup energy storage unit, solves the previously mentioned issues (e.g.,the low and variable output voltage of the FC, its slow dynamics, and current harmonics on the FC side). The single energy conversion stage includes both boosting and inversion functions and provides high power conversion efficiency, reduced converter size, and low cost [17]. The proposed single-phase grid-connected FC system can operate either in grid-connected or stand-alone mode. In the grid-connected mode, the boost inverter is able to control the active (*P*) and reactive (*Q*) powers through the grid by the proposed *PQ* control algorithm using fast signal conditioning for single-phase systems [20].

II. Electrical Design of Proposed Inverter with Fuel Cell for Power Balance

Fig.2. shows the proposed boost inverter with fuel for power balance in a standalone grid application. In Fig.3. , the backup unit and the FC power module are connected in the unregulated dc bus and the boost-inverter output is connected to the local load and the grid. The proposed system consists of two power converters: the boost inverter

and the bidirectional backup unit. The boost inverter is supplied by the FC and the backup unit, which are both connected to the same unregulated dc bus, while the output side is connected to the load and grid through an inductor. The system incorporates a current-mode controlled bidirectional converter with battery energy storage to support the FC power generation and a voltage-controlled boost inverter. The FC system should dynamically adjust to varying input voltage while maintaining constant power operation. Voltage and current limits, which should be provided by the manufacturers of the FC stack, need to be imposed at the input of the converter to protect the FC from damage due to excessive loading and transients. Moreover, the power has to be ramped up and down so that the FC can react appropriately, avoiding transients and extending its lifetime. The converter also has to meet the maximum ripple current requirements of the FC [6].

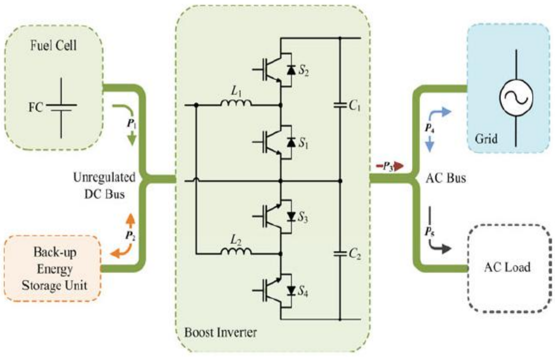

Fig.2. Block diagram for the proposed grid-connected FC system

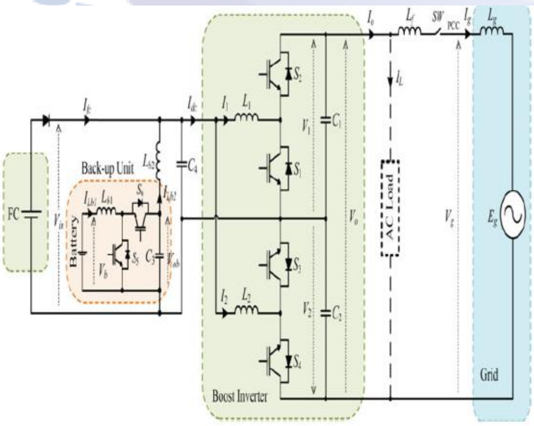

Fig.3.General structure of the proposed grid-connected FC system.

The currents through $L1$ and $L2$ are controlled by PR controller to achieve a stable operation under special conditions such as nonlinear loads and transients. The output voltage reference is determined by

$$V_{o.\mathrm{ref}} = (V_{\mathrm{PP}} + dV_{\mathrm{PP}}) \cdot \sin(\omega_o t + \delta),$$
$$A_o = V_{\mathrm{PP}} + dV_{\mathrm{PP}} \text{ and } \theta = \omega_o t + \delta$$

Where Vpp is the peak value of the typical grid voltage, $dVpp$ is a small variation of the output voltage reference affecting to the reactive power, ωo is the grid fundamental angular frequency, and δ is the phase difference between Vo and Vg relating with the active power.

The active and reactive powers at the point of common coupling (PCC) are expressed by

$$P = \frac{V_g \cdot V_o}{\omega_o \cdot L_f} \sin(\delta)$$
$$Q = \frac{V_g^2}{\omega_o \cdot L_f} - \frac{V_g \cdot V_o}{\omega_o \cdot L_f} \cos(\delta)$$

Where Lf is the filter inductance between the grid and the boost inverter. The detailed design parameters are given by Table.1

Table.1. Design Parameters

FC output voltage	36-69V (72-Cell FC)
AC output voltage	220V RMS, Single phase, 50Hz
AC Grid voltage	220V, 50Hz
Switching frequency	20kHz
Output power	1kW
V_{in}	42V (min)
R_a (resistance of L_1 and L_2)	≈10$m\Omega$
V_1(t)	353V (max)
V_2(t)	42V (min)
Δt_l (maximum on time)	42.5μs (max at 20kHz)
Δi_{Lmax}	5% of $i_{L(max)}$
ΔV_c	5% of V_{1max}
R_1 (load)	48.4Ω at 1kW
V_b (battery voltage)	22V(min)-27.3V(max)
I_{Lb1}	45.5A (max)

III. MATLAB Based Simulation & Results

A. MATLAB Simulation :

By using the electrical calculation parameters from the section II , the designed proposed fuel cell based boost inverter is given by Fig.4.

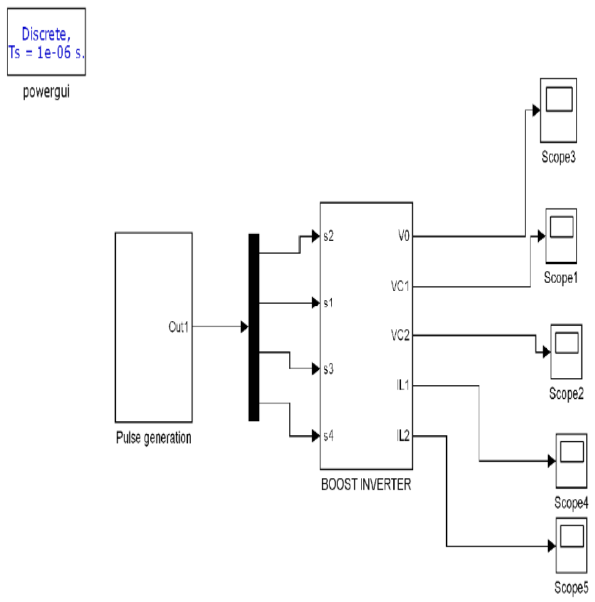

Fig.4. MATLAB based simulation masked diagram of proposed system

Fig.5. shows the inner blocks of a proposed fuel cell (FC) and Fig.6. shows the power circuit of the proposed system.

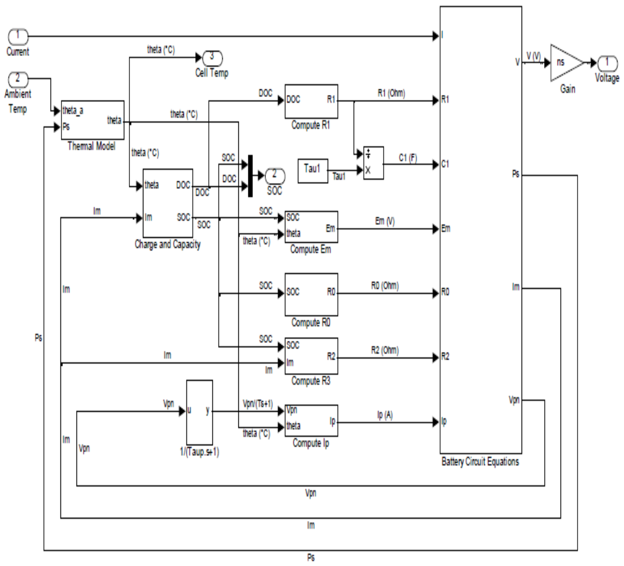

Fig.5. MATLAB based simulation masked diagram of proposed FC

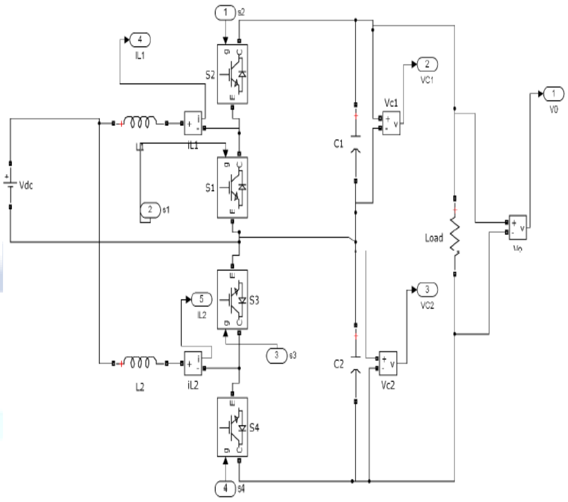

Fig.6. Power circuit of the proposed system.

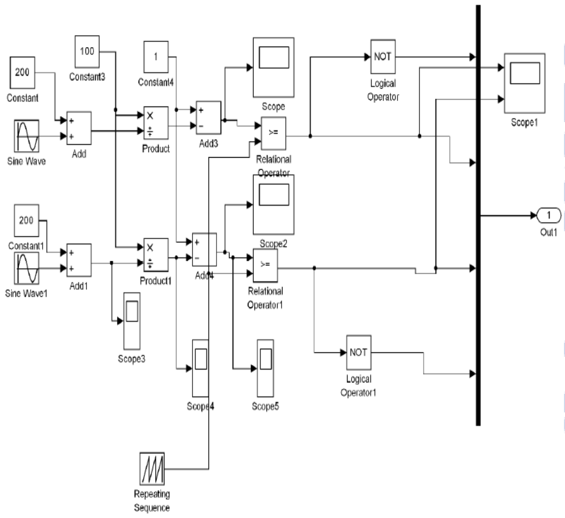

Fig.7.Trigerring circuit for boost inverter

B. Simulation Results :

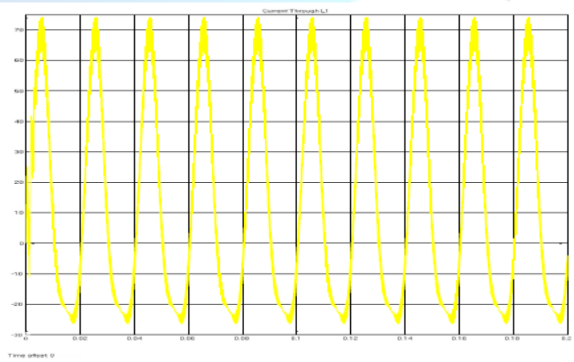

Fig.8.Current through inductor L1.

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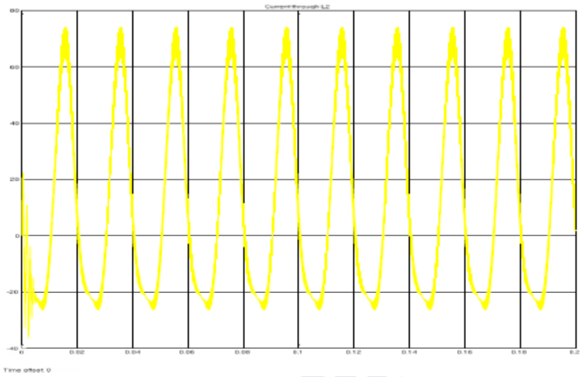

Fig.9.Current through inductor L2.

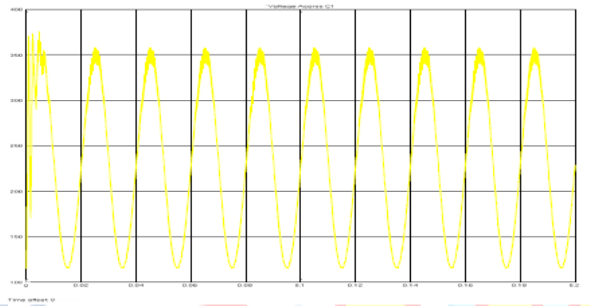

Fig.10. Voltage across capacitor C1

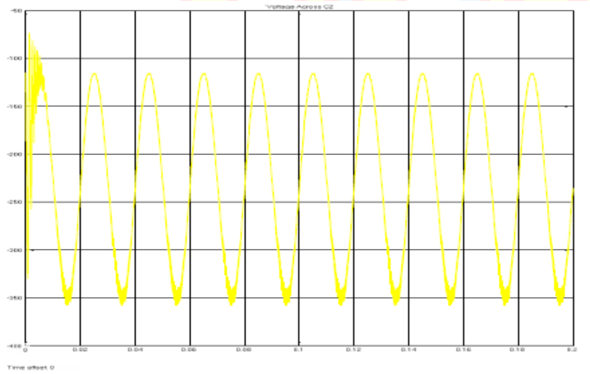

Fig.11. Voltage across capacitor C2

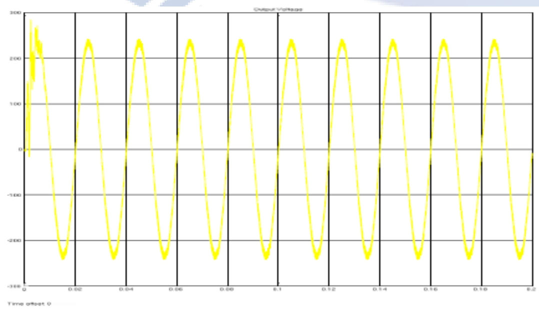

Fig.12. Load voltage

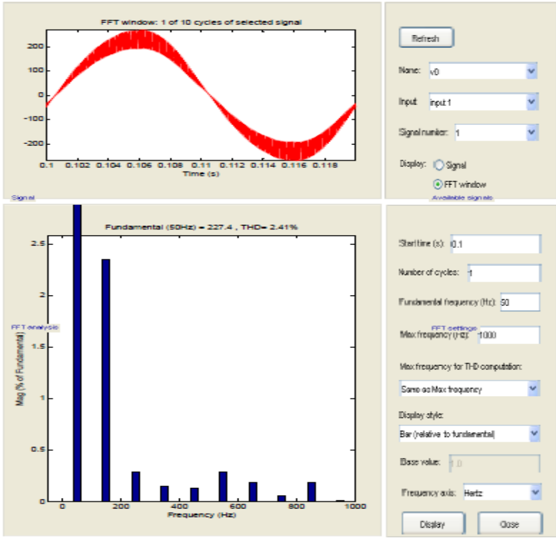

Fig.13. FFT analysis of load voltage for THD

CONCLUSION

Hence, the proposed FC system has been analyzed, designed, simulated, and tested experimentally to validate its overall performance. The simulations have been done using Simulink/MATLAB and block set to validate the analytical results. The ac output voltage of the system was chosen to be equal to 220 V, while the dc input voltage varied between 43 and 69 V. The simulation results show the operations of the boost inverter and the backup unit. Moreover, the backup unit protects the FC from potential damage by eliminating the ripple current due to the boost operation. Experimental results that confirm the feasibility of proposed boost inverter. Finally, MATLAB based simulink results shows the THD value at reasonable level.

REFERENCES

[1] Minsoo Jang, *Student Member, IEEE*, Mihai Ciobotaru, *Member, IEEE and Vassilios G. Agelidis, Senior Member, IEEE* , "A Single-Phase Grid-Connected Fuel Cell System Based on a Boost-Inverter" , IEEE Transactions on Power Electronics, Vol. 28, No. 1, January 2013 , pp. 279-288

[2] L. G. Franquelo, K. Gopakumar, S. Kouro, J. I. Leon, M. Malinowski, M. A. Pérez, J. Pou and B.Wu, J. Rodríguez, "Recent advances and industrial applications of multilevel converters" IEEE Trans. Ind. Electron ,2010, vol. 57, no. 8.

[3] K. Jin, X. Ruan, M. Yang, and M. Xu, "Power management for fuel-cell power system cold start," *IEEE Trans. Power Electron.*, vol. 24, no. 10, pp. 2391–2395, Oct. 2009.

[4] P. Thounthong, B. Davat, S. Rael, and P. Sethakul, "Fuel cell high-power applications," *IEEE Ind. Electron. Mag.*, vol. 3, no. 1, pp. 32–46, Mar. 2009.
[5] P. Ching-Tsai and L. Ching-Ming, "A high-efficiency high step-up converter with low switch voltage stress for fuel-cell system applications," *IEEE Trans. Ind. Electron.*, vol. 57, no. 6, pp. 1998–2006, Jun. 2010.
[6] A. Vazquez-Blanco, C. Aguilar-Castillo, F. Canales-Abarca, and J. Arau-Roffiel, "Two-stage and integrated fuel cell power conditioner: Performance comparison," in *Proc. IEEE Appl. Power Electron. Conf. Expo.*, comparison," in *Proc. IEEE Appl. Power Electron. Conf. Expo.*,
[7] M. Jang and V. G. Agelidis, "A minimum power-processing-stage fuel cell energy system based on a boost-inverter with a bidirectional backup battery storage," *IEEE Trans. Power Electron.*, vol. 26, no. 5, pp. 1568– 1577, May 2011.
[8] K. Jin, X. Ruan, M. Yang, and M. Xu, "Power management for fuel-cell power system cold start," *IEEE Trans. Power Electron.*, vol. 24, no. 10, pp. 2391–2395, Oct. 2009.
[9] P. Thounthong, B. Davat, S. Rael, and P. Sethakul, "Fuel cell high-power applications," *IEEE Ind. Electron. Mag.*, vol. 3, no. 1, pp. 32–46, Mar 2009.
[10] R.-J. Wai and C.-Y. Lin, "Active low-frequency ripple control for clean energy power-conditioning mechanism," *IEEE Trans. Ind. Electron.*, vol. 57, no. 11, pp. 3780–3792, Nov. 2010.
[11] H. Cha, T.-K. Vu, and J.-E. Kim, "Design and control of proportional resonant controller based photovoltaic power conditioning system," in *Proc. IEEE Energy Convers. Congr. Expo.*, Sep. 2009, pp. 2198–2205.
[12] *NP-Series Lead Acid Battery Manual*, (2007). [Online]. Available: http:// www.yuasa-battery.co.uk

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