# Fuel Cell System Based On Boost Inverter For Single Phase Grid Integration Using ANN

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*Abstract*—**Alternative energy sources, such as solar and fuel cells are desirable due to their pollution-free property. To utilize the current infrastructure of the grid for power transmission and distribution, grid-connected dc-to-ac inverters are needed.When a low-voltage unregulated fuel-cell (FC) output is conditioned to generate the ac power, two stages are required: a boost stage and an inversion one. Here the boost-inverter topology that achieves both boosting and inversion functions in a single-stage is used as a building block. It is used to develop a single-phase grid-connected FC-system which offers high conversion efficiency, low-cost and compactness.In addition, this system incorporates battery-based energy storage and a bidirectional dc-dc converter to support the slow dynamics of FC. The single-phase boost inverter is voltage-mode controlled and the bidirectional dc-dc converter is current-mode controlled. Artificial neural network is used here as the controller. The battery supplies the low-frequency current ripple which minimizes the effects of such ripple being drawn directly from the FC itself. Also, this system can operate either in a grid-connected or stand-alone mode. Simulation results are presented to confirm the performance of the proposed system.**

***Keywords—Boost inverter, fuel cell(FC), grid-connected inverter, PQ control***

## I. INTRODUCTION

Energy sources such as wind power systems, photovoltaic cells, and fuel cells have been extensively studied in response to global warming and environmental issues. For conditioning of both ac and dc loads,we can use alternative energy generation systems based on solar photovoltaics and fuel cells (FCs) . Also, size reduction and high efficiency are essential requirements. To achieve high-quality supply of power, the FC systems must be assisted by additional energy storage unit. An inversion stage is also required to power ac loads or to connect to the electricity grid when such systems are used.

The typical output voltage of low-power FC is low and variable on the load current. Due to the operation of components such as pumps, heat exchangers, and fuel-processing unit, the hydrogen and oxidant cannot respond the load current changes instantaneously. There will be cold-start which takes more than few seconds[1].

A two-stage FC power conditioning system to deliver ac power has been described. It encounters drawbacks such as being bulky and relatively inefficient. To alleviate these disadvantages, a topology that is suitable for ac loads and is powered from dc sources able to boost and invert the voltage at the same time has been proposed in [3]. The double loop control scheme of this topology has been proposed[4].A single-stage FC system based on a boost inverter has been proposed in[2], [5].

The aim of this paper is to introduce a grid-connected single-phase FC system using a single energy conversion stage only and also to present the simulation results. In particular, the proposed system, based on the boost inverter with a backup energy storage unit, solves the earlier mentioned issues. This single-stage including boosting and inversion functions provide a high power conversion efficiency, reduced converter size and low cost. The proposed single-phase grid-connected FC system can operate either in grid-connected or stand-alone mode.

Here neural network is used as the controller. Neural network has capabilities to approximate any nonlinear function relationship and more convenient learning means.

## II. PROPOSED FC ENERGY SYSTEM

### A. Description of the FC System

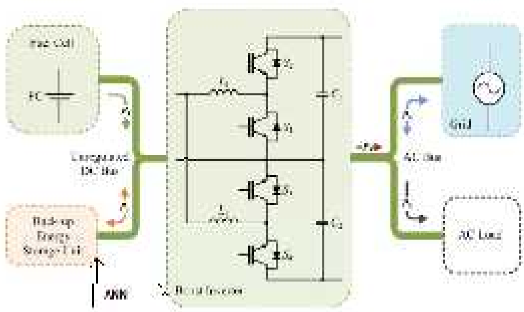


Fig. 1. Block diagram for the proposed grid-connected FC system. (P1: FC output power, P2: backup unit input/output power, P3: inverter output power, P4: power between the inverter and the grid, and P5: a power to the ac loads)

The block diagram shows the proposed grid-connected FC system in Fig. 1. Fig. 1 also shows the power flows between each part. This system consists of two power converters: the boost inverter and the bidirectional backup unit, as shown in Figs. 1 and 3. The FC and the backup unit are joined to the same unregulated dc bus, and the boost inverter gets supply from these two units.The output side is connected to the load and grid through an inductor. The system has a current-mode controlled bidirectional converter with battery energy storage to support the FC power generation and a voltage-controlled boost inverter.

In the grid-connected mode, the system is also providing active (*P*) and reactive (*Q*) power control.

### *B. Boost Inverter*

The boost inverter consists of two bidirectional boost converters. Their outputs are connected in series, as shown in Fig. 2. Each boost converter generates a dc bias with deliberate ac output voltage , so that each converter produces a unipolar voltage that is greater than the FC voltage with a variable duty cycle. Each converter output and the combined outputs are described by

$$V_1 = V_{dc} + 1/2 . A_1 . \sin \theta \quad (1)$$

$$V_2 = V_{dc} + 1/2 . A_2 . \sin(\theta - \alpha) \quad (2)$$

$$V_o = V_1 - V_2 = A_o . \sin\theta , when A_o = A_1 = A_2 \quad (3)$$

$$V_{dc} > V_{in} + \frac{A_o}{2} \quad (4)$$

where $V_{dc}$ is the dc offset voltage of each boost converter and have to be greater than 0.5 $A_o + V_{in}$.

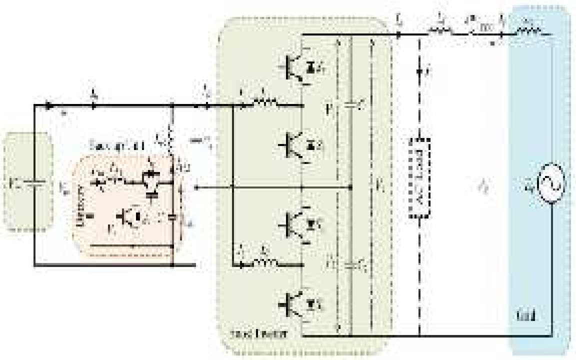

Fig. 2.The general structure of the grid-connected FC system.

### *C. Backup Energy Storage Unit*

There are two functions for the backup energy storage unit. First, the backup unit is designed to support the slow dynamics of the FC. Second, to protect the FC system, the backup unit generates low-frequency AC that is required for the boost inverter operation. The low-frequency current ripple supplied by the batteries has an impact on their lifetime, but between the most expensive FC components and relatively cheap battery components, the latter is preferable to be stressed by such low-frequency current ripple. The backup unit comprises of a current-mode controlled bidirectional converter and a battery as the energy storage unit.

## III. CONTROLLER

Boost inverter and backup unit uses artificial neural network as the controller. Boost inverter control also uses PI controller.

### *A. Boost Inverter Control*

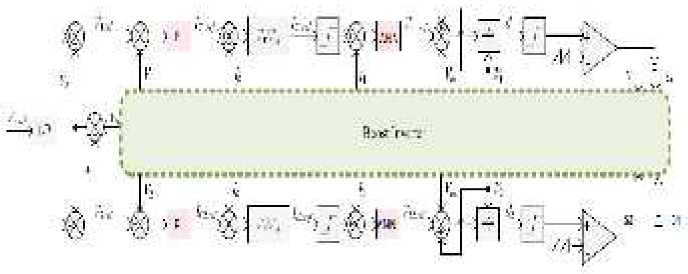

Fig. 3. Boost-inverter control block diagram.

A double-loop control scheme is chosen for the boost-inverter control.

The output voltage reference is divided to generate the two individual output voltage references of the two boost converters with the dc bias, $V_{dc}$. By adding the input voltage to the half of the peak output amplitude we can obtain the dc bias. $V_{dc}$ is also used to minimize the output voltages of the converters and the switching losses in the variable input voltage condition.

The output voltage reference is determined by

$$V_{o.ref} = (V_{pp} + dV_{pp}).\sin(\omega_o t + \phi)$$

$$when, A_o = V_{pp} + dV_{pp} and , \theta = \omega_o t + \phi \quad (5)$$

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, $\omega_o$ is the fundamental grid angular frequency, and $\phi$ is the phase difference between $V_o$ and $V_g$ relating to the active power.

### *B. Backup Energy Storage Unit*

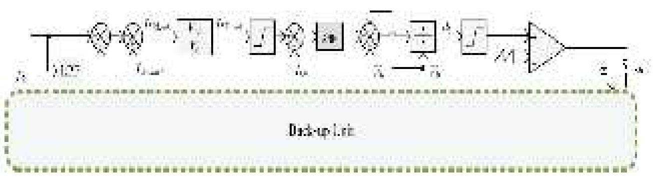

Fig. 4.The backup unit control blocks diagram.

The backup unit is controlled by the backup unit controller in Fig. 4. The reference of $I_{Lb1}$ is determined by $I_{dc}$ through a high-pass filter and the demanded current $I_{demand}$ that is related to the load change. The ac component of the current reference deals with eliminating the ac ripple current into the FC power module while the dc component deals with the slow dynamics of the FC.

### C. Control of the Grid Connected Boost Inverter

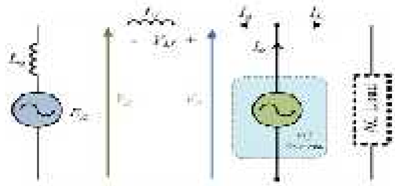

Fig. 5. The equivalent circuit of the grid-connected FC system.

Fig. 5 depicts the equivalent circuit of the grid-connected FC system consisting of two ac sources ($V_g$ and $V_o$ ), an ac inductor $L_f$ between the two ac sources, and the load. The boost inverter output voltage is indicated as $V_o$ and $V_g$ is the grid voltage.

The phase shift $\delta$ and voltage difference $V_g - V_o$ between $V_o$ and $V_g$ affect the active and the reactive powers, respectively.

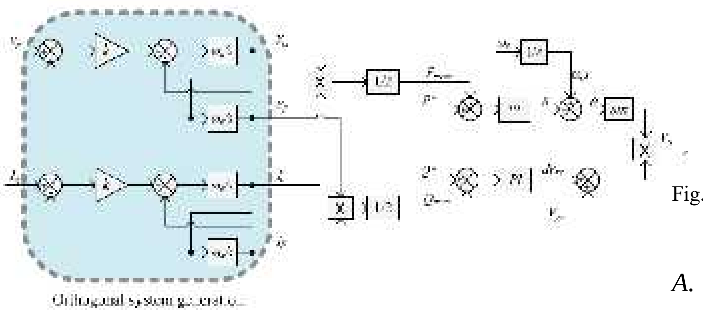

Fig. 6 . Boost-inverter output voltage reference generation block diagram with the *PQ* control algorithm.

Fig.6 illustrates the PQ control algorithm with the phase locked loop and the orthogonal system generator.

## IV. Artificial Neural Network

ANN is an interconnected group of nodes. The ANN is made up of an interconnection simple processing unit, known as neurons.

### A. Simple Neuron

Three distinct functional operations take place in this example neuron. Here,first, the input *p* is multiplied by the weight *w* to form the product *wp*. Second, the weighted input *wp* is added to the bias *b* to form the net input *n*. ( The bias is much like a weight, except that it has a constant input of 1.) Finally, the net input is passed through the transfer function *f*, which produces the output *a*. The three processes are the weight function, the net input function, and the transfer function. *w* and *b* are both adjustable parameters of the neuron.

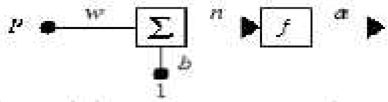

Fig. 7. A simple neuron.

## V. Simulation and Analysis

The introduced FC system has been analyzed and simulated to confirm its overall performance. The simulations have been done using MATLAB to validate the analytical results.

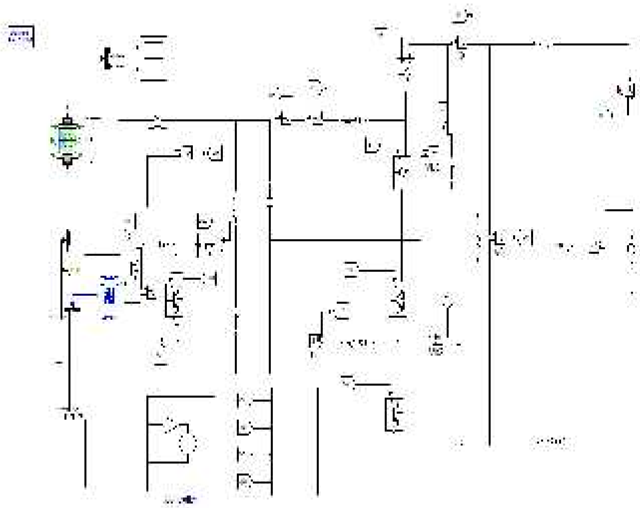

Fig. 8. The main block simulation Diagram for Grid connected FC system.

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### A. Boost Inverter Control

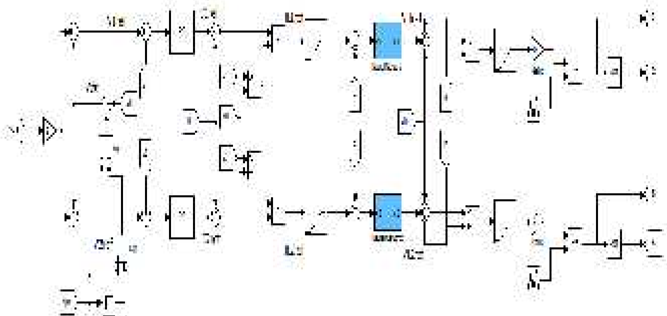

Fig. 9. Boost inverter control

The voltage references ( $V_{1.ref}$ and $V_{2.ref}$ ) are compared with the feedback voltages of the converters.After PI compensators, the reference currents of the capacitors are now obtained to be processed with the output current ( $I_o$ ).

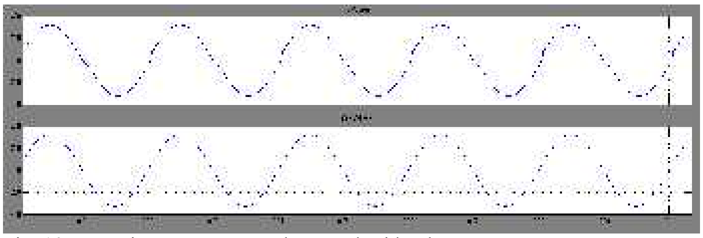

Fig. 10. Boost inverter output voltage and grid voltage.

### B. Backup unit Control

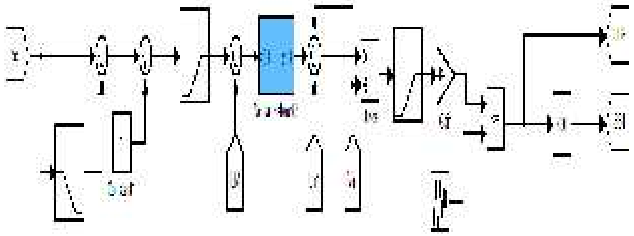

Fig. 11. Backup unit control.

The reference of $I_{Lb1}$ is determined by $I_{dc}$ through a high-pass filter and the demanded current that is related to the load change.The filtered component compares with $I_{Lb1}$ and is processed by the neural network.

### C. ANN

Here the neural network is used as the controller.

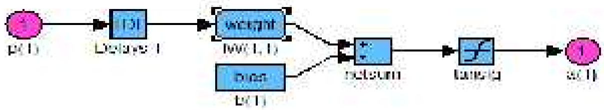


Fig. 12. Layer 1 of the neural network.

In the first layer transfer function used is tan sigmoid tf.

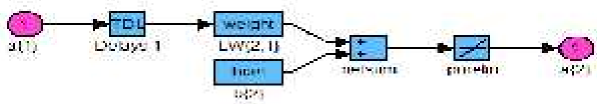


Fig. 13. Layer 2 of the neural network.

In the second layer transfer function used is purelin.

### D. PQ Control

The P-Q controller compares the actual values with the reference real and reactive powers.

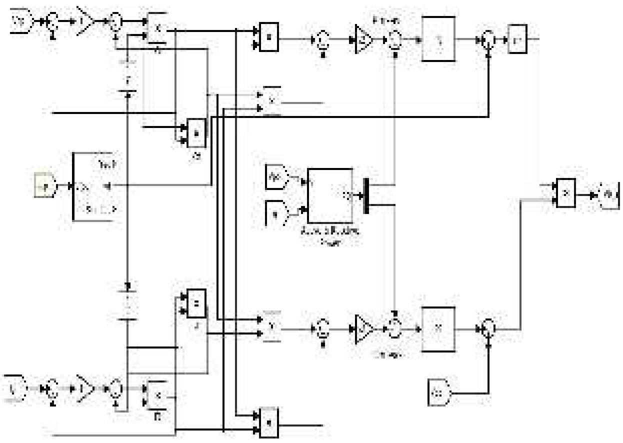

Fig. 14 PQ Control.

## VI. CONCLUSION

A grid-connected single-phase single power stage FC system based on the boost-inverter topology with a backup battery based energy storage unit is introduced in this paper. This gives the simulation results of the introduced FC system. In summary, the proposed FC system has some attractive features, such as single power conversion stage with high efficiency, simplified topology, low cost, and able to operate in stand-alone as well as in grid-connected mode. Also, in the grid-connected mode, the single-phase FC system is able to regulate the active and reactive powers by a PQ control algorithm.

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