

A Grid Connected Single Phase Hybrid Renewable Energy Source Based on a Single Conversion Stage with Battery Energy Storage System

**Nagesh Malothu**

M.Tech (Power Electronics),
Department of Electrical Engineering,
Sri Venkateswara Engineering College,
Suryapet, Nalgonda, T.S, India.

**Narendar Reddy Narra**

Assistant Professor,
Department of Electrical Engineering,
Sri Venkateswara Engineering College,
Suryapet, Nalgonda, T.S, India.

Abstract:

Integration of fuel-cell with single-phase grid, a boost converter is proposed in this paper. Battery Energy Storage System is proposed for storage of energy. Due to slow dynamics of fuel cell a bidirectional converter has been used. The single-phase boost inverter is voltage-mode controlled and the dc-dc bidirectional converter is current-mode controlled. The low-frequency current ripple is supplied by the battery which minimizes the effects of such ripple being drawn directly from the FC itself. The proposed system is having two modes of operations, are grid-connected and stand-alone modes. The active and reactive powers controlled by boost inverter, in grid connected mode.

Key words:

Hybrid energy system, BESS, Power Quality control, bidirectional converter.

I. INTRODUCTION:

In energy generation systems based on solar photovoltaic and fuel cells (FCs) need to be conditioned for both dc and ac loads. The overall system includes power electronics energy conversion technologies and may include energy storage based on the target application [1]-[2]. However, the FC systems must be supported through additional energy storage unit to achieve high-quality supply of power. When such systems are used to power ac loads or to be connected with the electricity grid, an inversion stage is also required.

The typical output voltage of low-power FC is low and variable with respect to the load current. For instance, based on the current-voltage characteristics of a 72-cell proton exchange membrane FC (PEMFC) power module, the voltage varies between 39 and 69 V depending upon the level of the output current [3]-[5]. Moreover, the hydrogen and oxidant cannot respond the load current changes instantaneously due to the operation of components such as pumps, heat exchangers, and fuel-processing unit. Caishen et al presented the cold-start which takes more than few seconds.

Thus, the slow dynamics of the FC must be taken into account when designing FC systems. This is crucial, especially when the power drawn from the FC exceeds the maximum permissible power, as in this case, the FC module may not only fail to supply the required power to the load but also cease to operate or be damaged. Therefore, the power converter needs to ensure that the required power remains within the maximum limit. A two-stage FC power conditioning system to deliver ac power has been commonly considered. The two-stage FC power conditioning system encounters drawbacks such as being bulky, costly and relatively inefficient due to its cascaded power conversion stages.

To alleviate these drawbacks, 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. The double loop control scheme of this topology has also been proposed for better performance even during transient conditions.

The proposed system, based on the boost inverter with a backup energy storage unit, solves the previously mentioned issues. The single energy conversion stage includes both boosting and inversion functions and provides high power conversion efficiency, reduced converter size, and low cost

**II. FUEL CELL ENERGY SYSTEM:
Design of fuel cell:**

The flow of power between the each section can be shown in fig 1. This system consists of two power converters: the boost inverter and the bidirectional backup unit. The maximum ripple current requirements of the FC. 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 [6]. The converter also has to meet them

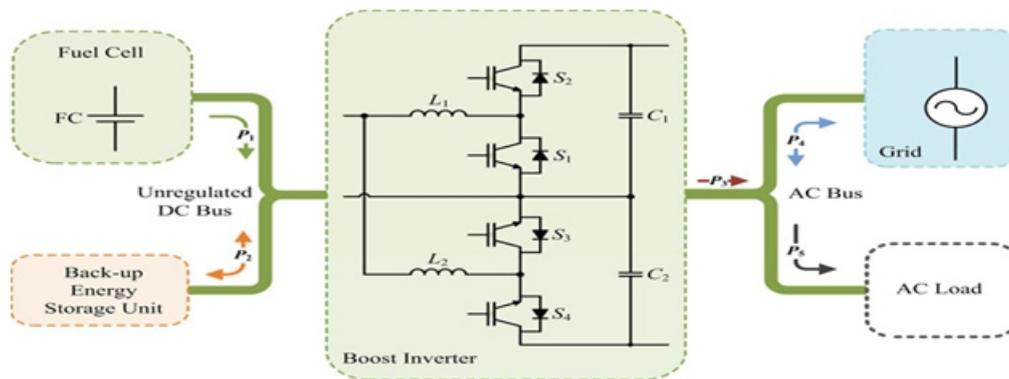


Fig 1: Block diagram for the proposed grid-connected FC system

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. (P1: FC output power, P2: backup unit input/output power, P3: inverter output power, P4: power between the inverter and the grid, and P5: power to the ac loads).

III. PROPOSED GRID-CONNECTED FC SYSTEM:

In the grid-connected mode, the system is also providing active (P) and reactive (Q) power control. A key concept of the PQ control in the inductive coupled voltage sources is the use of a grid compatible frequency and voltage droops [7]. Therefore, the active and reactive powers are controlled by the small variations of the voltage phase and magnitude. The control of the inverter requires a fast signal conditioning for single-phase systems. In the proposed system, the second-order generalized integrator (SOGI) algorithm has been employed.

Boost Inverter:

The boost inverter consists of two bidirectional boost converters and their outputs are connected in series. Each boost converter generates a dc bias with deliberate ac output voltage (a dc-biased sinusoidal waveform as an output), so that each converter generates a unipolar voltage greater than the FC voltage with a variable duty cycle. Each converter output and the combined outputs are described by

$$V_1 = V_{dc} + \frac{1}{2} \cdot A_1 \cdot \sin \theta$$

$$V_2 = V_{dc} + \frac{1}{2} \cdot A_2 \cdot \sin(\theta - \pi)$$

$$V_o = V_1 - V_2 = A_o \cdot \sin \theta, \text{ when } A_o = A_1 = A_2$$

$$V_{dc} > V_{in} + A_o/2$$

Where V_{dc} is the dc offset voltage of each boost converter and have to be greater than $0.5 A_o + V_{in}$. The output voltage V_o contains only the ac component.

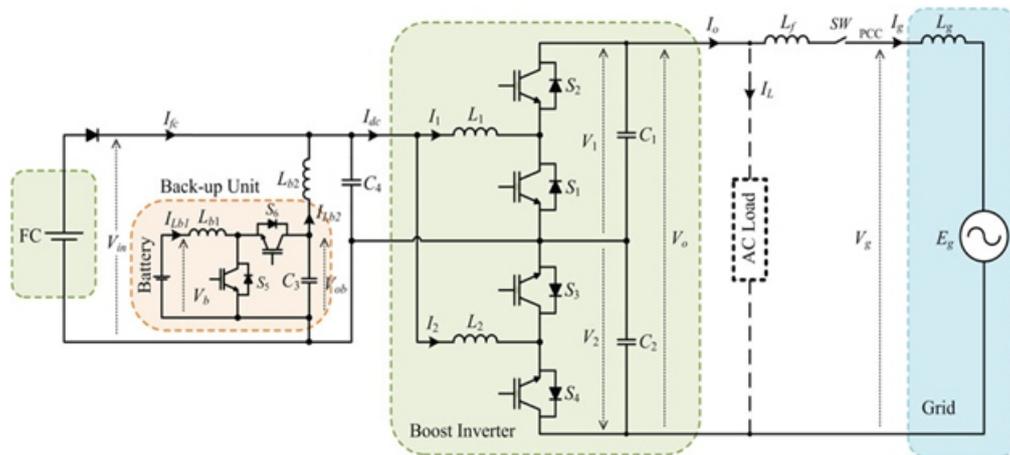


Fig 2: structure of the proposed grid-connected FC system.

A double-loop control scheme is chosen for the boost inverter control being the most appropriate method to control the individual boost converters covering the wide range of operating points. This control method is based on the averaged continuous-time model of the boost topology and has several advantages with special conditions that may not be provided by the sliding mode control, such as nonlinear loads, abrupt load variations, and transient short-circuit situations [8]. Using this control method, the inverter maintains a stable operating condition by means of limiting the inductor current. Because of this ability to keep the system under control even in these situations, the inverter achieves a very reliable operation.

The reference voltage of the boost inverter is provided from the PQ control algorithm being able to control the active and reactive power. The voltages across C1 and C2 are controlled to track the voltage references using proportional-resonant (PR) controllers [9]. Compared with the conventional proportional integral (PI) controller, the PR controller has the ability to minimize the drawbacks of the PI one such as lack of tracking asinoidal reference with zero steady-state error and poor disturbance rejection capability.

Backup Energy Storage System (BESS):

The functions of the backup energy storage system are divided into two parts. First, the backup unit is designed to support the low dynamics of the FC. Second, in order to protect the FC system, the backup unit provides low-frequency ac current that is required from the boost inverter operation.

The low-frequency current ripple supplied by the batteries has an impact on their lifetime [10], but between the most expensive FC components and the relatively inexpensive battery components, the latter is preferable to be stressed by such low-frequency current ripple. The backup system comprises of a current-mode controlled bidirectional converter and a battery as the energy storage unit. For instance, when a 1-kW load is connected from a no-load condition, the backup unit immediately provides the 1-kW power from the battery to the load. On the other hand, when the load is disconnected suddenly, the surplus power from the FC could be recovered and stored into the battery to increase the overall efficiency of the energy system.

IV. CONTROL SYSTEM

Control of Boost Inverter

The control block diagram for the boost inverter is shown in Fig. 3. 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} . The dc bias can be obtained by adding the input voltage V_{in} to the half of the peak output amplitude. V_{dc} is also used to minimize the output voltages of the converters and the switching losses in the variable input voltage condition. Therefore, the grid-connected FC system as parallel operation of voltage source inverters requires a precise control. Grid-compatible frequency and voltage droop were introduced to control active and reactive powers in this paper. The droop control for the boost inverter requires the fast acquisition of P and Q.

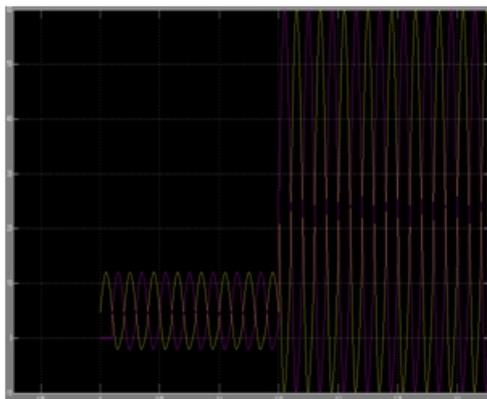


Fig 5(c): Current waveforms of L1 and L2

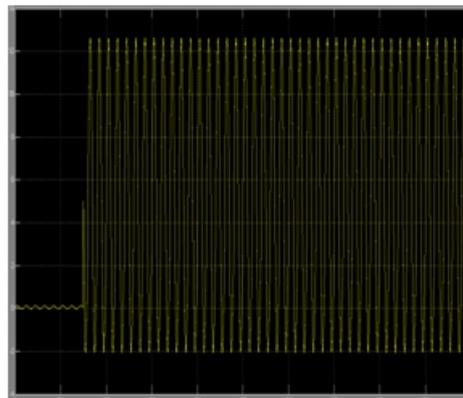


Fig 5(f): Output current of the backup unit, I_{Lb2}

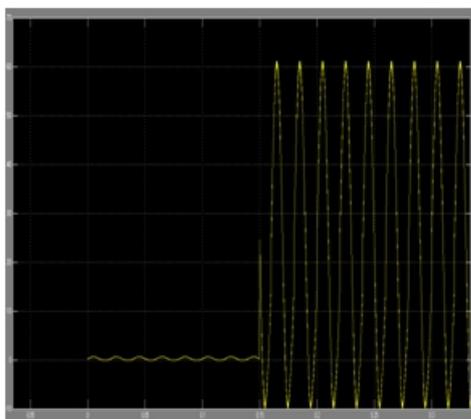


Fig 5(d): Input current of the boost inverter, I_{dc} .



Fig 6(a): Active power measurement and its reference.

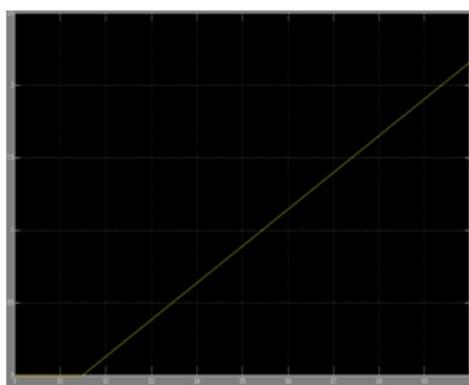


Fig 5(e): FC output current during transient, I_{fc} .

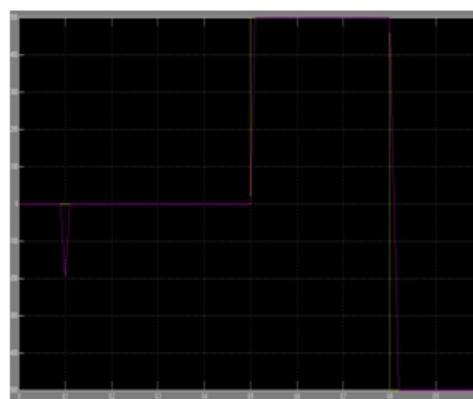


Fig 6(b): Reactive power measurement and its reference

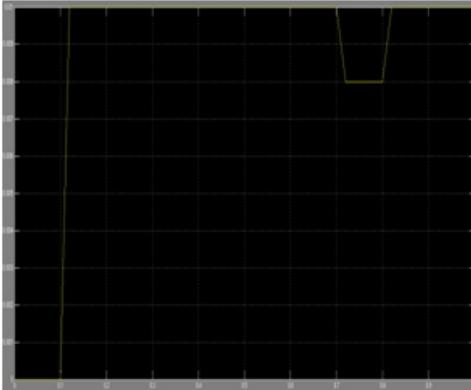


Fig 6(c): Small variation of the phase for the active power control.

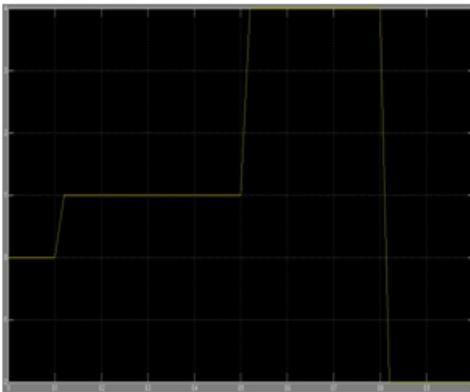


Fig 6(d): Small variation of the voltage amplitude for the reactive power control

VI. CONCLUSION:

A single-phase single power stage grid-connected FC system based on the boost-inverter topology with a backup battery based energy storage unit is proposed in this paper. The simulation results and selected laboratory tests verify the operation characteristics of the proposed FC system. In summary, the proposed FC system has a number of 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. Moreover, in the grid-connected mode, the single-phase FC system is able to control the active and reactive powers by a PQ control algorithm based on SOGI which offers a fast signal conditioning for single-phase systems. However, it should be noted that the voltage-mode control adopted for the boost inverter may result in a distorted grid current (under given THD) if the grid voltage includes a harmonic component.

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