APPLICATION OF BOOST INVERTER FOR GRID CONNECTED FUEL CELL BASED POWER GENERATION

P.Bhagyasri[1], N. Prasanth Babu[2]

[1] *M.Tech Scholar (PS), Nalanda Institute of Engineering and Tech. (NIET), Kantepudi, Guntur, A.P, (India)*

[2] *Assistant Professor (EEE), Nalanda Institute of Engineering and Tech. (NIET), Kantepudi, Guntur, A.P, (India)*

ABSTRACT

Here in this paper, the boost inverter topology is utilized as a building block for a single phase grid connected fuel cell (FC) system presenting low cost and compactness. In addition, the recommended system incorporates battery based energy storage and a dc-dc bidirectional converter to support the slow dynamics of the FC. The single phase boost converter is voltage mode maintained and low frequency current ripple is current mode controlled. The low frequency current ripple is delivered by the battery which reduces the effects of such ripple being drawn directly from the FC itself. Even though, this system can operate either in a grid connected or standalone mode. In the mode of grid connected, the boost inverter is capable in order to control the active (P) and reactive (Q) powers using an algorithm based on a second order generalized integrator which generates a fast signal conditioning for single phase systems. Here we can reduce the Total Harmonic Distortion (THD) at the grid side. Also we have the backup storage device in order to for the support of the slow dynamics of the FC sources which are integrated in a single system. Design model and guidelines, simulation, and experimental results gathered from a laboratory prototype are available to confirm the performance of the recommended system.

Keywords- Boost Inverter, Fuel Cell, and Grid Connected Inverter, Power Conditioning System (PCS), PQ Control

I. INTRODUCTION

Energy generation system based on solar photovoltaic and fuel cells (FC) need to be conditioned for both dc and ac loads. The overall system consists of power electronics energy conversion technologies and may also having energy storage based on the target applications. Even though the FC system must be supported through extra energy storage unit to obtain high quality supply of power. When such systems are utilized to power ac loads or to be integrated with the electricity grid, an inversion stage is also needed. The typical output voltage of low power FC is low and variable with respect to the load current. For instance, based on current- voltage characteristics of a 72 cell proton exchange membrane FC (PEMFC) power module, the voltage changes between 39 and 69V depending upon the level of the output current. Furthermore the hydrogen and oxidant cannot respond the load current changes instantaneously due to the working of components such as pumps, heat exchanging device, and fuel processing machine. A two stage FC power conditioning system to produce ac power has been generally considered. The two stage FC power conditioning system encounters disadvantages such as being bulky, costly, and relatively insufficient due to its cascaded power conversion levels. To reduce these drawbacks, a topology that is suitable for ac loads and is energized from dc sources able to boost and invert the voltage at the same time has been recommended. The double loop control strategy of this topology has also been suggested for better performance even during transient conditions A single stage FC system based on a boost inverter has been suggested. The single stage system is capable to minimize the problems with the two stage FC power conditioning system. Here in this paper reported overall efficiency dealing with the single level and traditional two level systems has been increased around 10 % over the range of the power rating. This paper demonstrates the performance of a standalone FC system utilizing boost inverter with a bidirectional backup storage unit to support the slow dynamics of the FC and to eliminate the ripple that causes reduction of the lifetime and efficiency of the FC. Even though 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 main aim of this paper is to suggest and report full experimental results of a grid connected single phase FC system utilizing a single energy conversion stage only. In detail the suggested system based on the boost inverter with backup energy storage unit, solves the previously mentioned issues like the low and variable output voltage of the FC, its slow dynamics, and harmonics of the current on the FC side. The single energy conversion stage consist both boosting and inversion functions and offers high power conversion efficiency, size of the converter will be reduces and low cost.

II. PROPOSED SYSTEM

2.1 Proposed FC Energy System

2.1.1 Description of the FC System

The block diagram of the recommended grid connected FC system is illustrated in Fig.1. And it also shows the power flow between each part. This system consists of the two power converters such as boost inverter and the bidirectional backup unit. The boost inverter is supplied by the FC and the backup units which are both integrated to the same unregulated dc bus.

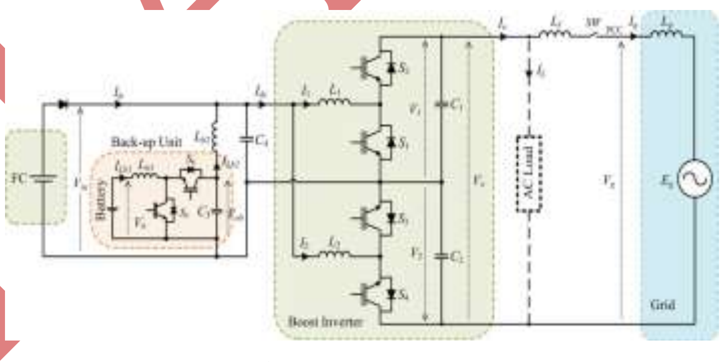

Fig.1.General Structure of the Suggested Grid-Connected FC System

While output side is integrated to the load and grid through an inductor. The system consists 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 control to varying input voltage while maintaining constant power operation. Voltage and current bandwidth, which should be provided by the manufacturers of the FC stack. In the grid connected mode the system is also generating active (P) and reactive (Q) power control. Key concepts of the PQ maintain in the inductive integrated voltage sources is the use of a grid compatible frequency and voltage droops.

2.1.2 Boost Inverter

The boost inverters consist of two bidirectional boost converters and their output responses are integrated in series. Each boost converter produces a dc bias with calculated ac output voltage so that each converter produces a unipolar voltage greater than the FC voltage with a variable duty cycle. Every converter output and the combined outputs are explained. Here in this paper a double loop control strategy selected for the boost inverter control being the most suitable method to maintain the individual boost converters covering the wide range of operating points. This control strategy is based on the averaged continuous time model of the boost topology and has several advantages with special conditions that may not be generated by the sliding mode control, such as nonlinear loads, sudden load fluctuations, and transient short circuit situations. Utilizing this control strategy, the inverter controls a stable operating condition by means of limiting the inductor current. Because of this capability to keep the system under control even in these situations, the inverter obtains a very reliable operation. The reference voltage of the boost inverter is generated from the PQ control algorithm being able to maintain the active and reactive power. The voltages across C1 and C2 are maintained to track the voltage references using proportional resonant (PR) controllers. Compared with the traditional proportional integral (PI) controller, the PR controller has the capability to minimize the drawbacks of the PI one such as lack of tracking a sinusoidal reference with zero steady state error and poor disturbance cancellation ability. The currents through L1 and L2 are maintained by PR controllers to obtain a stable operation under special conditions like nonlinear loads and transients. The control design diagram for the boost inverter is depicted in Fig.2. The output voltage reference is divided to produce the two individual output voltage references of the two boost converters with the dc bias, Vdc. The dc bias can be achieved by adding the input voltage Vin to the half of the peak output magnitude.

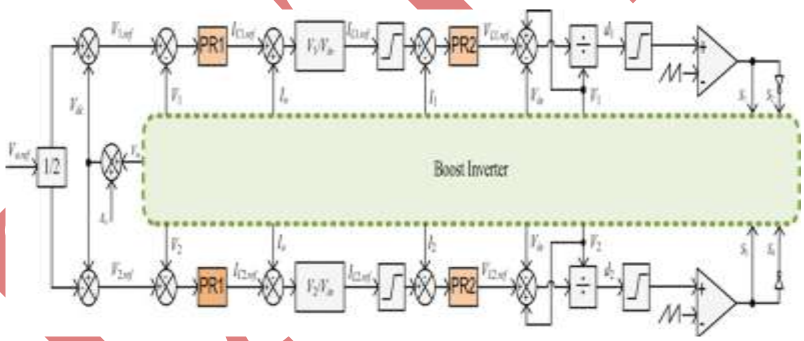

Fig.2. Boost Inverter Control Block Diagram

2.1.3 Backup Energy Storage Unit

The functions of the backup energy storage unit are divided into two parts. The backup unit is designed to support the slow dynamics of the FC is the first, and in order to protect the FC system, the backup unit generates low frequency ac current that is desired from the boost inverter operation. The low frequency ripple current supplied by the batteries has an impact on their lifetime, but between the most expensive FC components and the relatively inexpensive battery components, after that preferable to be stressed by such low frequency ripple current. The backup unit comprises of a current mode controlled bidirectional converter and a battery as the energy storage unit. For instance, when a 1 kW load is integrated from a no load condition, the backup unit immediately generates the 1kW power from the battery to the load. On the other hand when the load is disconnected suddenly, the unwanted power from the FC could be recovered and stored into the battery to improve the overall efficiency of the energy system.

2.1.4 Control of the Grid-Connected Boost Inverter

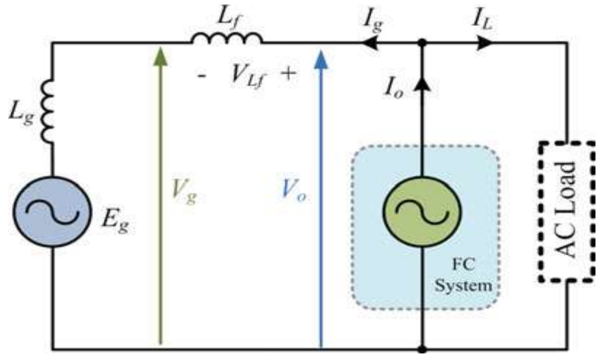

Fig.3. Equivalent Circuit of the Grid-Connected FC System

Fig3 illustrates the equivalent circuit of the grid integrated FC system consisting of two ac sources (Vg and Vo) an a.c inductor Lf between the two ac supplies, and the load. The boost inverter output response voltage (including the FC and backup unit) is indicated as Vo and Vg is the grid voltage. Fig 4 demonstrates the PQ control algorithm with the phase locked loop and the orthogonal system generator. The inverter voltage reference is generated to control the active and reactive power using the droop control method

2.1.5 Design Guidelines

The power components of the suggested system were designed with the parameters. The maximum inductor ripple current is chosen to be equal to 5% of the maximum inductor current, as calculated. When the V1 is maximum and V2 is minimum. The minimum inductance is calculated as 650 and 700 μH which are the selected values for L1 and L2.

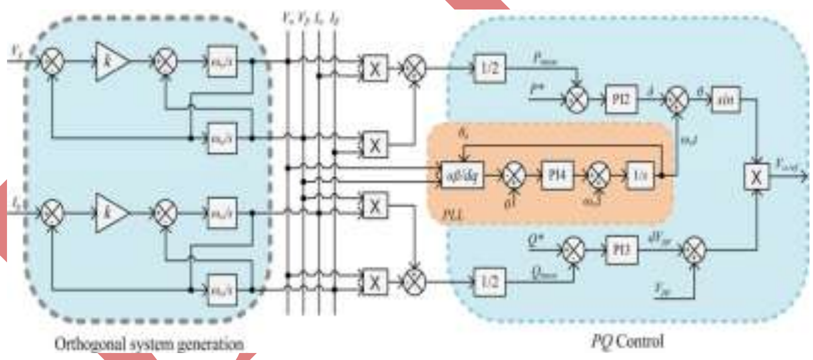

Fig.4 Boost-Inverter Output Voltage Reference Generation Block Diagram with the *PQ* Control Algorithm

During transient conditions, the backup unit should generate all the power desired by the load. In this case the maximum inductor current of the boost inverter should appear in the inductor Lb2. Hence the maximum inductance of Lb2 can be calculated. The capacity of the battery should be designed to recover the slow dynamics and start up time of the FC. Two generic 12V lead acid batteries are introduced for energy to deal with the need to generate fast dynamics and a relatively low cost solution. The FC startup time should be measured as worst case scenario to calculate the battery capacity. The low and high voltages of the battery are illustrated. To know the minimum voltage per cells, the low voltage of the battery is separated by the number of cells.

III. SIMULATION AND EXPERIMENTAL RESULTS

The suggested FC system has been explained, designed, simulated and tested experimentally to approve its overall performance. The ac output voltage of the system was selected to certify the analytical results. The ac response voltage of the system was selected to be equal to 220V, 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. When full load is desired from the no load operating point, the total power is generated by the backup unit to the load. Then the power absorbed from the battery starts decreasing moderately allowing gentle step up to deliver power which should increase up to meet the demand load power. The backup unit protects the FC from potential damage by mitigating the ripple current due to the operation called boost operation. The high frequency output response ripple current of the FC can be integrated by a passive filter placed between the FC and the boost inverter. The active and reactive power restraint performances are explained. The achieved experimental efficiency for the recommended system is about 93% at peak point and 83% at rated output power. Therefore the suggested FC system achieves an improved total efficiency when compared with a traditional two-level FC system. The suggested single phase grid connected FC system has been developed. Here in this paper a dc power supply is used to generate dc output between 43 and 69V same voltage range as a 72 cell PEMFC. The power electronics stack consist of three insulated gate bipolar transistor(IGBT) modules that are used to develop the boost inverter for two modules and backup unit for one module. The DSP controller unit has been utilized for a number of reasons such as low cost, embedded floating point unit, high speed, on chip analog to digital converter, and high performance pulse width modulation unit.

IV. CONCLUSION

A single phase single power stage grid connected FC system depends on the boost inverter topology with a backup battery based energy storage unit is recommended in this paper. The simulation response and selected laboratory tests verify the operation characteristics of the recommended FC system. In summary, the suggested FC system has a number of attractive features, such as single power conversion level with high efficiency, simplified topology, low cost, and capable to operate in standalone as well as in grid integrated mode. Moreover in the grid connected mode in single phase FC system is able to maintain the active and reactive powers by a PQ control algorithm based on SOGI which offers a fast signal conditioning for single phase system. Here we can reduce the Total Harmonic Distortion (THD) at the grid side. Also we have the backup storage device in order to for the support of the slow dynamics of the PV and FC sources which are integrated in a single system. Even though it should be noted that the voltage mode control taken for the boost inverter may result in a distorted grid current, if the grid voltage includes a harmonic component.

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AUTHOR DETAILS

P.BHAGYASRI,

Pursuing M.Tech (PS) from Nalanda Institute of Engineering and Technology (NIET), Kantepudi, sattenapalli(M),Guntur Dist,A.P, INDIA.

N.PRASANTH BABU,

Working as Assistant Professor (EEE) from Nalanda Institute of Engineering and Technology (NIET), Kantepudi, sattenapalli(M),Guntur Dist,A.P, INDIA.