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A Novel Grid Connected Multilevel DC-DC Boost Converter based Fuel Cell based Power System

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ABSTRACT

In this paper new topologies and interleaving modulation concepts for grid connected multilevel DC-DC boost converter enabling a significantly less loss and a reduced chip size of the power semiconductors are proposed. The distributed generation (DG) systems based on the renewable energy sources have rapidly developed in recent years. These DG systems are powered by micro sources such as fuel cells, photovoltaic (PV) systems, and batteries. Fuel cells are considered to be one of the most promising sources of distributed energy because of their high efficiency, low environmental impact and scalability. Non-isolated high step-up DC-DC converters are required in the industrial applications. Many of these conventional DC–DC converters have the disadvantages of operating at high duty-cycle, high switch voltage stress and high diode peak current. A three-level step up converter is implemented to boost the fuel cell stack voltage of 96V to 340V. The proposed converter consists a system of fuel cell based Multilevel DC-DC converter with PI controller is modeled and simulated by using Matlab/Simulink.

KEYWORDS: *Power Quality, Wind Energy, STATCOM, Renewable Energy, Grid*

I. INTRODUCTION

For reducing greenhouse gas emissions and for establishing a sustainable energy supply, in the future more renewable energy sources and distributed energy storage systems are required. Many of these systems, as e.g. photovoltaic modules, fuel cells or batteries, provide a relatively low DC output voltage. At high-power levels such systems are advantageously connected to medium voltage distribution grids through multilevel voltage source inverters (VSI) [1], which enable operation at relatively low switching frequencies and to use fast low voltage devices as switching elements resulting in high efficiencies and in low harmonic distortions.

In order to adapt the output voltage of the energy supplies/storage systems to the medium voltage level, boosting of the DC voltage is required. For large voltage step-up ratios this task is advantageously performed by DC-DC converters based on galvanically isolated transformers. However, in case of smaller step-ratios, as often given in the considered applications, and if the galvanic isolation is not mandatory, a much higher efficiency and power density can be achieved with non-isolated boost converter systems [2, 3]. As with the inverter systems, multilevel boost converter concepts basically enable to use faster semiconductor devices. This results in a higher efficiency especially if a high operating frequency is required in order to achieve higher power densities and to avoid acoustic noise. Additionally, with the multilevel boost converter the DC-link capacitors of VSI can be balanced allowing a straightforward inverter control based on multilevel pulse-width modulation without regard to redundant state selection which limits the maximal modulation index [4, 5].

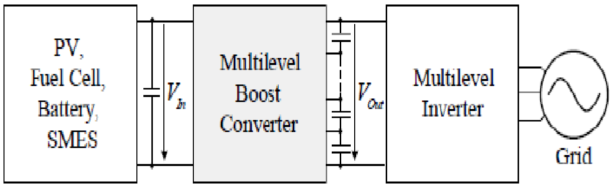


Fig 1 Connection of renewable energy sources and/or storage systems as photovoltaic systems (PV), fuel cells, batteries or superconducting magnetic energy storage systems (SMES) to medium voltage distribution grids via a DC-DC multilevel boost converter.

Fuel cells are environmentally sound renewable energy sources that are capable of operating at efficiencies greater than traditional energy production methods. Distributed generation (DG) systems based on renewable energy sources (RES) have experienced a fast development in recent years with more DG units being integrated into the power system. The fuel cells are electrochemical devices that convert chemical energy directly into electrical energy by the reaction of hydrogen from fuel and oxygen from the air without regard to climate conditions, unlike hydro or wind turbines and photovoltaic array.

II. Fuel Cell Construction

In 1839, William Grove discovered that by combining Oxygen and hydrogen in a particular configuration, electricity could be generated. Although this discovery was made more than 160 years ago, the basic operating principle discovered still applies. A basic schematic diagram of a fuel cell is shown in Fig. 2. Hydrogen is applied to the anode where a catalyst separates the hydrogen into electrons and positive hydrogen ions. A membrane separating the anode and cathode allows the positive hydrogen ions to permeate through while rejecting the electrons. This forces the electrons to take the provided electrical path, or circuit, to the cathode. Once the electrons reach the cathode, they recombine with the oxygen and hydrogen ions to form water. The following basic reactions demonstrate the process:

When pure hydrogen is used as the fuel, only electricity and water are generated from the fuel cell. This attributes the fuel cell as an environmentally friendly source of energy.

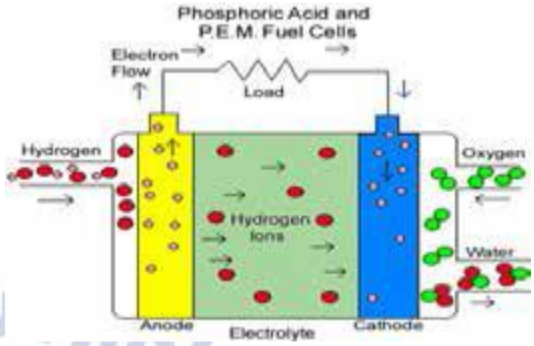


Fig.2. Basic schematic of fuel cell operation

III. Converters

A. DC-DC Converters:

In the calculations on the fuel cell stack the number of cells is chosen with respect to that the voltage over the stack should have the same voltage as the grid voltage. If for some reason the number of cells is chosen differently a DC/DC converter can be used to achieve the desired output voltage level [5]. The voltage over the stack is normally not constant and when the current increases there will be a voltage drop. In fuel cells this voltage drop is greater than in normal electrical power generators. In this case there is also need for a DC/DC converter to solve this problem [8].

B. DC-AC Converters

The output of fuel cell stack is a DC current. In Ships, the fuel cells will be used to deliver power to 400/230 volts three phase system and for this purpose an inverter will be needed. When using a DC/AC converter here is no use for a DC/DC converter because it is also capable of regulating the output voltage level [9].

IV. Existing System

The control diagram for the boost converter is illustrated in Fig.3. The inner proportional-plus-integral (PI) control loop controls current drawn from the fuel cell, while the outer voltage PI control is used to regulate output voltage delivered to the ultra capacitor to its reference value. The current loop is much faster than the voltage loop to ensure that it keeps up with the variable reference set by the voltage loop. As a rule of thumb, secondary-loop process dynamics must be at least four times as fast as primary-loop process dynamics. The closed loop control of the primary DC–DC converter subsystem was designed using the AC equivalent model and transfer characteristics of the selected converter topology.

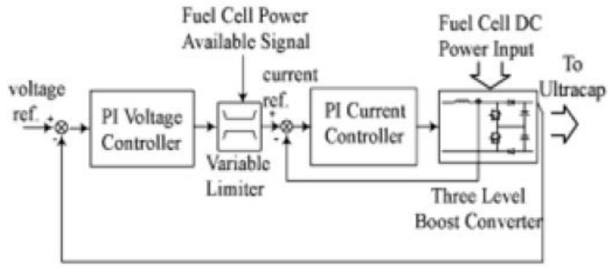


Fig. 3. Block diagram of the three-level boost converter control subsystem.

Three Level Boost Converter

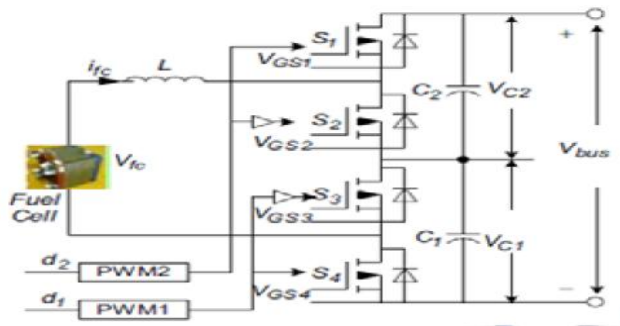


Fig. 4: Three-level DC-DC boost converter

In conventional boost converter, the boost ratio is limited by the inductor's equivalent series resistance (ESR).The voltage gain of the boost converter is limited owing to the losses associated with the inductor filter, capacitor, main power switch and rectifier diode. In this converter, the boost factor is quasi-linear when the duty cycle is from [0-0.5] the boost factor becomes non-linear for high duty cycles [8]. This behavior complicates the boost converter control in renewable energy generation systems. The necessary boost factor for renewable generation systems is from 4-6. But the maximum boost factor obtained from this converter is around 2 when operated in linear region. Therefore, three-level DC/DC boost converters are a well-adopted solution in applications with high input voltage and high switching frequency. The switches are stressed on half of the total dc bus voltage. This allows us to use lower voltage rated switches, having better switching and conduction performance compared to the switches rated on the full blocking voltage [6]. Therefore, the converter's overall performance, including cost and efficiency, can significantly be better compared to conventional converters, particularly when the switching frequency is above 20 kHz or metal–oxide semiconductor field-effect transistors (MOSFETS

MOSFETS) are used. In three-level boost converter, by cascading the output voltage *VC1* and the output voltage *VC2* high output voltage *Vbus* is easily obtained [4] as shown in Fig. 4. The output voltage obtained here is (N-1) times the voltage obtained from the conventional boost converter where N=3, the number of levels. A smaller size of the inductor is needed to achieve comparably low ripple. The inductor volume is one-fourth of that of the conventional one. In addition, it reduces the required semiconductor device voltage rating by a factor of two [7]. When multi-level boost converter is employed in open loop mode, it exhibits poor voltage regulation and unsatisfactory dynamic response, and hence, this converter is generally provided with closed loop control for output voltage regulation. In turn, the DC link bus voltage which is fed to the voltage source inverter should be almost constant. In order to maintain the DC link bus voltage constant, the control signals d1 and d2 have to be controlled. For different values of duty cycles, we get different values of DC link bus voltages. A feedback control loop is provided through comparator, gain block, PI controller. The output of the PI controller is nothing but the duty cycles d1 and d2 which varies the switching functions generated by the pulse width modulators PWM1 and PWM2. The DC link reference voltage is taken as 340V.

V. Grid Connected Boost-Converter

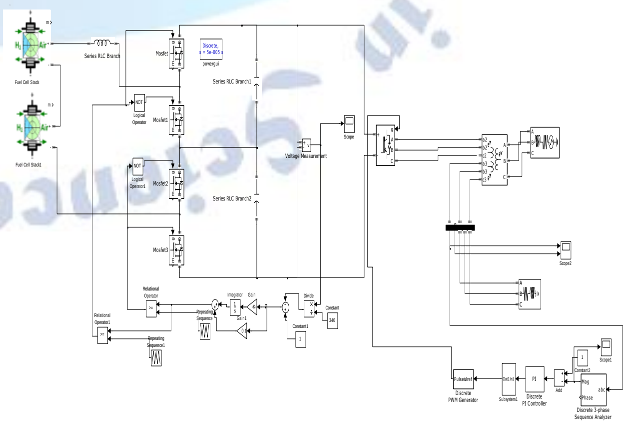


Fig 5 Proposed Grid Connected Fuel Cell Based DC-DC

Figure 5 shows the grid connected Fuel Cell Based DC-DC converter.

VI. Simulation Results

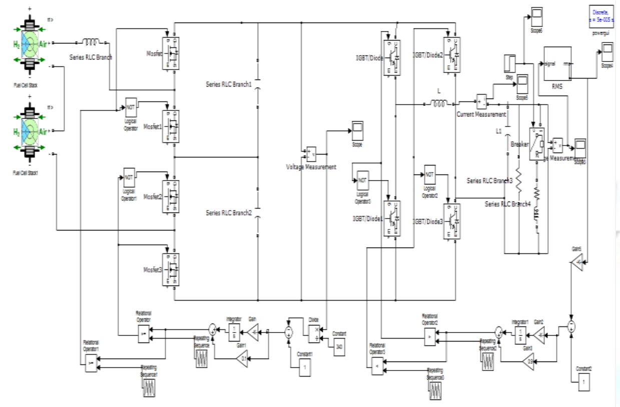


Figure: 6 Traditional DC-DC system in Matlab/Simulink

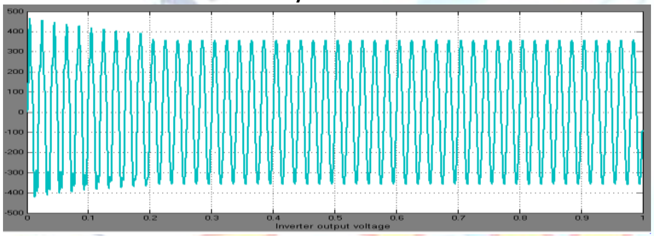


Figure: 7 Load voltage waveform during load variations

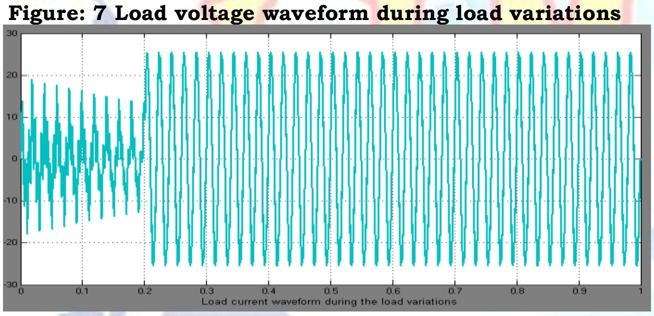
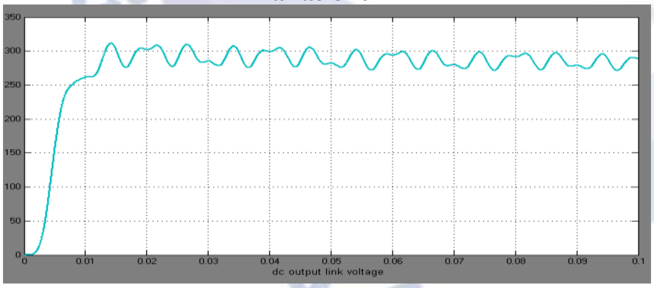


Figure: 8 Load current waveform during the load variations



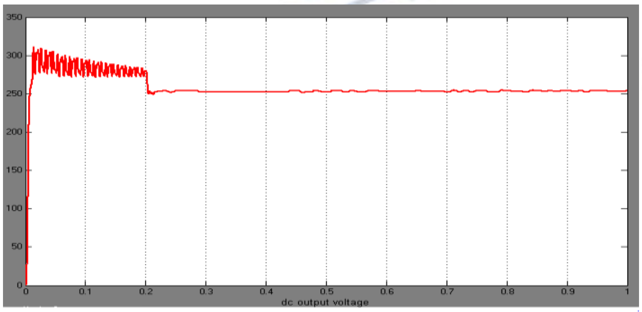


Figure: 9 Inverter output voltage waveform during the load variations

a) **When run time is 0.1s b) when run time is 1s**

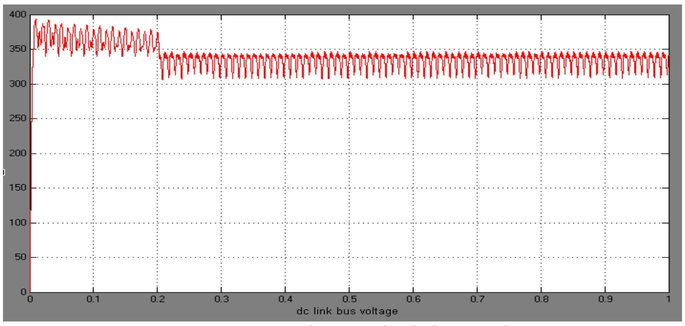


Figure: 10 The DC link bus voltage

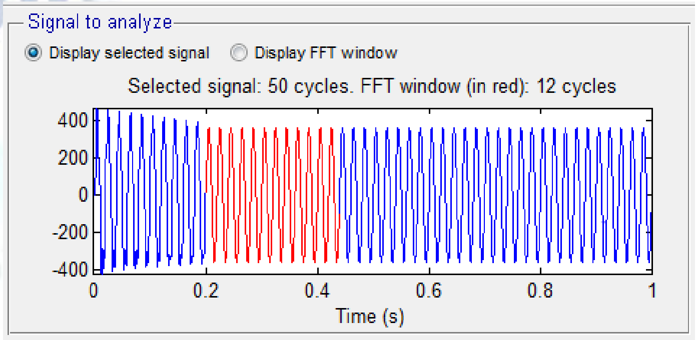


Figure: 11 FFT analysis of the load voltage

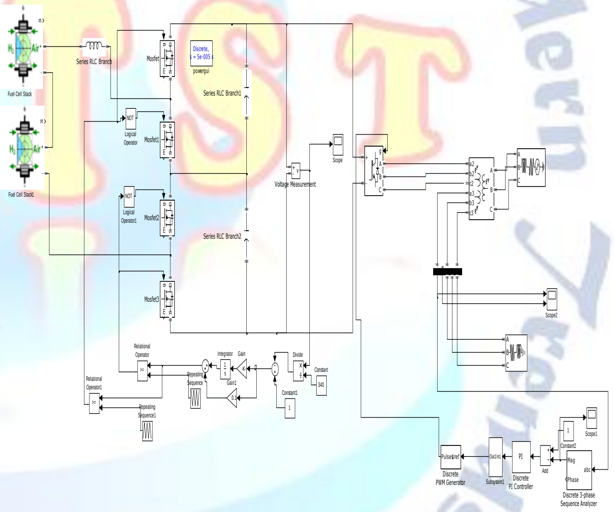


Figure: 12 Proposed Grid Connected Fuel Cell Based DC-DC system in Matlab/Simulink

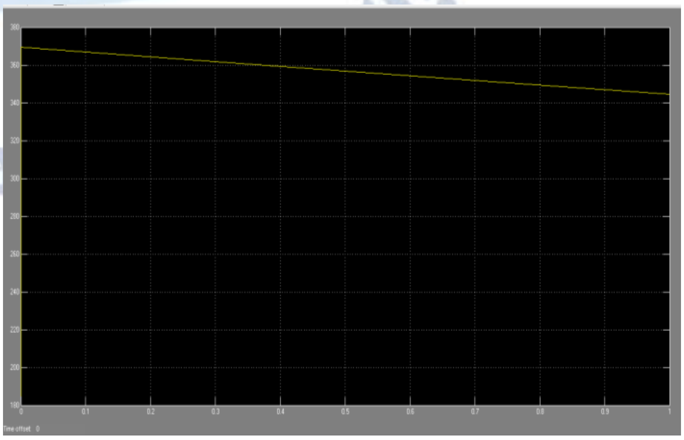


Figure 13 DC-DC Converter output voltage

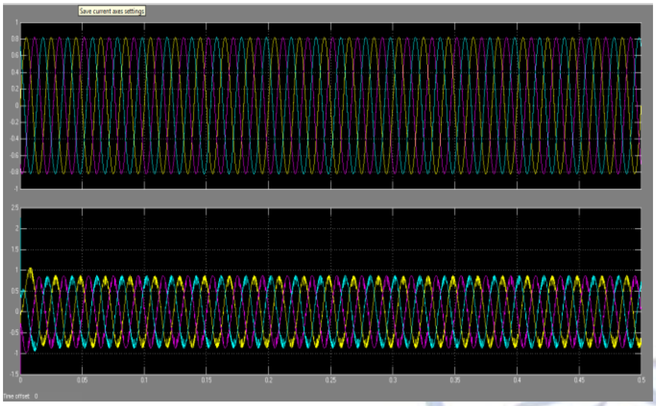


Figure 14 Load Voltage and Current Wave forms

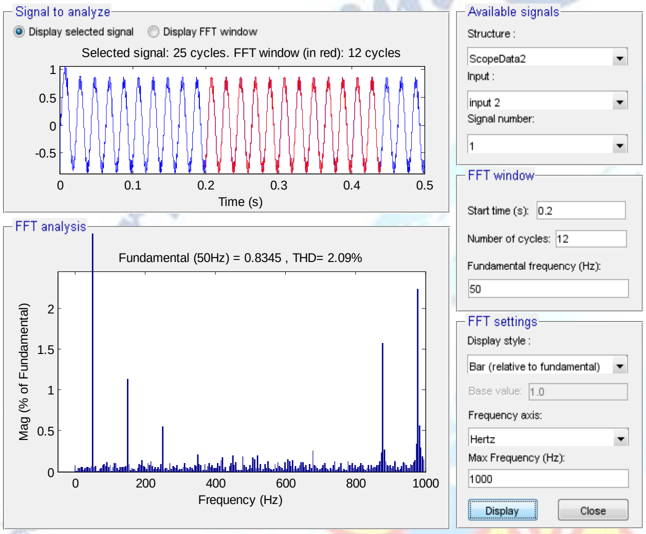


Figure 15 FFT Analysis of Load Current

VII. Conclusion and Future Scope

A Three–Level DC/DC boost converter and DC/AC inverter is implemented in MATLAB environment. A constant high DC link bus voltage is obtained and converted into standard 230V RMS voltage for fuel cell based residential applications. The two feedbacks PI controllers are designed to make the system perform well for both steady state and transient conditions. The % THD presents at the inverter is also within the limits of 5% IEEE standards. In addition, the switching stresses of the inverter can be reduced with high DC link voltage. Therefore, the proposed multi-level DC-DC converters are more suitable for renewable generation systems with improved efficiency and reduction in cost.

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