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Title: **A GRID CONNECTED BOOST-INVERTER-BASED, BATTERY-SUPPORTED, FUEL-CELL SOURCED THREE-PHASE POWER SUPPLY**

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A GRID CONNECTED BOOST-INVERTER-BASED, BATTERY-SUPPORTED, FUEL-CELL SOURCED THREE-PHASE POWER SUPPLY

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ABSTRACT: In this project, a three-phase boost-inverter topology is used to condition a typical low output voltage fuel cell (FC) as a stand-alone power supply. The key benefits of the proposed power supply include ability to deliver both the boosting and inversion functions in a single stage, compactness, and low cost. Additionally, the power supply incorporates a battery storage unit through a bidirectional converter to support the slow dynamics of the FC and simultaneously protect the FC as it acts as a filter for the low-frequency harmonics. The three-phase output voltage of the boost-inverter is voltage-mode controlled and the battery unit is current-mode controlled. Analysis, simulation results taken from a 1-kW laboratory prototype three-phase boost inverter operating at 20 kHz and bidirectional converter with two 12 V–24 Ah lead acid batteries are presented to confirm the operational performance of the proposed power supply.
Keywords: Fuel cell (FC) power conditioning system, remote area power supply (RAPS), three-phase boost-inverter

I. INTRODUCTION

The shift from large centralized energy resources to small battery located at the point of consumption is one of the emerging trends in the electricity industry with having the multiple advantages over the traditional energy technologies, like improved asset utilization, better power quality, and enhanced power system reliability and capacity. The renewable energy sources, like solar cells and fuel cells, usually generate dc power. The application of the inverters for the grid inter-connection has become much more popular because of increasing use of the renewable energy resources, mostly the solar PV cells and fuel cells as the battery.

II. FUEL CELL

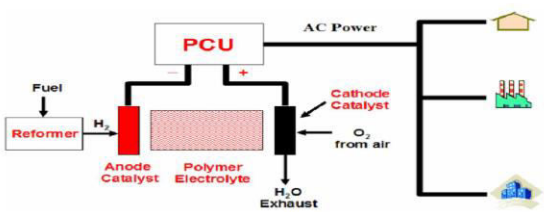

Fig.1 Fuel cell block diagram

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. 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. Moreover, the hydrogen and oxidant cannot respond the load current changes instantaneously due to the operation components such as pumps, heat ex changers, and fuel-processing unit. Caishenget 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.

III. FUEL CELL OPERATION

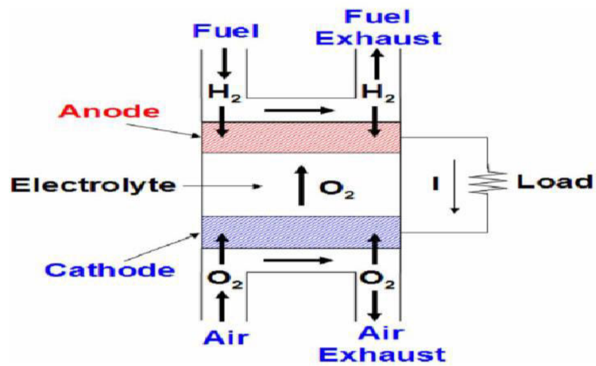

Fig.2 Fuel cell overall operational diagram

The fuel such as natural gas, coal, methanol, etc. is fed to the fuel electrode (anode) and oxidant (oxygen) is supplied to the air electrode (cathode). The oxygen fed to the cathode allows electrons from the external electrical circuit to produce oxygen ions. The ionized oxygen goes to the anode through the solid electrolyte and combines with hydrogen to form water. Even though chemical reactions at anode and cathode may be a little different according to the types of fuel cells, the overall reaction can be described as follows:

Overall reaction: 2 H2 (gas) + O2 (gas) →2 H2O + energy (electricity, heat) Since hydrogen and oxygen gases are electrochemically converted into water and energy as shown in the above overall reaction, fuel cells have many advantages over heat engines: high efficiency and actually quiet operation and, if hydrogen is the fuel, no pollutants are released into the atmosphere. As a result, fuel cells can continuously generate electric power as long as hydrogen and oxygen are available. Among several types of the fuel cells categorized by the electrolyte used, four types are promising for distributed generation systems: Phosphoric Acid fuel cell (PAFC), Solid Oxide fuel cell (SOFC), Molten Carbonate fuel cell (MCFC), Proton-Exchange Membrane fuel cell (PEMFC). All types of the fuel cells produce electricity by electrochemical reaction of hydrogen and oxygen, and the oxygen can be easily obtained from compressing air. On the contrary, hydrogen gas required to produce DC power is indirectly gained from the reformer using fuels such as natural gas, propane, methanol, gasoline or from the electrolysis of water. A typical configuration of an autonomous fuel cell system is described in Figure 2. As shown in this figure, the fuel cell plant consists of three main parts: a reformer, stack, and a power conditioning unit (PCU). First, the reformer produces hydrogen gas from fuels and then provides it for the stack. Second, the stack has many unit cells in series to generate a higher voltage needed for their applications because a single cell that consists of electrolyte, separators, and plates, produces approximately 0.7 V DC. Last, the PCU including power converters converts a low voltage DC from the fuel cell to a high voltage DC and/or a sinusoidal AC.

IV. DC-DC CONVERTERS

DC-DC converters are electronic devices used whenever we want to change DC electrical power efficiently from one voltage level to another. They are needed because unlike AC, DC cannot simply be stepped up or down using a transformer. In many ways, a DC-DC converter is the equivalent of a transformer. The dc-dc converters can be viewed as dc transformer that delivers a dc voltage or current at a different level than the input source. Electronic switching performs this dc transformation as in conventional transformers and not by electromagnetic means. The dc-dc converters find wide applications in regulated switch-mode dc power supplies and in dc motor drive applications. DC-DC converters are non-linear in nature. The design of high performance control for them is a challenge for both the control engineering engineers and power electronics engineers. In general, a good control for dc-dc converter always ensures stability in arbitrary operating condition. Moreover, good response in terms of rejection of load variations, input voltage changes and even parameter uncertainties is also required for a typical control scheme. After pioneer study of dc-dc converters, a great deal of efforts has-been directed in developing the modeling and control techniques of various dc-dc converters. Classic linear approach relies on the state averaging techniques to obtain the state-space averaged equations. From the state-space averaged model, possible perturbations are introduced into the state variables around the operating point. On the basis of the equations, transfer functions of the open-loop plant can be obtained. A linear controller is easy to be designed with these necessary transfer functions based on the transfer functioned to DC converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different than that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage, and possibly

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even negative voltage).Additionally, the battery voltage declines as its stored power is drained. Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing. DC-DC converters are electronic devices that are used whenever we want to change DC electrical power efficiently from one voltage level to another. In the previous chapter we mentioned the drawbacks of doing this with a linear regulator and presented the case for SMPS. Generically speaking the use of a switch or switches for the purpose of power conversion can be regarded as a SMPS. From now onwards whenever we mention DC-DC Converters we shall address them with respect to SMPS.A few applications of interest of DC-DC converters are where 5V DC on a personal computer motherboard must be stepped down to 3V, 2V or less for one of the latest CPU chips; where 1.5V from a single cell must be stepped up to 5V or more, to operate electronic circuitry. In all of these applications, we want to change the DC energy from one voltage level to another, while wasting as little as possible in the process. In other words, we want to perform the conversion with the highest possible efficiency.

V. BOOST CONVERTER

A boost converter (step-up converter) is a DC-to-DC power converter with an output voltage greater than its input voltage. It is a class of switched- mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element, a capacitor, inductor, or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.

VI. THE BASIC SCHEMATIC OF A BOOST CONVERTER

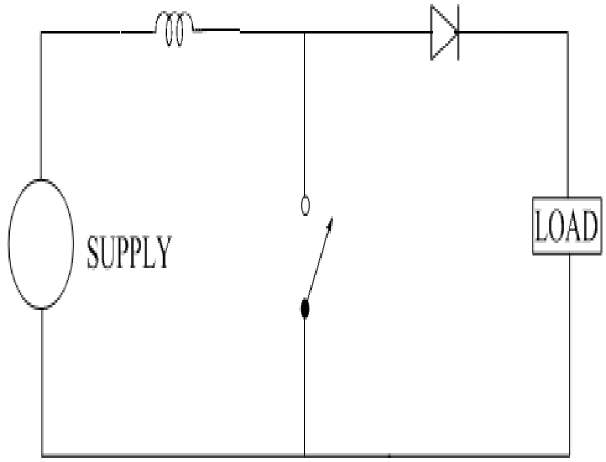

Fig.3 basic boost converter circuit diagram

Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC-to-DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it “steps up” the source voltage. Since power (P=VI) must be conversed, the output current is lower than the source current.

a) Two Configuration of Boost Converter, depending On the State of the Switch S

The ripple amplitude of the current is too high; the inductor may be completely discharged before the end of a whole commutation cycle. This commonly occurs under light loads. In this case, the current through the inductor falls to zero during part of the period (see waveforms in figure 2.10).

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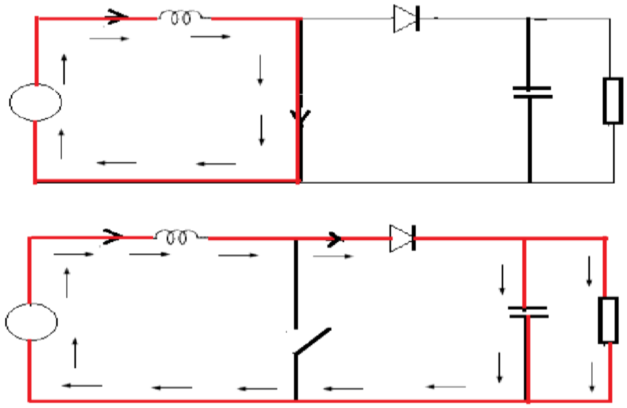

Fig.4 switching operation circuit of boost converter

Although slight, the difference has a strong effect on the output voltage equation. It can be calculated as follows:

As the inductor current at the beginning of the cycle is zero, its maximum value I_{LMax} (at t=DT) is

$$I_{LMax} = \frac{V_i DT}{L} \quad (1)$$

During the off-period, I_L falls to zero after δT:

$$I_{LMax} + \frac{(V_i - V_0)\delta T}{L} = 0 \quad (2)$$

Using the two previous equations, δ is:

$$\delta = \frac{V_i D}{V_0 - V_i} \quad (3)$$

The load current I_o is equal to the average diode current (I_D). As can be seen on figure 5, the diode current is equal to the inductor current during the off-state. Therefore the output current can be written as:

$$I_0 = \bar{I_D} = \frac{I_{LMax}}{2}\delta \quad (4)$$

Replacing I_{Lmax} and δ by their respective expressions yields:

$$I_0 = \frac{V_i DT}{2L} . \frac{V_i D}{V_0 - V_i} = \frac{V_i^2 D^2 T}{2L(V_0 - V_i)} \quad (5)$$

Therefore, the output voltage gain can be written as follows:

$$\frac{V_0}{V_i} = 1 + \frac{V_i D^2 T}{2 L I_0} \quad (6)$$

Compared to the expression of the output voltage for the continuous mode, this expression is much more complicated. Furthermore, in discontinuous operation, the output voltage gain not only depends on the duty cycle, but also on the inductor value, the input voltage, the switching frequency, and the output current.

VII. PROPOSED CONCEPT & CONTROL STRATEGY

Fuel Cells (FCs) need to be conditioned through power electronics converters in both stand-alone and grid connected applications. In many applications, the power supply may include energy storage to enhance performance and achieve high quality supply of power. The typical output voltage of any 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 output dc voltage varies between 39 and 69 V, depending upon the level of the output current as shown in Fig.5. Moreover, the slow dynamics due to the natural electrochemical reactions required for the balance of enthalpy must be taken into account when designing the FC converter system. The FC power converter needs to ensure that the demanded power remains within the limit of the maximum availability to avoid any fail, shut down, or damage.

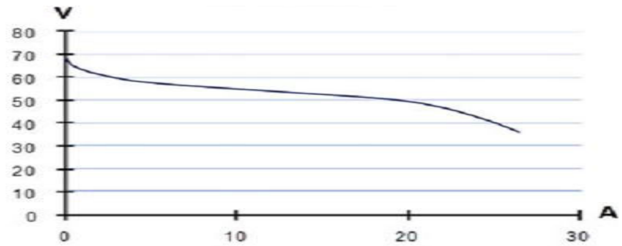

Fig.5 Power–current characteristic showing the output:

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Some methods that support the slow dynamics of the FC and low frequency ripple current elimination were reported. In a super capacitor or battery as an energy storage and a bidirectional dc/dc converter were used to support the slow dynamics of the FC and to extend its lifetime. In the dc active filter was used to cancel the ripple current that causes reduction of the lifetime and efficiency of the FC. The two-stage single-phase FC power conditioning system has been commonly considered and studied in many technical papers. However, the two-stage FC power conditioning system encounters drawbacks such as being bulky, costly, and inefficient due to its cascaded power conversion stages (i.e., first from dc–dc and then from dc–ac). A dc–ac single-stage boost-inverter topology was proposed in and a double-loop control scheme was also proposed for high performance. In order to alleviate the drawbacks of the two-stage FC power conditioning system, a single-phase FC energy system with single power conversion stage based on the boost-inverter was proposed.

FC power conditioning systems for three-phase applications was discussed. The paper compared different types of dc–dc converters and dc–ac inverters, including voltage source and current source, e.g., a boost converter followed by a voltage source inverter, single-stage current source inverter (CSI), and z-source inverter. Specifically, CSI and z-source inverters provide boosting and inversion functions in a single stage and a wide input voltage range while limited input voltage lower than the peak grid voltage and insufficient voltage gain are considered.

VIII. FC SOURCED STAND-ALONE POWER SUPPLY BASED ON THE THREE-PHASE BOOSTINVERTER.

The single-stage three-phase boost inverter topology based on the three identical boost converters has been presented in some technical papers. In and, three phase boost-inverter topology was proposed including sliding mode control and small signal analysis. The double-loop control scheme for the three-phase boost-inverter was reported in However, none of these papers has reported the boost-inverter topology in the context of a complete three-phase stand-alone energy conversion system based on such topology and sourced by an FC while addressing specific converter and overall control design requirements of the FC that needs to be supported by a battery based backup unit.

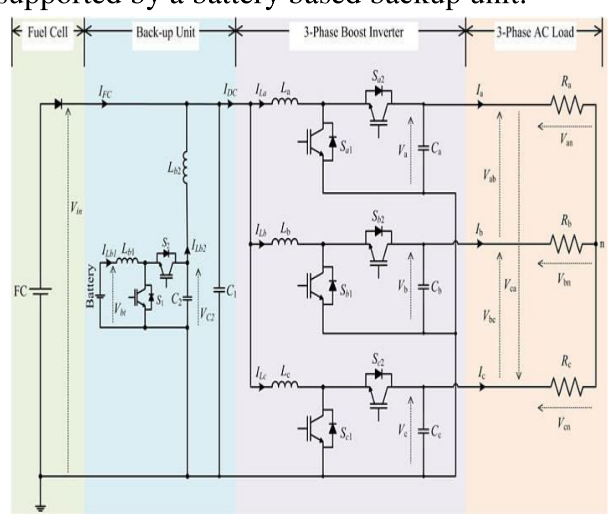

Fig.6 three-phase FC stand-alone power supply using only a single energy conversion stage including a back-up unit with battery storage

For instance, the proposed three-phase stand-alone FC power supply can be used as a remote area power supply (RAPS). The objective of this paper is to propose and report experimental results of a three-phase FC stand-alone power supply using only a single energy conversion

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stage including a back-up unit with battery storage as shown in Fig. 3.2. This single-stage conversion that includes boosting and inversion functions provides converter size reduction and low cost due to compactness. Additionally, the back-up unit supports the slow dynamics of the FC and supplies the low-frequency current harmonics, hence extending its lifetime and minimizing the stresses and losses of the FC.

IX. PROPOSED FUEL CELL ENERGY SYSTEM

The proposed three-phase FC stand-alone power supply consists of two power converters: the three phase boost-inverter and the bi-directional back-up unit as shown in Fig. 6 also shows the laboratory setup for the proposed three-phase FC power supply. The boost-inverter is supplied by the FC and the back-up unit, which are both connected to the same unregulated DC bus while the output side of the converter is connected to a balanced three-phase resistive load. The FC system incorporates a current mode controlled bi-directional converter with battery-based energy storage to support the FC power generation and three voltage-controlled boost converters making up the three phase boost-inverter stage.

X. DESCRIPTION OF THE THREE-PHASE BOOST-INVERTER

The three-phase boost-inverter consists of three identical bi-directional boost converters and their outputs are connected to a three-phase AC load, as shown in Fig. 7 (a). The DC-biased three-phase output voltages are described by:

$$V_a = V_{DC} + A_o \cdot \sin\theta$$
$$V_b = V_{DC} + A_o \cdot \sin(\theta - \frac{2\pi}{3}) \qquad (1)$$
$$V_c = V_{DC} + A_o \cdot \sin(\theta + \frac{2\pi}{3})$$

Where Ao is the peak amplitude of line-to-neutral voltage and VDC is the DC offset voltage of each boost converter and has to be greater than Ao+Vin. Each boost converter generates a DC bias with deliberate AC output voltage (a DC-biased sinusoidal waveform as an output), so that the individual boost converters generate a unipolar voltage greater than the FC output voltage with a variable duty cycle. The DC components are canceled in the three-phase three-wire balanced output and the line-to-line voltages are described By

$$V_{ab} = V_a - V_b = \sqrt{3}A_o \cdot \sin(\theta + \frac{\pi}{6})$$
$$V_{bc} = V_b - V_c = \sqrt{3}A_o \cdot \sin(\theta + \frac{5\pi}{12}) \qquad (2)$$
$$V_{ca} = V_c - V_a = \sqrt{3}A_o \cdot \sin(\theta - \frac{5\pi}{12})$$

From (2), it can be noticed that the line-to-line voltages contain only the AC component. This concept was first discussed. When the three-phase outputs are balanced and node 'n' is floating as shown in the Fig. 6(b), the line-to-neutral voltages in the load side do not include any dc component as described by

$$V_{an} = \frac{2}{3}V_a - \frac{1}{3}V_b - \frac{1}{3}V_c = V_a$$
$$V_{bn} = \frac{2}{3}V_b - \frac{1}{3}V_a - \frac{1}{3}V_c = V_b \qquad (3)$$
$$V_{cn} = \frac{2}{3}V_c - \frac{1}{3}V_a - \frac{1}{3}V_c = V_c$$

In this paper, 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. Specifically, this control method provides stable operating condition using direct current control of the inductor even in special conditions such as nonlinear loads, load variations, and transient short circuits [19]. The boost-inverter is based on the voltage mode control, as shown in Fig.7. The voltages across Ca, Cb and Cc and the currents through La, Lb and Lc are controlled by proportional-integral (PI) controllers which have been tuned to achieve good performance and stability margins. The model equations based on the averaging concept for each boost converter are expressed by

$$v_{in} - v_{Lx} = (1 - d_x) \cdot v_x \quad (4)$$

$$i_{cx} - i_x = (1 - d_x) \cdot i_{Lx} \quad (5)$$

where x represents each phase (a, band c), vLx and iLx are the inductor voltage and current, vx and iCx are the capacitor voltage and current, ix is the output phase current, and dx is the duty cycle. When the internal resistances of the inductors and capacitors are ignored, the differential equations of the inductor voltage and capacitor current are expressed by

$$v_{Lx} = Lx \cdot \frac{d \cdot i_{Lx}}{dt} \quad (6)$$

$$i_{Cx} = Cx \cdot \frac{d \cdot v_x}{dt} \quad (7)$$

Where Lxand Cxare inductance and capacitance. In the double loop control scheme, inductor voltages and capacitor currents are used as control variables for the current and voltage control loops. The duty cycles need to remain between 0.15 and 0.85 p.u. to generate sinusoidal output voltage. Based on the averaging concept and the continuous conduction mode (CCM) for the boost converter, the duty cycles can be expressed by using (4)

$$d_x = 1 - \frac{v_{in} - v_{Lx.ref}}{v_x} \quad (8)$$

Where vLx.ref is the inductor voltage reference as control variable for the current control loop. The Vx and Vin in (8) provide a compensation of the variable gain of the boost converters and cancelation of the input voltage variation [19].

The control variable of the inductor voltage reference (vLx.ref) can be obtained by using a PI controller with a current error as follows:

$$v_{Lx.ref} = \left(K_{PCx} + \frac{1}{K_{ICx} \cdot s} \right) \cdot \left(i_{Lx.ref} - i_{Lx} \right) \quad (9)$$

where KPCx and KICx are the proportional gain and integral gain for the inner current control loop. From (5) and (8), if the inductor energy variations are ignored the inductor current reference (iLx.ref) of the current controller is given by

$$i_{Lx.ref} = \frac{v_x}{v_{in}} \cdot \left(i_{cx.ref} + i_x \right), \text{ when } v_{Lx.ref} \approx 0 \quad (10)$$

where iCx.ref is the capacitor current reference as control variable for the voltage control loop. The control variable of the capacitor voltage reference (iCx.ref) can be obtained by using a PI controller with a voltage error as follows:

$$i_{Cx.ref} = \left(K_{PVx} + \frac{1}{K_{IVx} \cdot s} \right) \cdot \left(v_{x.ref} - v_x \right) \quad (11)$$

where vx.ref is the output voltage references of the three-phase boost-inverter as (1)and KPVx and KIVx are the proportional gain and integral gain for the outer output voltage control loop respectively that should be selected as lower bandwidth compared with the inner loop. Fig. 3 shows the control block diagram of the three-phase three-line boost inverter including the voltage and current control loops. The DC offset voltage (VDC) is added to the three individual phase voltage references. The DC offset can be obtained by

adding the input voltage (Vin) to the peak output amplitude (Ao). The VDC can be minimized in order to reduce the output peak voltages of each boost converter and the switching losses in the case of a variable input voltage. The voltage references (Va.ref,)

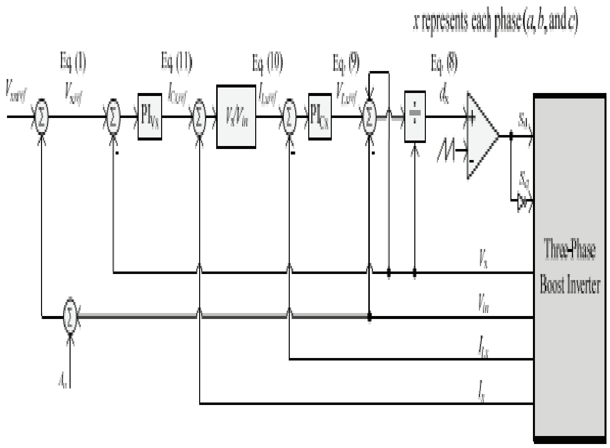

Fig 7 (a). The control block diagram of the three phase three line boost inverter

Vb.ref and Vc.ref) are compared with the feedback voltages (Va, Vb and Vc) of the individual boost converters to generate voltage errors. These voltage errors are processed by PIVx to generate capacitor current reference as shown in (11). When the capacitor current references and the output current are applied with the block (Vx/Vin) each reference current of the inductors are given by (10). These inductor current references are compared with the feedback currents of the inductors (Lx) to produce the current errors. Then the inductor voltage references expressed in (9) are provided using PICxwith the current errors. Finally, using (9) the duty cycles can be obtained for the three-phase boost inverter.

XI. BATTERY STORAGE BACK-UP UNIT

The battery storage back-up unit is designed to support the slow dynamics of the FC and is shown in Fig. 7 (a). The back-up unit comprises of a current controlled 1kW IGBT based bidirectional boost converter operating at 20 kHz and the energy storage component. For instance, when a load is connected or disconnected the back-up unit immediately discharge or charge the battery through the bidirectional converter with a limitation of 4A/s current slew rate. Two generic 12V-24Ah lead acid batteries are used for energy storage to deal with the need to provide fast response and a relatively low cost solution. The back-up unit performs not only the support function for the FC module during transients but also recovers any surplus power delivered by the FC. Other energy storage technologies such as lithium-ion batteries or super-capacitors can also be used instead of lead-acid but it is beyond the scope of this paper to deal with the type of the storage of the back-up unit. Additionally, in order to protect the FC system, the back-up unit provides low frequency AC current harmonics and high-frequency switching ripple that is required from the dc-ac boost-inverter operation.

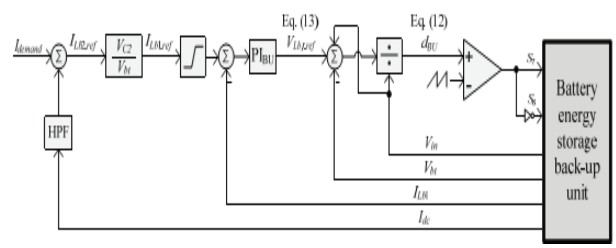

Fig 7 (b). The control block diagram of the three phase three line with battery energy storage back up unit

More detailed analysis of the backup unit based on equivalent circuit of the PEMFC has been presented. The paper illustrates the compensation characteristics for the low-frequency ac ripple using current control and the high-frequency ripple performed by LC passive filter. Specifically, C2and Lb2are tuned at switching frequency to suppress on the FC-side [27]. The back-up unit controller is designed to control the output current of the back-up unit, as presented in Fig. 3.4. The duty cycle for the back-up unit based on the averaging concept can be expressed by using (4)

$$d_{BU} = 1 - \frac{v_{bt} - v_{Lb1.ref}}{v_{in}} \qquad (12)$$

Where the dBU is the duty cycle, vbt is the battery voltage, and vLb1.refis the inductor voltage reference as control variable for the current control loop. The control variable of the inductor voltage reference (vLb1.ref) can be expressed using a PI controller with current error as follows:

$$vLb1.\text{ref} = KPBU + 1/KIBU \cdot s(iLb1.\text{ref} - iLb1)$$

where KPBU and KIBU are the proportional gain and integral gain for the current controller of the back-up unit. The current reference (ILb1.ref) is determined by IDC through a high-pass filter (HPF) and the demanded current (Idemand) that is related to the load change. In order to detect the ac components higher than the fundamental frequency, a relatively low cut-off frequency has been used as 5Hz. The AC component of the current reference deals with the elimination of the AC ripple current from the FC power module while the DC component deals with the slow dynamics of the FC.

XII. DESIGN GUIDELINES

The design parameters are given in Table. I. The following equations have been used in order to calculate the inductor and capacitor value

TABLE I. DESIGN SPECIFICATIONS

V_{in}	42V (min)
R_a (resistance of inductor)	≈10$m\Omega$
V_{max}(t)	381V (max)
V_{min}(t)	42V (min)
Δt_1 (maximum on time)	42.5μs (max at 20kHz)
Δi_{Lmax}	2.4A (5% of $i_{L(max)}$)
ΔV_c	19V (5% of V_{max})
R_{eq} (load)	65Ω at 1kW
V_b (battery voltage)	22V(min)-27.3V(max)
I_{Lb1}	20A (max)

TABLE II
SPECIFICATIONS OF THE FC POWER SUPPLY

FC output voltage	43-69V DC (72 Cell PEMFC)
AC output voltage	210V AC (line to line), 50 Hz
Switching frequency	20 kHz
Rated power	1.0kW (43V at 23.5A)
Switching power module	SKM100GB (IGBT)
Controller	TMS320F28335
Energy storage unit	2x12V-24Ah lead acid batteries
$L_a=L_b=L_c$	700μH
$L_{b1}=L_{b2}$	150μH
$C_a=C_b=C_c=C_1=C_2$	20μF
PI_{Cx}	K_p: 0.1, K_I: 2.5×10^{-3}
PI_{Vx}	K_p: 1.5, K_I: 2.5×10^{-2}
PI_{BU}	K_p: 0.1, K_I: 5×10^{-3}

$$i_L(\max) = \frac{V_{in} - \sqrt{V_{in}^2 - 4R_a\left(-V_{\max}(t)\right)\cdot\left(\frac{V_{\min}(t) - V_{\max}(t)}{R_{eq}}\right)}}{2R_a} \qquad (14)$$

$$\Delta i_L(t) = \frac{\left(V_{in} - R_a i_L(t)\right)\cdot \Delta t_1}{L} \qquad (15)$$

Where iL(max) is maximum inductor current and ΔiL is high-frequency ripple current of the inductor caused by the switching operation. In (14), the single-phase model equivalent resistance (Req) can be introduced

$$R_{eq} = 3/2\, R_a \qquad (16)$$

The maximum inductor current ripple ΔiLmax is chosen to be equal to 5% of the maximum inductor current, as calculated from (14). From (14) and (15) the inductance is calculated and chosen as 700μH for La, Lb and Lc. The ripple voltage of the C1and C2is given by

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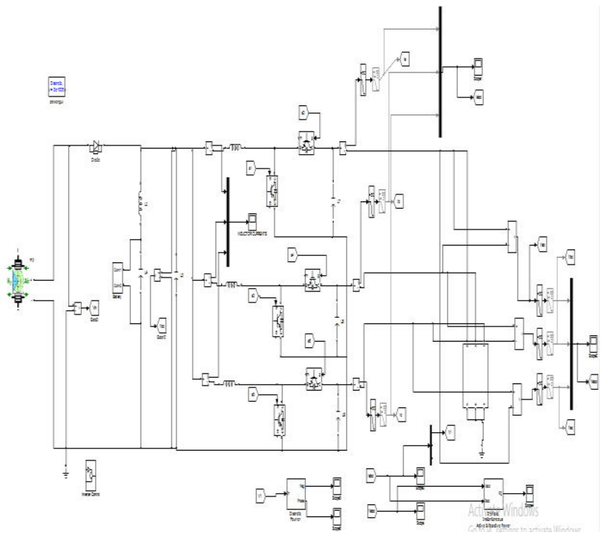
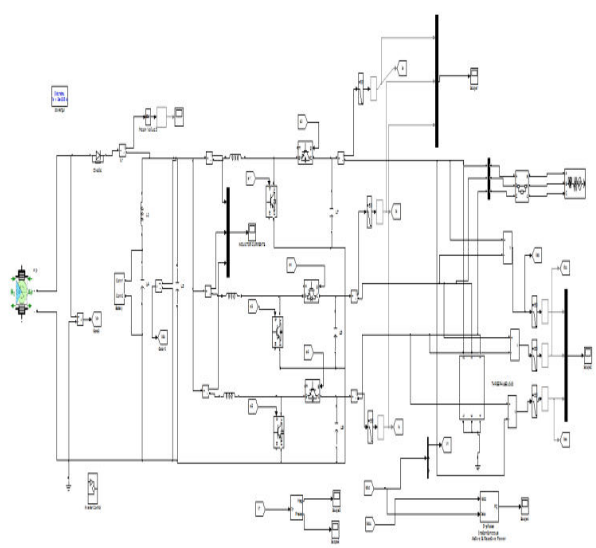
$$\Delta V_C = [\text{Vmin (t)-Vmax (t)/ (Cx.Req)}].\ \Delta t \quad (17)$$

From (17), a capacitor value has been obtained as 12μF and a 20μF 800V rated metalized polypropylene film capacitor has been used for Ca, Cb and Cc for the experimental prototype. The design parameters of the backup unit have been obtained a 150μH and 20μF using (15) and (17).

XIII. SIMULATON DIAGRAM



The fig.8 shows simulation diagram of fuel cell based boost inverter in standalone mode.



The fig.9 shows simulation diagram of proposed system with grid connected mode.

a) SIMULATION RESULTS

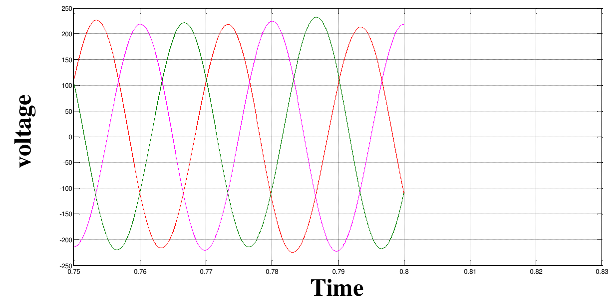


Fig.10 Simulation result for three Phase line-line output voltage

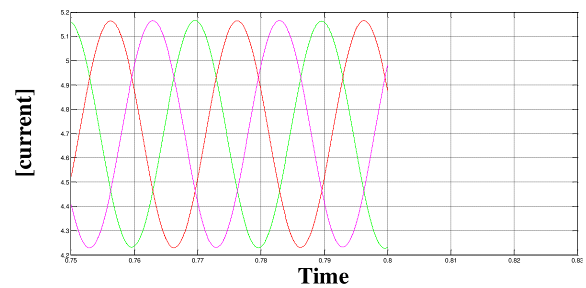


Fig.11 Simulation result for three phase output current

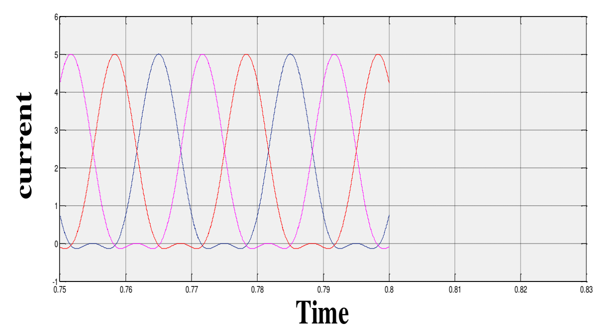


Fig.12 Simulation result for Inductor currents

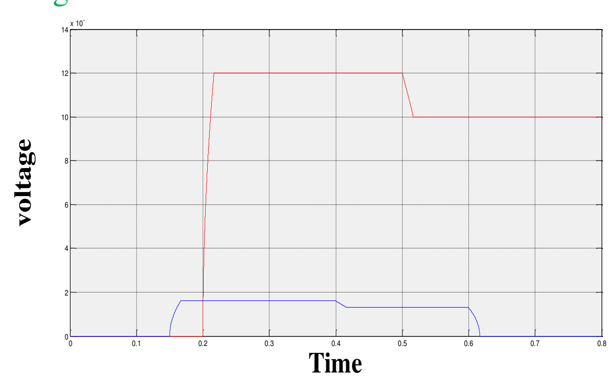


Fig.13 Simulation result for Active and reactive Powers

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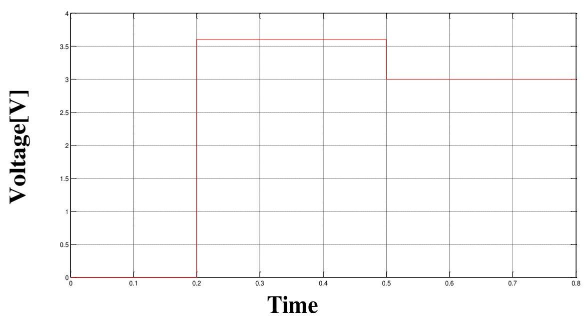

Fig.14 Simulation result for Voltage variation

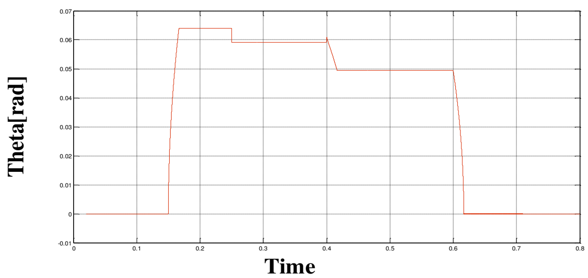

Fig.15 Simulation result for Delta variation

b) RESULT ANALYSIS

The proposed fuel cell based battery supported boost inverter is simulated in MATLAB/Simulink platform. The fig.7 shows simulation diagram of fuel cell based boost inverter in standalone mode. The slow dynamics of fuel cell is supported by the battery storage. The slow dynamics of fuel cell are less when the system is operated in grid connected mode. The fig.8 shows simulation diagram of proposed system with grid connected mode. The simulation result of line voltages, phase currents, inductor currents, active and reactive powers, voltage variation and delta variations are shown in fig 9. To 15.

XIV. CONCLUSION

A stand-alone three-phase FC sourced power supply based on the boost-inverter topology with a backup battery-based energy storage unit has been proposed in this project. The presented simulation and experimental results have verified the operation characteristics of the power supply. The results of the proposed three-phase FC supply have confirmed its satisfactory performance in delivering boosting and inversion functions in one conversion stage to generate 210 Vac from 43Vdcat rated power. The back-up unit key function is to support the slow dynamics of the FC. In summary, the proposed stand-alone system has a number of attractive features, such as being a single power stage and offering a simplified topology and a low cost.

XV. FUTURE SCOPE

The performance of fuel cell sourced battery supported three phase boost inverter can be analyzed using fuzzy logic.

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