Fuel Cell Converter Topology With and Without Filter.

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Abstract: *Utilizing fuel cell for distributed power generation requires the development of an inexpensive converter topology which converts the variable d.c. of fuel cell into useful a.c. power converter topologies for fuel cell systems residential applications are presented in this paper for efficiency, cost, component count, input ripple current minimization technique, reliability for comparison analysis. The commercial feasibility of fuel cells rests on the cost of the fuel cell system and operating efficiency and fuel cost. The proposed power converter topology consists of DC-DC converters, and 180 degree mode of conduction with and without filter. Advantages of the proposed topology are reduced input ripple current, high efficiency, low maintenance cost, smaller size, modularity, redundancy.*

Keywords: *Fuel cell, Renewable Energy, Distributed Generation , DC-DC converter*

I.   INTRODUCTION

The Inverter is used to convert DC output Voltage to AC. which generate power as a direct current (DC), require power conversion units to convert the power from DC to AC. This power could be connected to the transmission and distribution network of a utility grid. There are other applications, where it is necessary to be able to control power flow in both directions between the AC and DC sides. For all these cases power conditioning units are used. Power conditioning unit are defined generally as electronic units that transform DC power to AC power, AC power to DC power, both bi-directional power electronic converters, or convert DC power at one voltage level to DC power at another voltage level. Using PCUs in Fuel Cell power systems, the input power of the system varies continuously with time. FC power systems can use the power conditioning units for this purpose and also to prevent the expensive electrochemical units such as fuel cell or electrolyser from damage, to step-up voltage for electrochemical units, to invert, to regulate, and to wave-shape the output voltage from all components.

An inverter is also needed to connect the system to the AC consumer loads. When all components of the system are directly connected, the two electrochemical components (fuel cell and electrolyser) have a relatively low output voltage. Therefore, the feasible system must enclose PCUs DC/AC inverter, and also to prevent the expensive electrochemical devices from damage. It seems reasonable that problems concerning efficiency are mainly caused by technical components of this system. Which can be attributed to operating the converters most of the time at very low power levels? Therefore, an accurate design of the components is very important. Most improvements in the circuit design of the PCU to increase the efficiency are in the use of modern power semiconductors with low conduction and driving losses, and in the use of recently developed designs of the integrated control circuits. The cost reduction of storing energy in hybrid systems can be achieved by increasing the efficiency and decreasing the cost of the PCU. The power conditioning sensitivity in systems has the greatest effect relative to other components in the system (Electrolyser, Fuel cell, Battery,). When an increase in the PCU efficiency by 1% is achieved, the cost of electric power generated is reduced by 0.94%.

II.   SYSTEM DESCRIPTION

A. Operation and Topology

A fuel cell is an electrochemical cell that converts a source fuel into an electrical current. It generates electricity inside a cell through reactions between a fuel and an oxidant, triggered in the presence of an electrolyte. The reactants flow into the cell, and the reaction products flow out of it, while the electrolyte remains within it. Fuel cells can operate continuously as long as the necessary reactant and oxidant flows are maintained. Fuel cell has higher energy storage capability, thus enhancing the range of operation for automotive applications and is a cleaner source of energy. Fuel cell also has the further advantage of using hydrogen as fuel that could reduce world's dependence on nonrenewable hydrocarbon sources. In recent years different types of technologies have been developed , such as the: Alkaline Fuel Cell (AFC);Proton Exchange Membrane (PEM) Fuel Cell; Phosphoric Acid Fuel Cell (PAFC); Molten Carbonate Fuel Cell (MCFC);Solid Oxide Fuel Cell (SOFC) and Direct Methanol Fuel Cell(DMFC). One of the most diffused, the PEM fuel cell, has a high proton conductivity membrane as electrolyte. The Fuel Cell model used in this Proposed Work is realized in MATLAB[TM] and Simulink.
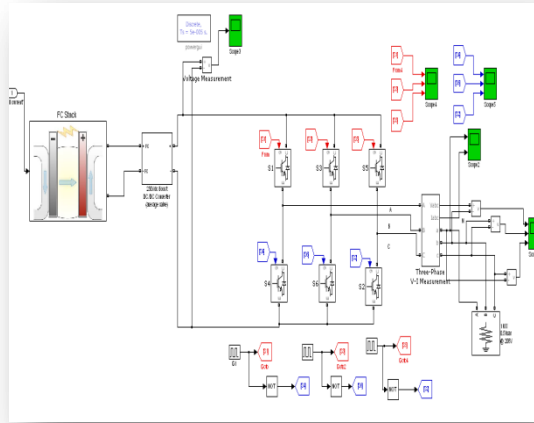
Fig1.1.simulink model of fuel cell inverter for 180 degree mode of conduction without filter.
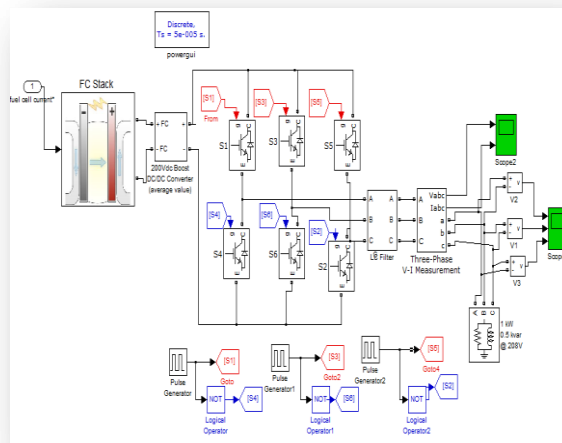

Fig.1.2. simulink model of fuel cell inverter for 180 degree mode of conduction with filter.

1. Fuel Cell Stack Model
1.1. Model Assumptions
- The stack model will be based on the following assumptions.
- The gases are ideal.
- The stack is fed with hydrogen and air. If natural gas instead of hydrogen is used as fuel, the dynamics of the fuel processor must be included in the model, upstream of the hydrogen inlet; a first-order transfer function 6.The transfer function gain should reflect the changes in composition occurring during the process. The effect of the fuel processor in the model will be tested in the future. The channels that transport gases along the electrodes have a fixed volume, but their lengths are small, so that it is only necessary to define one single pressure value in their interior. The exhaust of each channel is via a single or if ice. The ratio of pressures between the interior and exterior of the channel is large enough to consider that the orifice is choked. The temperature is stable at all times. The only source of losses is ohmic, as the working conditions of interest are not close to the upper and lower extremes of current. The Nernst equation can be applied.

1.2 Characterization of the Exhaust of the Channels:
According to Ref. 7, an orifice that can be considered choked, when fed with a mixture of gases of average molar mass M_kgrkmol.and similar specific heat ratios, at a constant temperature, meets the following characteristic:

$$\frac{W}{P_U} = K\sqrt{M} \qquad (1.1)$$

Where W is the mass flow kg/s; K is the valve constant, mainly depending on the area of the orifice . P is the pressure up stream inside the channel. For the particular case of the anode, the concept of fuel utilization U can be introduced, as the ratio between the f fuel flow that reacts and the fuel flow injected to the stack is also a way to express the water molar fraction at the f exhaust. According to this definition, Eq. 4.1. can be written as:

$$\frac{W_{an}}{P_{an}} = W_{an}\sqrt{(1-U_f)M_{H2} + U_f M_{H_2O}} \quad (1.2)$$ where W is the mass flow through the

anode valve an kg/s; Kan is the anode valve constant ; M are the molecular masses of hydrogen H2. H2O and water, respective kg/kmol; P is the pressure an inside the anode channel [atm]. If it could be considered that the molar flow of any through the valve is proportional to its partial pressure inside the channel, according to the expressions:

$$\frac{q_{H_2}}{p_{H_2}} = \frac{K_{an}}{\sqrt{M_{H_2}}} = K_{H_2} \qquad (1.3) \qquad\qquad\qquad\qquad and$$

$$\frac{q_{H_2O}}{p_{H_2O}} = \frac{K_{an}}{\sqrt{M_{H_2o}}} = K_{H_2o} \qquad (1.4)$$

where q , q are the molar flows of hydrogen and H2 H2O water, respectively, through the anode kmol/s; p , p are the partial pressures of hydrogen and water, H2 H2O respectively (atm); K , K are the valve molar con- H2 H2O stants for hydrogen and water, respectively kmol/(satm); the following expression would be deduced:

$$\frac{W}{P_{an}} = K_{an}\left[(1-U_f)\sqrt{M_{H_2}} + U_f\sqrt{M_{H_2o}}\right] \quad (1.5)$$

The comparison of Eqs. 4.2. and eqs4.5 Shows that for U)70% the error is less than 7%. It is possible to f redefine slightly Eqs. 4.3and 4.4 so that the error is even lower. This error shows that it may be reasonable to use Eqs. 4.3 and eqs.4.4.. The same study for the cathode shows that the error in that valve is even lower, because of the similar molecular masses of oxygen and nitrogen.

$$p_{H_2}V_{an} = n_{H_2}RT \qquad (1.6)$$

1.3 Calculation of The Partial Pressures:
Every individual gas will be considered separately, and the perfect gas equation will be applied to it. Hydrogen will be considered as an example.

$$\frac{d}{dt}pH_2 = \frac{RT}{V_{an}}qH_2 \qquad (1.7)$$

where q is the time derivative of n , and represents the H2 H2 hydrogen molar flow kmol/s. There are three relevant contributions to the hydrogen molar flow: the input flow, the flow that takes part in the reaction and the output flow, thus:

$$\frac{d}{dt}pH_2 = \frac{RT}{V_{an}}\left(q_{H2}^{in} - q_{H2}^{out} - q_{H2}^{r}\right) \qquad (1.8)$$

where $q$in is the input flow of kmol/s; $q$out is the output H2 H2 flow of kmol/s; qr is the hydrogen flow that reacts H2 kmol/s. According to the basic electrochemical relationships, the molar flow of hydrogen that reacts can be calculated

as: $$q_{H2}^{r} = \frac{N_0 I}{2F} = 2K_r I \qquad (1.9)$$

where N is the number of cells associated in series in the 0 stack; F is the Faraday's constant/kmol; I is the stack current [A]; K is a constant defined for modeling pur- r poses kmol/(s a). Returning to the calculation of the hydrogen partial pressure, it is possible to write:

$$\frac{d}{dt}pH_2 = \frac{RT}{V_{an}}\left(\left(q_{H2}^{in} - q_{H2}^{out} - 2K_r I_i\right)\right) \ (1.10)$$

Replacing the output flow by Eq. _3., taking the Laplace transform of both sides and isolating the hydrogen partial pressure, yields the following expression:

$$p_{H_2} = \frac{1/K_{H_2}}{1+\tau_{H_2}s}\left(q_{H_2}^{in} - 2K_r I_j\right) \qquad (1.11)$$

Where, $TH_2 = (van/KH_2RT)$,expressed in seconds, is the H2 an H2 value of the system pole associated with the hydrogen flow.

1.4 Calculation of the stack Voltage

Applying Nernst's equation and Ohm's law _to consider ohmic losses., the stack output voltage is represented by the following expression:

$$V = N_0 \left(E_0 + \frac{RT}{2F} \left[\ln \frac{p_{H_2} p_{o_2}^{0.5}}{p_{H_2O}} \right] \right) - rI \quad .(1.12)$$ where E is the voltage associated

with the reaction free energy V; R is the same gas constant as previous, but care should be taken with the system unit $J/kmolK$; r describes the ohmic losses of the stack Ω

1.5. Modeling of Power Conditioning Unit

The Power Conditioning unit is used to convert DC output Voltage to AC. which generate power as a direct current (DC), require power conversion units to convert the power from DC to AC. This power could be connected to the transmission and distribution network of a utility grid. There are other applications, where it is necessary to be able to control power flow in both directions between the AC and DC sides. For all these cases power conditioning units are used. Power conditioning unit are defined generally as electronic units that transform DC power to AC power.

1.6 DC-AC Converter (Inverter)

The main circuit is the part where the DC electric power is converted to AC [6]. This is virtually implemented with the one that is shown at the Fig. In this circuit we use a 3 leg inverter for 3-phase conversion which is composed of 6 IGBTs and the control unit. The last generates control pulses to drive
the IGBTs. The pulse generation to gives a digital signal to the IGBTs. When the signal from the pulse generator is not zero then it reacts as a switch and opens. This consists the basic operation in order to convert the DC to AC, with the technique of the Pulse Width Modulation (PWM).The frequency of the IGBTs we use is 1 KHz. For the time interval the IGBTs are open, we get a pulse at power circuit, which has the same amplitude of source. The RMS time integral give us the output values. The on-off is determined by a control unit which is analyzed below. The modulation factor ma can be used as a parameter for the dynamic control of the system.. The losses will be analogue to the change over the ma. A useful reference for cascaded multilevel converters which discuses the control circuit of new topology. A three phase inverter has the basic advantage that generates power in 3-phase and is working without a hitch. At one node of the circuit, supposing we have an input voltage $V_{oi}(t)$ an LC filter ,L inductance and C capacitance and the r_L resistant Load ,if we apply the Kerchief's laws and if we consider that the IGBTs at an open state, we get:

$r_L i_L + L \, di_L/dt + V_C = V_{oi}(t)$ (1.13)
$i_L - C(dV_c/dt) - V_c/R$ (1.14)

The above problem is depending on the output of the PV array and in order to have a simple solution we consider only the switching part of the circuit that is in fig. one obtain the solution which is:

$V_{SN} = \sum_{n=1,5,7,11}^{\infty} 4V/3n\pi(\cos n\pi/3+1)\text{Sin}n(\omega t120)$
(1.15)

$V_{TN} = \sum_{n=1,5,7,11}^{\infty} 4V/3n\pi(\cos n\pi/3+1)\text{Sin}n(\omega t240^{\circ})$
(1.16)

$V_{RN} = \sum_{n=1,5,7,11}^{\infty} 4V/3n\pi(\cos n\pi/3+1)\text{Sin}n(\omega t)$
(1.17)

Each one of the 3-phases to neutral voltage, the 1, 5, 7, 11 are the harmonics appearing and $\omega = 2\pi f$ the basic frequency at 50Hz.

II.EXPERIMENTAL RESULT: A Comparative analysis of Simulation Result Of Fuel Cell Inverter For 180 Degree Mode Of Conduction with and without filter along with the its total harmonic distortion[TDH] is shown in the following figures**.**

Fig.1.3. Three phase Load Current and Load Voltage waveform for inverter 180^0 mode of conduction without filter
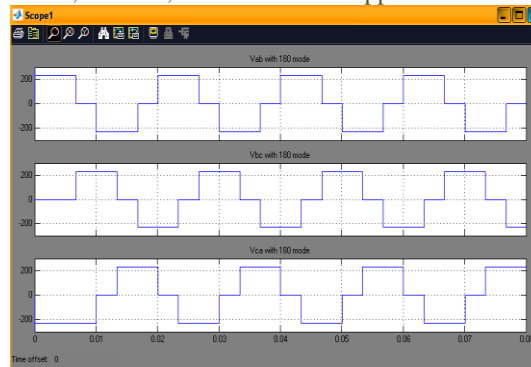
Fig.1.4. Vab, Vbc and Vca line to line Voltage waveform for inverter 180^0 mode of conduction without filter
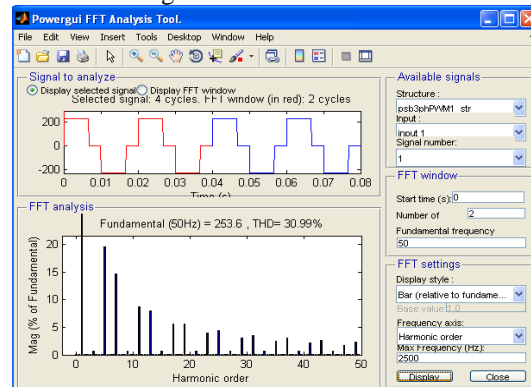

Fig.1.5.THD spectrums for Voltage waveform for inverter 180^0 mode of conduction without filter .

Fig.1.6. Three phase Load Current and Load Voltage waveform for inverter 120^0 mode of conduction with filter .
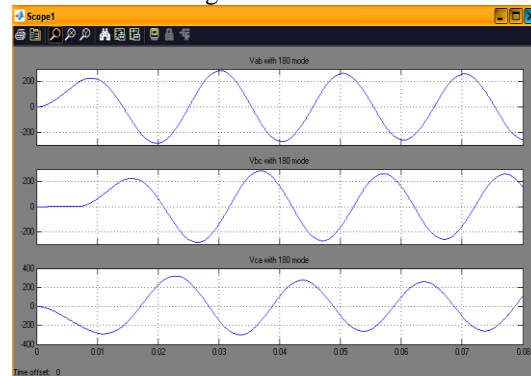

Fig.1.7. Vab, Vbc and Vca line to line Voltage waveform for inverter 180^0 mode of conduction with filter
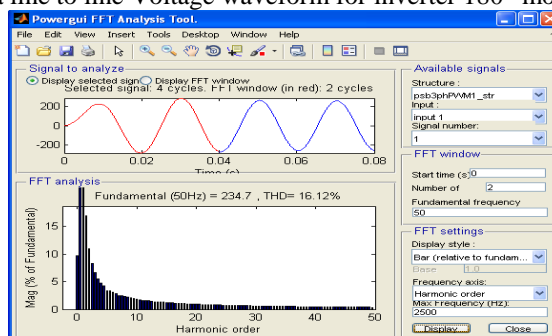

Fig.1.8.THD spectrums for Voltage waveform for inverter 180^0 mode of conduction with filter .

III.   CONCLUSIONS

Based on the literature review, simulations results and the performed experiments,

Following points can be concluded:

1. Those Fuel Cells are preferred which have high voltage ratings and low current profile. This is because at higher current the losses within the fuel cell will be more and hence the efficiency of the system, for which it is known, will deteriorate. But the main drawback of higher voltage fuel cells is that voltage level can be increased only by adding series stacks. This adds to the system cost.

2. In low power rating fuel cells, low voltage is an issue. Boost converter provides solutions to raise the voltage level of the FC stack. Besides this bi-directional DC DC converters are also used for boosting and isolation. This increases the bulkiness of the whole application. For AC applications the inverter discussed in the above theory is a good candidate for single stage grid connected system. It is capable of boosting up the voltage level from a low level to a higher level, hence overcoming such systems where boost converter and other topologies are used. The output voltage of the capacitor is in good agreement with the reference grid voltage.

3. Simulation results show that the operation of the the inverter is such that it feed a nearly unity power factor current into the grid ($pf = 0.967$). Experimentally it is shown that the grid current is in phase with the voltage.

IV.   FUTURE SCOPE

1. The operation of the converter, considered for the grid connection connection, can also be investigated for continuous conduction mode.

2. We have considered an application in which FC stack is integrated to the grid. FC can also be considered for stand alone power application systems or even backup systems.

3. FC stacks integration with various other DC/DC converters and study the behavior of a closed-loop controller for the same.

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