Literature Survey on Modeling and Simulation of FUEL CELL system using Dual Active Bridge (DAB) DC-DC Converter

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***Abstract**: This paper deals with the literature review of modeling and simulation of Fuel cell system using Dual Active bridge DC-DC Converter and the effectiveness of harmonic current absorption by the energy storage branch in fuel cell power conditioning system is critically evaluated. The closed-loop output impedances of the converter under single-voltage-loop and dual-loop controls are derived and compared. The DC source from the fuel cell is given to DC-DC converter then it is filtered and it is given to inverter then supplied to load. The open loop control system is a non feedback system in which there is no feedback to determine if the system is achieving the desired output based on the reference input. A closed loop control system otherwise termed as feedback control system in which some or all of its output is used as its input.*

***Keywords**: Fuel cell, Energy storage system, Dual-active bridge (DAB) DC-DC Converter, Fuel cell control, PR control and MATLAB.*

1.0 INTRODUCTION

Around the world, Conventional power system is facing the following problems like:

a. Gradual depletion of fossil fuel
b. Poor energy efficiency
c. Environmental pollution

To overcome the above problems, non-conventional / Renewable energy sources like Natural gas, biogas, wind power, solar photovoltaic cells, fuel cells, combined heat and power (CHP) system are employed. Fuel cell is a electrochemical device that converts chemical energy into electrical energy and used in clean power Generators .Due to higher efficiency and emit less co $_2$ and NO x per kilowatt of power generated, no air pollution occurs. As there are no moving parts, almost free from noise and vibration, robust and low maintenance, then suitable for urban and suburban locations. Electrical efficiencies of fuel cell lies between 36% to 60% depending upon the type and system configuration. By using conventional heat recovery equipment, overall efficiency can be enhanced to 85%. Fuel cell systems do not require recharging.

Fuel cells used in portable appliances and power tools, consumer electronics like laptops, cell phones, transport applications, distribution of power in various fields like homes and small businesses. Among various types of fuel cells, Proton exchange membrane (PEM) fuel cells are currently used in medium power applications such as fuel cell vehicles and standalone power Generators.

FROM IEEE REFERENCE

As per S. K. Pradhan, S. K. Mazumder, J. Hartvigsen, and M. Hollist, [1] previous researches on PEM fuel cells revealed that their lifetime performance and reliability can be adversely affected when they have to handle low-frequency current ripple below 400 Hz .According to G. Fontes, C. Turpin, R. Saisset, T. Meynard, and S. Astier, [2], fuel cells exhibit hysteresis at low frequencies around 100 Hz due to the proximity of these frequencies to the natural frequency of the chemical reaction kinetics at the fuel cell electrodes. As per R. Ferrero, M. Marracci, and B. Tellini [3],the hysteretic behavior can cause additional loss to the operation of fuel cells.

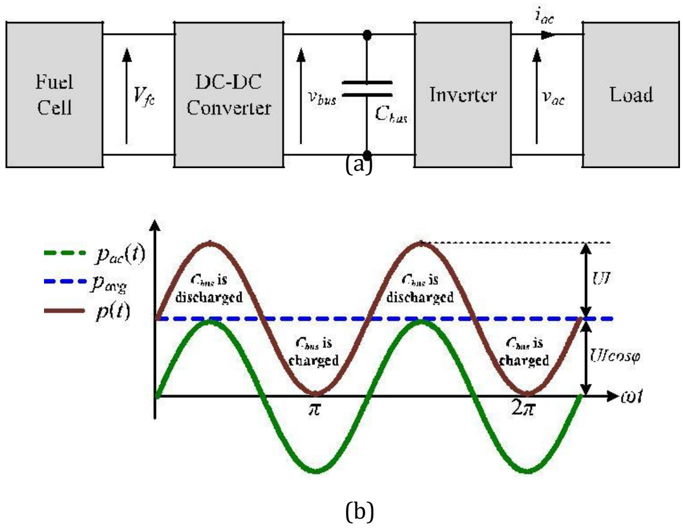


Fig. 1. Typical fuel cell power conditioning system: (a) system block diagram, and (b) power demand when a single-phase inverter is connected as load.

Another research conducted by Choi *et al.* [4] show that there is a 6% reduction in the available output power when significant low-frequency current ripple is imposed on fuel cells. Recently, Sergi *et al.* [5] reported that degradation in the cathode catalyst was observed when fuel cells are subjected to low-frequency current ripple.

In general, for fuel cell power conditioning systems connected to single-phase inverter load, Fig. 1(a), the fuel cell's output current ripple occurs at twice the inverter frequency, typically 100 or 120 Hz. Assuming that the system has an efficiency of 100%, the inverter output voltage and current, and hence, the instantaneous power drawn from the fuel cell are given by

$$p(t) = v_{ac}(t) i_{ac}(t) = U I \cos\phi + U I \cos(2\omega t - \phi)$$
$$= p_{avg} + p_{ac}(t). \quad (1)$$

It can be seen that the instantaneous power drawn from the fuel cell is a summation of the dc component p_{avg} and the harmonic component $p_{ac}(t)$ oscillating at twice the inverter frequency. In order to prevent the fuel cell from excessive power fluctuations, which will degrade its lifetime, the dc–dc converter is typically designed with a very small closed-loop bandwidth so that the fuel cell will mainly deliver the dc power component p_{avg} while the harmonic power component $p_{ac}(t)$ is drawn from the dc-link capacitor C_{bus} The dc-link capacitor is discharged when $p(t) > p_{avg}$ and is charged when $p(t) < p_{avg}$. These periodic charging and discharging processes will cause the existence of voltage ripple (at twice the inverter frequency) on the dc-bus voltage, and the inverter's operation can be adversely affected when the amplitude of the voltage ripple becomes excessively large.

2.0 DC to DC CONVERTER

A DC to DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another.

2.1 Purposes

a. To match the loads to the power supply
b. To isolate primary and secondary circuits
c. To simplify power supply systems.

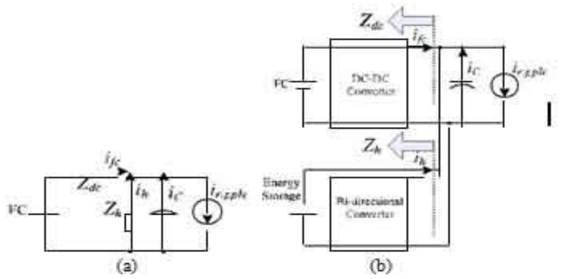
2.2 Applications

a. To step down the voltage from a high voltage source to a lower voltage needed at the load.
b. To step up voltage from a low voltage to a higher voltage to an external system.
c. To invert the voltage and provide negative voltages. The isolated grounds makes this possible.
d. To provide various voltages in a very clean and simple for some systems and non-standard voltages.

Initially, the use of dc-link capacitors for passive filtering of low-frequency harmonic current is traditionally employed in fuel cell power conditioning systems. since the dc-link capacitors are required to create an extremely low impedance to the flow of low-frequency harmonic current, the required capacitance is very large (usually microfarad). As an alternate solution, K. Fukushima, I. Norigoe, M. Shoyama, T. Ninomiya, Y. Harada, andxbrk Tsukakoshi [6], a series-connected *LC* network can be inserted to the capacitor branch to create a zero-impedance branch for bypassing the low-frequency harmonic current when the resonant frequency of the *LC* network is accurately tuned to the harmonic frequency. However, in this method, the required inductance is typically very large and such an approach is not applicable to the situation where multiple harmonic currents exist. Instead of reducing the impedance of the capacitor branch, it was proposed to increase the impedance of the fuel cell branch by C. Liu and J. S. Lai, [7], R. Bojoi, C. Pica, D. Roiu, and A. Tenconi [8], Y. J. Song and P. N. Enjeti ,[9] ,J. M. Kwon, E. H. Kim, B. H. Kwon, and K. H. Nam,[10] and X. Liu, H. Li, and Z. Wang, " [11]. These methods using dual-loop control with a very small bandwidth to give a ripple-free reference for the fuel cell current as per C. Liu and J. S. Lai [7], feed forwarding, and subtracting the low-frequency ripple derived from the dc-bus voltage to generate a ripple-free reference for the fuel cell current according to R. Bojoi, C. Pica, D. Roiu, and A. Tenconi [8], Y. J. Song and P. N. Enjeti ,[9] ,J. M. Kwon, E. H. Kim, B. H. Kwon, and K. H. Nam,[10] . According to X. Liu, H. Li, and Z. Wang[11], the low-frequency ripple on the fuel cell current minimized by adopting proportional-resonant (PR) control . Since the harmonic current must be completely delivered by the dc-link capacitor, the capacitance required to maintain a smooth dc-bus voltage must remain to be very large. All the passive-filter-based methods requires large inductors or capacitors for low-frequency harmonic absorption. In contrast, when small dc-link capacitor is used, and large voltage ripple exists on the dc-bus voltage, additional control must be introduced into the inverter for minimizing its effects on the inverter's output voltage .

To overcome this limitation, according to P. T. Krein, R. S. Balog, and M. Mirjafari,[12], C. Y. Hsu, and H. Y. Wu, [13] and A.C.Kyritsis, N. P. Papanikolaou, and E. C. Tatakis [14], active-filter-based methods should be employed, where energy storages such as batteries and super capacitors are interfaced to the dc voltage bus through the use of bidirectional dc–dc converters. Since the dc–dc converters are typically configured to tightly regulate the dc-bus voltage, thus behaving as voltage source, they are effectively characterized by low-output impedance that favors harmonic current flow.

Fig. 2(a) shows the harmonic current i_h contributed by the bidirectional converter having an effective output impedance of Z_h in addition to those contributed by the fuel cell (i_{fc}) and dc-link capacitor (i_C).



a) impedance model, and (b) practical implementation of system.

To minimize the harmonic current drawn from the fuel cell, it is required that either the impedance of the fuel cell branch Z_{dc} is increased or the impedance of the bidirectional dc–dc converter Z_h is reduced by means of suitable controller designs.

Due to the slow dynamic response of the fuel cell branch, the use of active filter with energy storage and bidirectional dc– dc converter is beneficial in terms of improving the overall dynamic response of the fuel cell-energy storage system by effective harmonic current absorption by the converter-interfaced energy storage and tight regulation of the dc-bus voltage by fast voltage control. Various control strategies have been proposed for achieving the following desired control objectives. Amongst, J. L. Duarte, M. Hendrix, and M. G. Simoes, [15] and as per H. Tao, A. Kotsopoulos, J. L. Duarte, and M. A. M. Hendrix[16], To control the system in such a way that the fuel cell branch delivers the average load power, while the energy storage branch compensates for any power surplus or deficit due to transient load power variations.Alternatively, H. Tao, A. Kotsopoulos, J. L. Duarte, and M. A. M. Hendrix, [17], one outer voltage loop that generates the current references for the inner current loops of the fuel cell and energy storage branches, which makes them share the total transient load power demand.

Acc to X. Li, W. Zhang, H. Li, R. Xie, M. Chen, G. Shen, and D. Xu, [18], the energy storage branch is controlled as current source, while the fuel cell branch is responsible for dc-bus voltage regulation.

3.0 CONTROL STRATEGIES

As per discussion made by previous researches, the control strategies for parallel-connected fuel cell-energy storage systems is classified into three categories as detailed below:

(a) fuel cell branch controlled as current source and energy storage branch controlled as voltage source,

(b) fuel cell branch controlled as voltage source and energy storage branch controlled as current source, and

(c) both fuel cell and energy storage branches controlled as current sources.

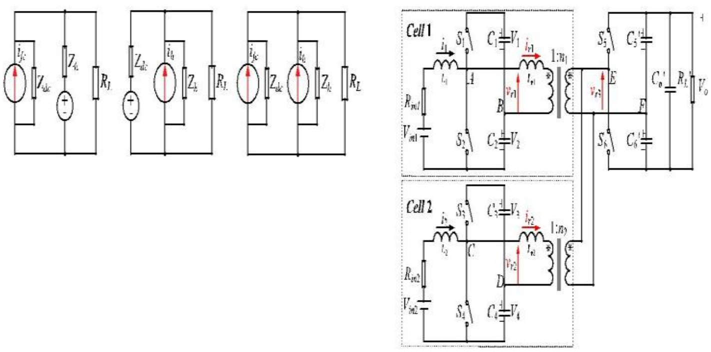


Fig. 3. Possible control strategies in fuel cell-energy storage system: (a) fuel cell branch controlled as current source and energy storage branch controlled as voltage source, (b) fuel cell branch controlled as voltage source and energy storage branch controlled as current

source, and (c) both fuel cell and energy storage branches controlled as current sources.

In general, fuel cells are characterized by slow dynamic response and lifetime degradation if they are subjected to frequent power fluctuations. Due to this characteristics, the fuel cell branch cannot be used for dc-bus voltage regulation, hence control strategy (b) could not be adopted.

Control strategy (c) is feasible with the fuel cell branch configured to respond to slow power changes, while the energy storage branch responds to fast power changes.

The dc-bus voltage regulation is obtained by combination of slow and fast power changes of the two branches equal the load power changes. The problem is that the energy storage branch will not compensate for the slow power changes even if the fuel cell branch fails to meet them due to various reasons, such as fuel starvation, which can lead to stability problems of the hybrid system. Control strategy (a) offers more versatility since the energy storage branch is configured to regulate the dc-bus voltage, it will respond to all power changes that cannot be met by the fuel cell branch. Hence, the fuel cell branch can be configured to operate in load-following mode or constant-power mode depending on applications. Any power surplus or deficit caused by the fuel cell branch will be compensated by the energy storage branch.

Under this control strategy, the energy storage branch, therefore, plays a critical role in both aspects of achieving dc-bus voltage regulation and absorption of harmonic current.

4.0 ENERGY STORAGE BRANCH

As the energy storage branch is made up of battery or super capacitor banks which exhibits fast dynamic characteristic, the overall performance of fuel cell-energy storage systems relies heavily on the performance of the bidirectional dc–dc converter interface.

5.0 CONVERTER USED

A bidirectional dual active bridge (DAB) dc–dc converter with multi-input operation is chosen as the platform for analysis due to its common use in renewable energy systems employing multiple dc energy sources.

6.0 CONTROL METHOD USED

PR (Proportional Resonant) control, which is commonly used in grid-connected inverters for harmonic suppression, is proposed to be used to account for the possible variations of the inverter frequency that occurs when interfaced with grid. A frequency-adaptive PR controller is proposed to ensure an effective harmonic current absorption under variable inverter frequency.

7.0 CONCLUSIONS

The above literature does not deal with reduction of Ripple in the output using a cascade filter. The above papers do not report closed loop controlled DAB Converter for fuel cell based systems. It is proposed to use cascade filter at the output to reduce the ripple. This work aims to control the closed loop systems using PI (Proportional Integral) and Fuzzy logic controllers by using MATLAB simulation.

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