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Dual-input DC-DC Buck Converter using Fuel Cell and Battery Source

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Abstract: The integration of various energy sources to efficiently utilise renewable energy is a current trend in the power system. The development of a power electronic interface is very significant for the successful integration of those sources. In this paper, a dual-input dc-dc buck converter is designed and simulated for load supply using MATLAB Simulink software. The dual-input dc-dc converter can work with two different sources. The use of Fuel Cell (FC) and battery sources is an alternative way to get a larger output power value for the load supply. The simulation results show that the dual-input dc-dc buck converter can work in a state-supplied by two different sources and show better output performances than a single-input dc-dc converter with an output power of 107.5 W.

Keywords: Battery, Fuel Cells, Multi-Input DC-DC Converter, Hybrid Energy System

1. Introduction

Energy storage is a significant barrier to the advancement of a clean energy solution. Integrating multiple energy storage has been the subject of numerous research; thus, it has become a feasible economic option for improving renewable energy sources' efficiency. The implementation of multiple energy storage systems must be emphasized. It is applicable in various areas ranging from local microgrids to multiple types of electric vehicles [1]. The hybrid energy system (HES) is a rising and important innovation for the future's energy needs. HES are reliable, sustainable, and renewable sources of energy that are superior to traditional sources.

Several energy sources control systems have been proposed in the literature with different power electronic converters, such as the conventional ac-coupled system [2]-[3]. However, the primary drawbacks of these traditional integration approaches include complex system configuration, a high number of components, significant power losses, high costs, and large size. Moreover, it often minimizes the system's overall efficiency and reliability [4]. The primary challenge of integrating various energy systems is to build a DC-DC multi-input converter to maximize stability and efficiencies. Fuel cells (FCs) are being used as an upcoming alternative power source due to their

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positive attributes, such as high efficiency and reliability [5]-[6]. However, it does not provide enough power as it is limited by the effects of the cell output voltage changes and the electrochemical reaction rate [7]. Besides, a load differential power output must be controlled by an energy storage system (ESS) due to a long initialization time and slow dynamic response. Batteries are typically used to store energy, save power starting and boost peak power capacity [8]. Hence, this project proposes a dual-input DC-DC converter that utilizes FC and batteries as inputs to improve stability, enhancing efficiency in respect of HES.

2. Materials and Methods

2.1 System Configuration

Dual-input buck converter circuit diagram and the proposed system block diagram for HESS based on dual-input DC-DC converter is shown in Figure 1 and 2. Battery integration inside the system is since a load differential power output of an FC must be controlled by an energy storage system in the system [8]. Therefore, the FC is the primary power source in this system, and the battery for auxiliary power is used in respect of the battery will support power. In contrast, the FC supports the load condition.

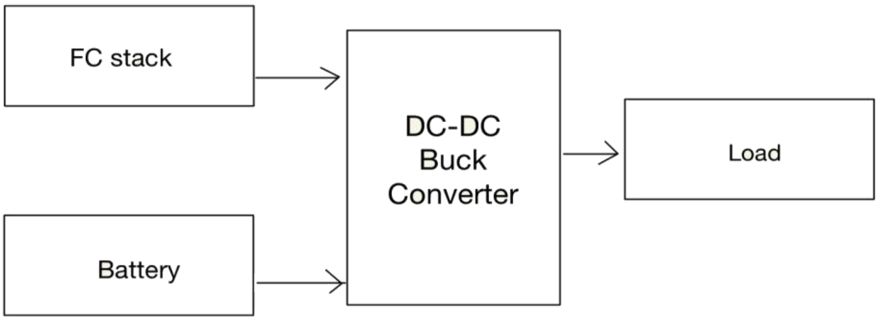

Figure 1: Proposed system block diagram for hybridization of energy sources based on Dual-input DC-DC converter

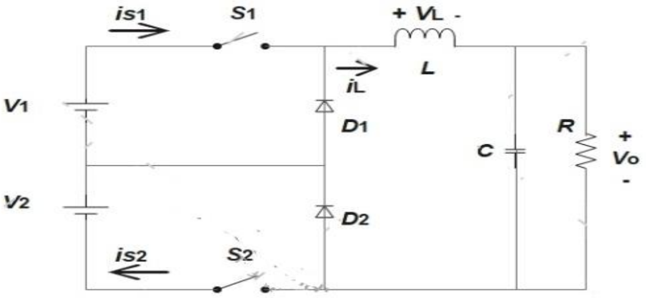

Figure 2: The Dual-input Buck converter circuit diagram

2.2 Sources Parameter

For the system input: Battery (12 Vdc lithium-ion battery) [9], FC (fuel stack with 69 Vdc, 30 W proton exchange membrane (PEM)) [9]. The system parameter will be implemented in the simulation model via Simulink MATLAB software concerning the HES application. The FC parameter specifications are shown in Table 1.

Table 1: PEM FC stack parameter specifications [10]

Parameters	Value
Rated output power, *Po*	30 W
Nominal Current, *Inom*	133.3 A
Nominal Voltage, *Vnom*	69 V
Current at maximum power, *Im*	225 A
Voltage at maximum power, *Vm*	37 V
Nominal stack efficiency, %*nom*	55 %
Number of cells	65
Operating temperature	65
Nominal supply pressure of [H2, Air]	1.5, 1
Nominal composition percentage (%) [H2, O2, H2O]	99.99,21,1

2.3 System Design

The initial design process is to determine the electrical parameters used in the dual-input buck converter circuit. The determined electrical parameters include input voltage, output voltage, switching frequency, current and voltage ripple, and output power. These parameters are useful as a reference in determining the value of the inductor, capacitor, and load. The parameters used as a reference in designing a dual-input buck converter are shown in Table 2 as follows:

Table 2: Initial specifications of converter design

Parameter	Value
Output Power, *Po*	30 Watt
Output Voltage, *Vout*	24 Volt
Input Voltage 1 (FC), V1	69 Volt
Input Voltage 2 (Battery), V2	12 Volt
Switching Frequency (*f*)	40 kHz
Ripple VO(ΔVO)	1%
Ripple IL(ΔIL)	30%

In this design, the input voltage is set at 69 volts for the FC, while the input voltage for the battery is set at 12 volts. The output voltage is determined to be 24. The output power is set at 30 watts. The input current ripple through the inductor is set at 30%, and the output voltage ripple is set at 1%. Based on the input voltage and output voltage determined on the converter circuit, the value of the energy conversion ratio or the gain value used can be seen.

2.4 Derivation of Parameter

In accordance with the equation for buck converter, the duty cycle value can be found as follows:

$$D_1 = \frac{v_{out\ (FC)}}{v_{in\ (FC)}} \qquad Eq.1$$

From the equation (2.1), the duty cycle equation can be obtained as follows:

$$D_2 = \frac{v_{out-}v1D_1}{v_2} \qquad Eq.2$$

For V1 + V2 = Vs, the following equation and calculation is obtained [11]:

$$L = \frac{V_0(1-max(D_1,D_2))}{0.3\left(\frac{Pout}{v_{in}}\right)*f} \qquad Eq.3$$

The equation for obtaining the capacitor value is as follows [1]:

$$Q = CV_0 \qquad Eq.4$$

$$\Delta Q = C\Delta V_0 \qquad Eq.5$$

$$\Delta V_0 = \frac{\Delta Q}{C} \qquad Eq.6$$

$$\Delta Q = \frac{1}{2}\left(\frac{T}{2}\right)\left(\frac{\Delta iL}{2}\right) = \left(\frac{T\Delta iL}{8}\right) \qquad Eq.7$$

$$\Delta V_0 = \frac{T\Delta iL}{8C} \qquad Eq.8$$

$$\Delta V_0 = \frac{T\Delta iL}{8C}(1-D)T = \frac{V_0(1-D)}{8LCf^2} \qquad Eq.9$$

$$\frac{\Delta V_0}{C} = \frac{(1-D)}{8LCf^2} \qquad Eq.10$$

$$C = \frac{1-max(D_1,D_2)}{8L(\frac{\Delta V_0}{V_0})f^2} \qquad Eq.11$$

In order to achieve maximum system performance in term of output voltage, the inductor and capacitor used in this simulation is 3.375mH and 1.157µF.

3. Simulation and Results using MATLAB

In this design, the system was tested using FC and battery as the input sources. The dual-input dc-dc converter design is shown in the Figure 3.

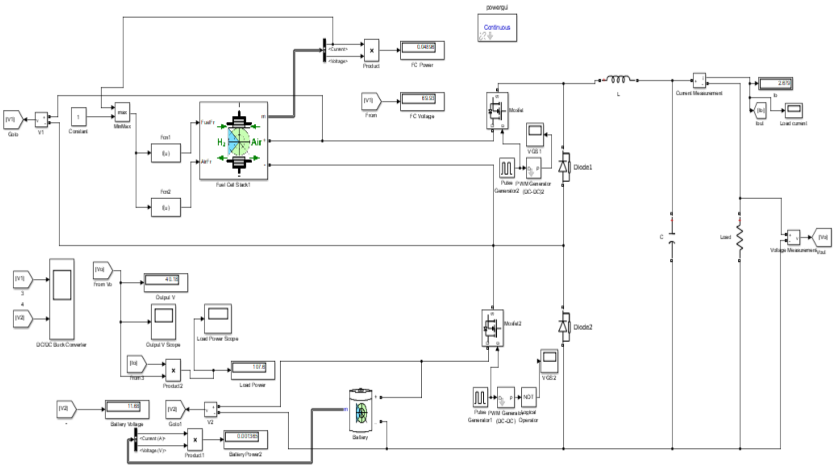

Figure 3: Simulation of Dual-input DC-DC converter

In the simulation of the dual-input dc-dc buck converter circuit with the integration of FC and battery as the input sources, several parameter waveforms will be observed, namely the output power at load R (Po) and the output voltage at the load R (Vo) and the load output current (Io). The parameters used in the simulation are ideal components, including MOSFET switches and diodes.

For the duty cycle D1, D2 equal to 0.5, the output current, output voltage and output power waveforms are shown in Figure 4, Figure 5 and Figure 6 respectively.

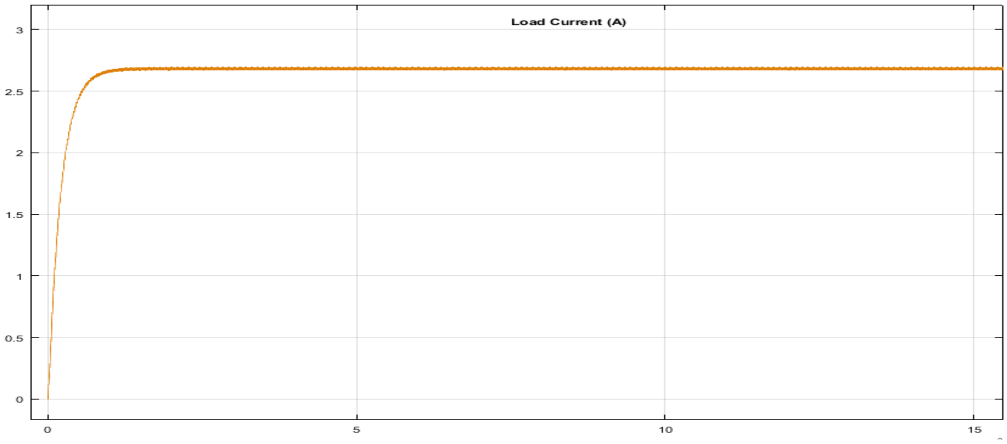

Figure 4: Output load current of Dual-input DC-DC converter (A)

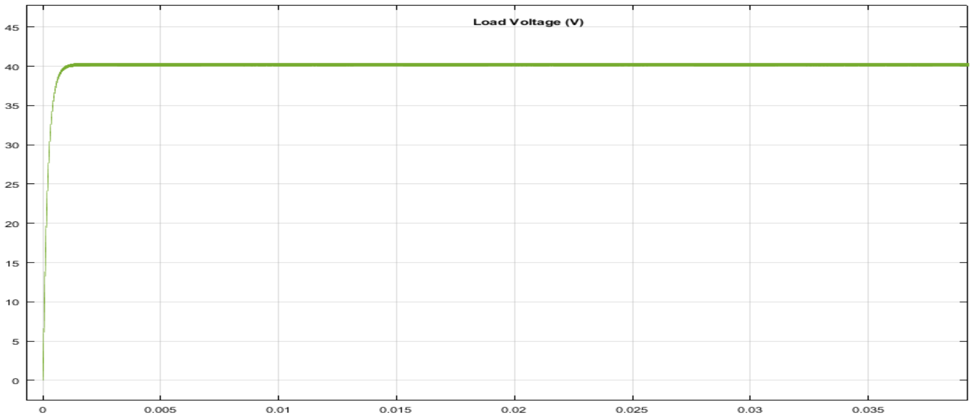

Figure 5: Output load voltage of Dual-input DC-DC converter (V)

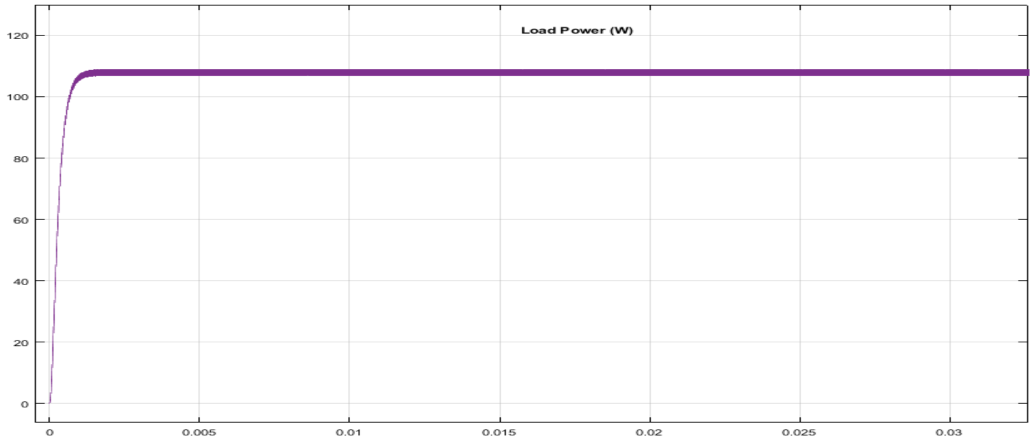

Figure 6: Output load power of Dual-input DC-DC converter (W)

In an open-loop system, the converters are developed and simulated. Table 3 shows the result of simulated output voltage of a dual-input dc-dc buck converter for various duty cycles.

Table 3: Result of simulated output voltages based on various duty cycle inputs

Input Voltages VFC & VBattery	**Duty Cycles**	**Simulated value (Vo)**
VFC = 69 V VBattery = 12 V	0.75	60.15
	0.45	36.17
	0.35	28.13
	0.25	20.09

4. Conclusion

This paper discusses the design of the dual input DC-DC converter using FC and battery sources system. The converter system is designed to manage the load sharing between FC and battery. The findings of this study conclusively demonstrate the integration of multiple energy sources using dual-input dc-dc buck converter advantages. During peak power demand, the energy management system successfully met the system needs. Furthermore, the simulation study proves that the auxiliary energy source overcame the FC's constraints, providing a better and well-regulated output voltage performance of the dual-input dc-dc converter. In addition, this dual-input dc-dc converter is easy to construct, uses few electronic components, and can manage energy sources.

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