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A power management unit with a polarity changing inverter for fuel cell/ultra-capacitor hybrid power systems

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ABSTRACT

Compared to the other energy conversion systems, Fuel Cells are preferred in many applications due to quitter working and their sensitivity to the environment. However an energy storage system with sufficient power capacity should be incorporated with FCs to compensate its slow dynamics. Ultra-capacitors with their high power densities and fast response times are potential candidates for a solution in this aspect. In conventional methods DC bus voltage is regulated by DC/DC converters to be able to generate a voltage controlled sine waveform by controlling inverters modulation index. In this study, on the contrary to conventional methods DC bus voltage is chosen like a rectified sinusoidal waveform. By this way as the DC bus is sinusoidal the inverter is controlled as a polarity changing inverter which provides to switch inverter switches at 50 Hz. However this method requires an excessive care on DC/DC converter controls as excessive humidification and membrane drying may occur on a FCs in case of sudden changes in load demand. A group of simulation studies are done in this study to design and test the required controller and compare the method for this mentioned necessity in literature.

Introduction

Environmental reasons like greenhouse emissions and air pollution and depletion of fossil fuels which are the main sources of electric energy, motivated researchers to focus on alternative fuels. Beyond many other alternatives one of the most promising technology is Hydrogen fuel cells (FCs) that generates electricity from hydrogen and oxygen without producing any harmful exhaust gasses [1,2]. However there are several challenges those need to be solved to achieve widespread usage of FCs. Thus, almost every government all around the world supported the R&D projects to investigate and prepare the FCs for the end users.

Among the other studies hydrogen storage, material developments and more efficient and safer use of FCs are the featured ones [3–8]. One of the most challenging point of FCs is the slow response time [9,10]. Sudden changes in both increasing and decreasing loading conditions may cause humidification and membrane drying. Hybridization of FCs with an energy storage system (ESS) are the most common method to overcome this mentioned challenges [11,12]. An ESS with sufficient power capacity should be incorporated with FCs to compensate its slow dynamics. Ultra-capacitors (UCs) are potential candidates for a solution in this aspect [13].

Structural deformations such as excessive humidification and membrane drying may occur on a FC in case of instantaneous changes in load demand; using it as a main energy

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source alone for residential systems is not sufficient [14]. Therefore, to increase the efficiency and lifetime of the FC, additional energy storage units that cooperating with FC should be integrated into the system and also the optimum energy management should be provided [15]. UCs are generally preferred as energy storage units as their power density is high on contrary to this their energy density is low where the FC fills the deficiency of the UC [16]. However more complex power management systems (PMS) are needed because of this requirement [17].

The main aim of the controllers for hybrid systems is to split the power demand according to sources characteristic behaviors in an optimum way. General characteristics of mentioned PMS is sudden changes in the load demand is supplied by the ESS and the main portion of the load demand is supplied by the FCs In other words the low frequency components of the load demand are supplied by the FCs contrary to this the high frequency components are supplied by the ESS [11,18].

According to load type, number of sources and their characteristics several kinds of energy management strategies are applied to hybrid systems [19,20]. Common point of all of them is they use power electronic converters as the hardware to achieve desired management strategies [21].

A general structure of PMS for mentioned hybrid systems are used which consists of DC/DC converters and an inverter as shown in Fig. 1. To control the power flow; the FC and ESS are connected through DC/DC converters to DC bus and the energy is transferred from DC bus to the AC loads through an inverter. FCs are used with unidirectional DC/DC converters and due to the FC output voltage buck or boost converters are chosen and ESS need to be connected through bidirectional converters [21]. Inverter is used to generate an AC sinusoidal voltage waveform from the DC bus to supply AC loads.

In conventional methods DC bus voltage is regulated by DC/DC converters to be able to generate a voltage controlled sine waveform by controlling inverters modulation index by using sinusoidal PWM. Therefore to reduce the ripples on DC bus and in another word to minimize the passive circuit elements in DC converters, the switching frequency is chosen at 20 kHz levels or higher [21]. In addition to that to generate a pure sinusoidal voltage waveform with low THD the switching frequency of the inverter is also chosen approximately 10 kHz or more.

In this paper a novel energy management method that enables to switch inverter switches at 50 Hz and still can generate very low THD sinusoidal load voltage is proposed for FCs and UC hybrid systems. Losses in a conventional single phase inverters can be divided in to three parts conducting losses, switching losses and I2R losses on the output filter [22]. With the proposed method as the switching frequency is 50 Hz, switching losses in inverter are decreased dramatically. Also there is no output filter which decreases the total losses and increases operating margin. However the control of the DC/DC converters are more complex than conventional methods and there is a slightly increase in the switching losses of the DC/DC converters. In addition to this the total losses in the hybrid power system is decreased. In second section, proposed system and the methodology is explained in detail, third section is about the controllers, simulation and results are the fourth section and the conclusion is the last section.

Proposed system and the methodology

In this study (Fig. 2), contrary to existing methods DC bus reference voltage is not a constant value, it is chosen as a Rectified Sinusoidal Waveform (RSW). By this way as the DC

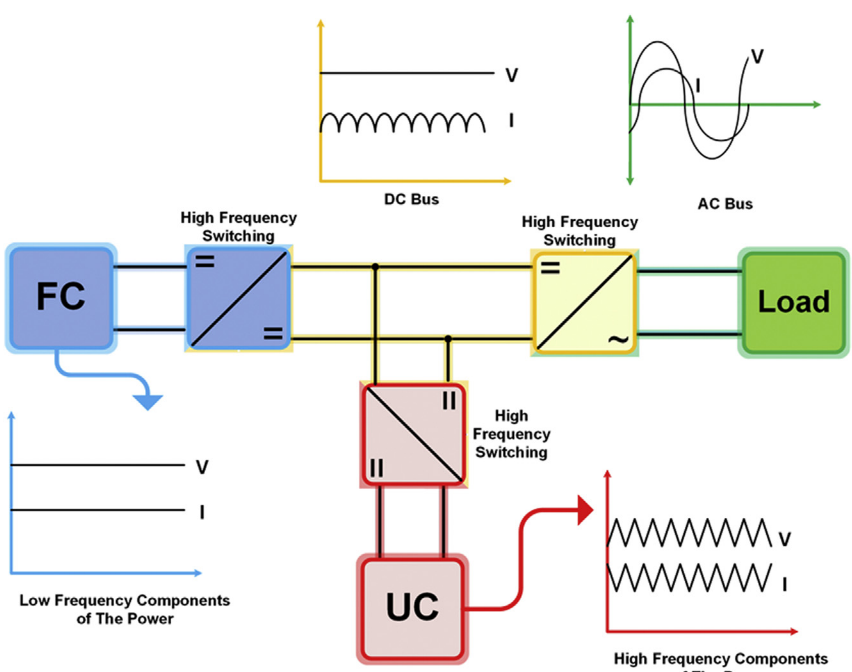

Fig. 1 – General block diagram for FC–UC hybrid systems.

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